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Research Paper

Experimental research on evaluation of the possibility of using crushed stone dust at Nghe An province-Viet Nam for reinforced concrete beams

Phan Van Duc [a], Ho Van Phuc [a], Ho Van Hung [a], Truong Quoc Đinh [a], Nguyen Xuan Hieu [a], Tran Ngoc Long [a], Nguyen Trong Kien [a,*]

[a] *Faculty of Civil Engineering, Vinh University, 182 Le Duan Str., Vinh City, Nghe An, Vietnam*

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ABSTRACT

In this paper, the use of crushed stone dust in Nghe An province is studied to replace natural sand in the production of concrete of compressive strength level B15. To evaluate the possibility of replacing part of natural sand in concrete with crushed stone dust according to the Vietnamese system of standards for designing reinforced concrete structures, the experimental study is analyzed based on experiments including: (i) Determining grain size, (ii) determining slump, (iii) compressing cube specimens to determine compressive strength, (vi) pulling out test to determine the bond force between steel and concrete, (v) bending compression of beam specimens of size 10×15×120 cm to failure. The initial research results show that the compressive strength at 28 days of cube concrete specimens using crushed stone dust exceeds 7,2-12,6% compared to concrete using natural sand. The beam sample using a small aggregate of 50% natural sand + 50% crushed stone dust has a greater load-bearing capacity than the reinforced concrete beam sample using 100% natural sand and is 6% larger.

1 Introduction

Statistics from provinces and cities show that the demand for construction sand in Vietnam is about 120-130 million m3/year, the demand for sand for filling in the period of 2016 - 2020 is 2.1 to 2.3 billion m3, while the reserve of construction sand and sand for filling is forecasted at 2.1 billion m3. The supply of natural sand from legal mining areas is forecasted only to meet about 40 - 50% of the demand [1]. Thus, by 2020, Vietnam will not have enough natural construction sand to serve the needs of localities. Some provinces have experienced a shortage of natural sand, and the high price of sand has significantly affected construction activities. Therefore, research on replacing natural sand with artificial sand is one of the effective solutions not only economically but also ecologically [2, 3].

* *Corresponding author. Tel.: +084.0982761498.*
E-mail address: trongkienkxd@vinhuni.edu.vn,
nguyentrongkien82@gmail.com

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In the world, many standards have been issued to guide the use of artificial sand for concrete production, such as British standards BS:882-1992 [4], French P18-540 [5], and American ASTM C33-90 [6]. In some countries, where there is a great demand for the use of artificial sand to gradually replace natural sand exploited from river beds, many studies have been conducted to compare and evaluate the physical and mechanical properties of concrete using artificial sand instead of natural sand. Experimental studies by Sahu [7], and Ilangonava [8] evaluated the tensile strength, compression strength, and elastic modulus of concrete using artificial sand to be able to reach values equivalent to concrete using natural sand. When observing the microstructure of artificial sand by scanning electron microscopy (SEM), Vijaya [9] pointed out the rough surface with many sharp corners of artificial sand, with a longer grain shape compared to the smooth surface and spherical shape of natural sand. This surface state of artificial sand allows for a good bond between the sand grain surface and the cement stone layer and a tighter arrangement between the grains, thereby reducing the porosity in concrete. However, the long, angular shape of artificial sand grains gives low grain strength and a higher cracking ability than natural sand. Therefore, the quality control of concrete using artificial sand instead of natural sand depends largely on the crushing and screening lines, stone selection, and the quality of the original rock mined in different regions of the world and in each territory. Currently, in our country, the trend of using artificial sand to replace natural sand in concrete production is receiving great attention from the state and localities. Vietnam standard 9205:2012 [10] and Vietnam standard 9382:2012 [11] have issued technical requirements and guidelines for the use of artificial sand in concrete and mortar production. Many studies in Vietnam have been conducted to evaluate the physical and mechanical properties of concrete using artificial sand instead of natural sand in the production of mortar and concrete. Pham The Hiep [12] studied the use of crushed stone in concrete production in Dong Nai province. Nguyen Duc Dung and colleagues [13] used crushed sand in Ba Ria Vung Tau mixed with natural sand. Duong Minh Thuan [14] evaluated the feasibility of using crushed stone in concrete production in An Giang. Le Viet Dung and colleagues [15] conducted an experimental study to evaluate the possibility of using crushed sand from limestone in Ha Nam for compressed reinforced concrete columns. Although there have been many studies on the use of crushed stone to replace sand in concrete production. However, the research results are not the same because the quality of crushed stone sources along the territory of Vietnam varies widely, affecting the quality of artificial sand in each region.

Some other studies reported the use of crushed sand in making concrete, including a combination of crushed sand and river sand, to enhance the strength of concrete containing them [16-20]. Shanmugapriya et al. [16] replaced 50% of the natural sand with crushed sand to achieve the optimal compressive and flexural strength of concrete, while Mudra et al. [17] (India) recommended that the crushed sand used should not exceed 50%. Sahu et al. [18] also reported that crushed sand could produce a similar compressive strength in concrete. Rajput [19] conducted an experimental investigation with the crushed sand amount changing from 20% to 100%. They stated that the compressive strength of concrete increased with the increase in crushed sand used. Nguyen et al. [13], through a study of the crushed sand grain composition in southern Vietnam, concluded that crushed sand accounts for 30% to 70% of the grain gradation in accordance with AASHTO M6 [20] and ASTM C33 standards. Calculations based on Fuller's ideal gradation show that a sand mixture of 60% crushed sand with 40% fine sand gives the gradation curve closest to the ideal gradation curve.

Based on the literature review, two research gaps can be identified:

a) Are the grain size, mechanical properties, and workability of Nghe An crushed stone similar to crushed stone in other parts of Vietnam? Research has shown that concrete using crushed stone aggregate has better mechanical resistance but poorer workability.

b) Does combining crushed stone from Nghe An with sand improve the workability and mechanical properties of concrete ?

For the above reasons, the authors have been motivated to conduct experimental research to determine the mechanical properties of concrete using crushed stone from Nghe An, combining 50% crushed stone with 50% sand to create concrete for beam structures, to compare its durability with beams made of traditional river sand concrete. The results of this study contribute to supplementing data on the use of crushed stone as fine aggregate for civil concrete. Helps reduce costs and conserve natural resources.

2 Materials and research methods

In this paper, the authors use experimental research methods to determine the grain size of aggregates and the physical and mechanical properties of concrete, and the load-bearing capacity of beams.

2.1 Determination of grain size of aggregate for concrete according to ASTM

2.1.1 River sand

The river sand used in the experiment was taken from Nghe An province. The particle size distribution is summarized in Fig. 1.

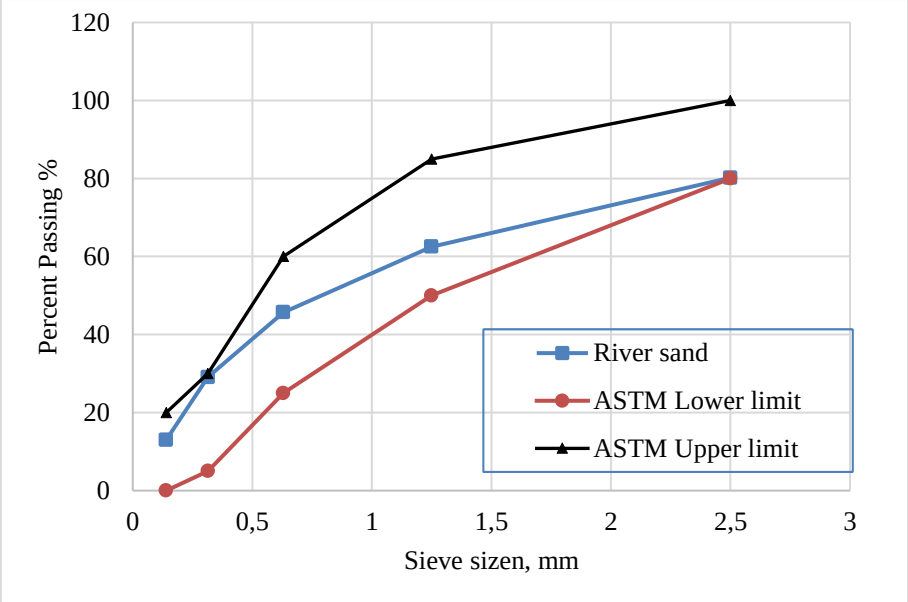


Fig. 1 - Diagram the determination of the grain size of river sand

2.1.2 Crushed stone dust

Crushed stone is a by-product of the process of crushing bedrock to make construction materials. In this study, crushed stone was taken from a quarry in Nghe An province. The particle size distribution is summarized in Fig. 2.

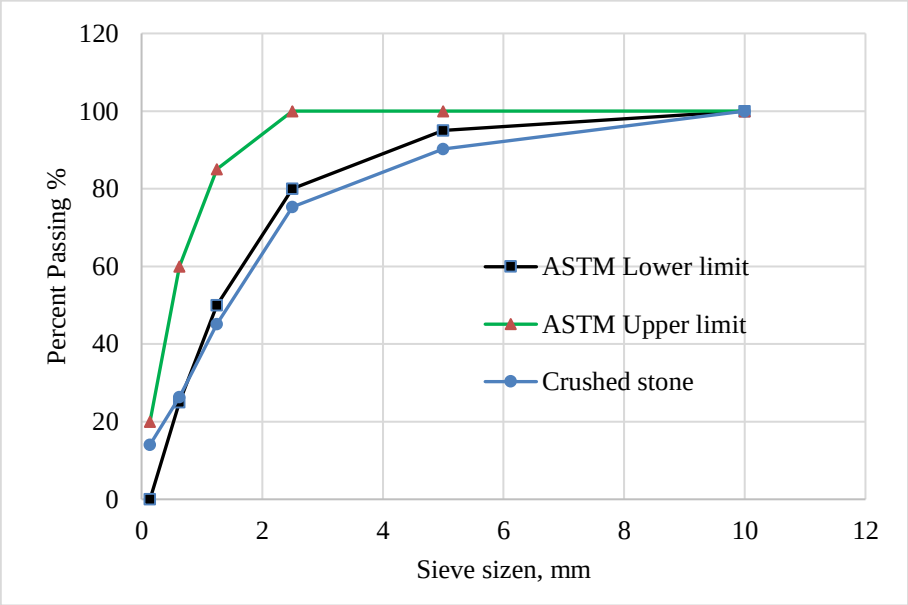


Fig. 2 - Diagram the determination of the grain size of crushed stone

2.1.3 50% crushed stone + 50% river sand

Mixing river sand with Nghe An crushed stone in different proportions, the results from reference documents show that crushed stone accounts for 30% to 70% of the grain size distribution in accordance with ASTM standards. In this paper, the authors take the proportion of 50% crushed stone mixed with 50% river sand. The grain size of this mixture is shown in Fig. 3.

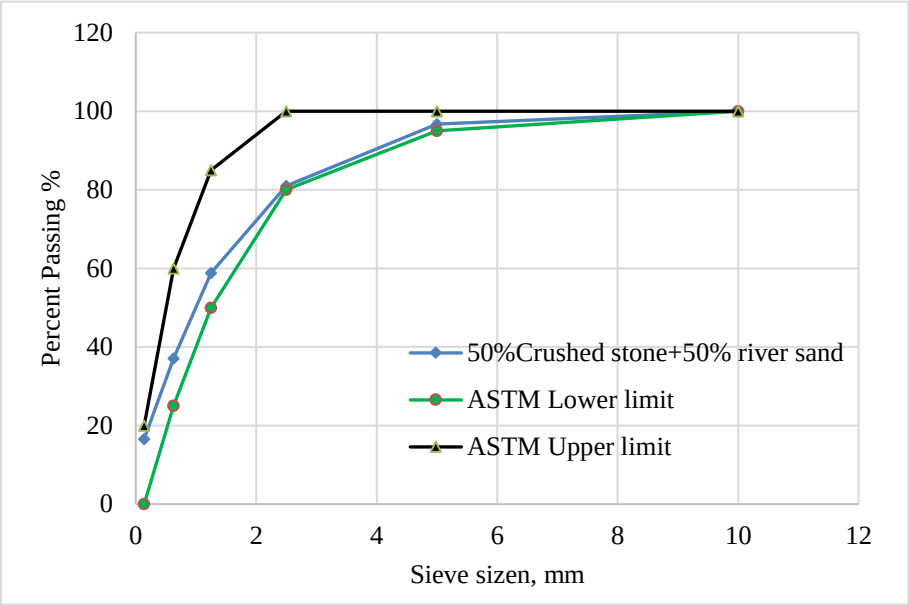


Fig. 3 - Diagram of determination of grain size of 50% crushed stone + 50% river sand

2.1.4 Large aggregate

The grain size of the large aggregate is shown in Fig. 4.

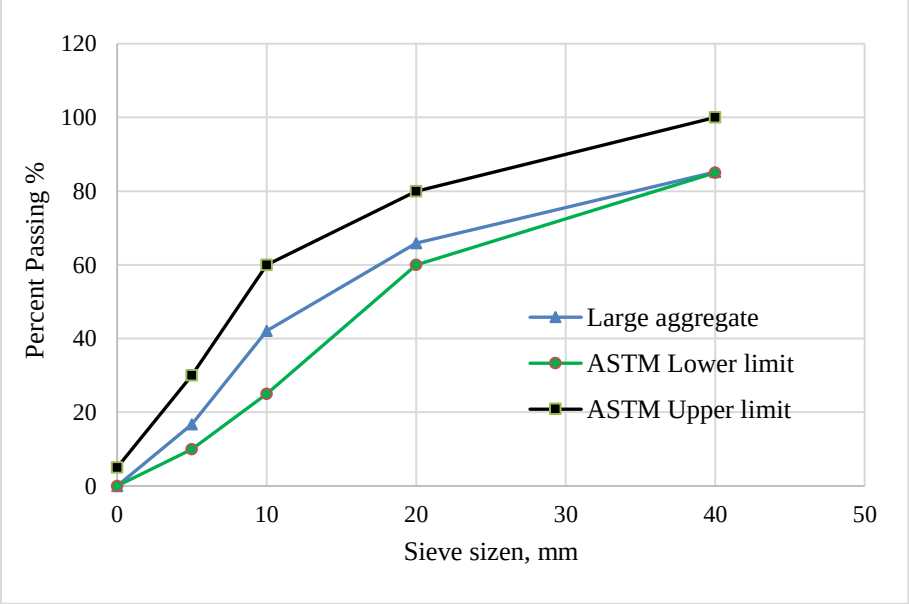


Fig. 4 - Diagram of the determination of the grain size of large aggregate

2.2 Determine concrete mix

To study the possibility of using crushed stone dust to replace natural sand for conventional reinforced concrete structures, four concrete mixes were designed for three types of sand to ensure durability level B15, with a required slump SN = 6 ± 2 cm.

CM1: Cement + natural sand + crushed stone + water

CM2: Cement + crushed stone dust + crushed stone + water

CM3: Cement + crushed stone dust + crushed stone + water + additives

CM4: Cement + 50% natural sand + 50% crushed stone dust + crushed stone + water

The mix composition is determined by the absolute volume principle according to the following equation [11, 21]:

$$\frac{C}{\rho_c}+\frac{W}{\rho_w}+\frac{Sa}{\rho_{sa}}+\frac{St}{\rho_{st}}+A=1000$$

in which: C, W, Sa, and St are the mass (kg) used of Cement, Water, Sand, and Stone; ρC, ρW, ρSa, ρSt are the density of Cement, Water, Sand, and Stone respectively; A is the air bubble content in the concrete mixture (preliminary research chose A = 1% - equivalent to 10 liters/m3 of concrete). The proportion of stone and two types of natural sand (SN) and artificial crushed stone dust (SD) is determined based on experiments to determine the reasonable composition of the aggregate mixture to ensure the tightest arrangement, according to the method of maximum compaction volume. The four concrete mixes used in the study were initially determined at the Construction Laboratory - Vinh University. These four types of mixes were then used to expand the research to the structural model: (i) steel-concrete adhesion force and (ii) reinforced concrete beam structure subjected to bending.

2.3 Experiment to determine the physical and mechanical properties of concrete

Compressive strength of concrete is determined according to TCVN 3118:2022 [22].

A total of 36 cubes with a size of 15×15×15 cm were tested to determine the compressive strength at 7, 14, and 28 days of concrete using two types of sand SN and SD (Fig. 5). After casting, the samples were soaked in water and cured in the laboratory until the testing age.

The compressive strength of the sample is calculated according to the formula: $R=\alpha\frac{P}{A}$



Fig. 5 - Experiment to determine the slump of concrete mixture and casting cube sample



Fig. 6 - Curing of concrete samples and testing to determine the compressive strength of cubic concrete samples

2.4 Experiment to determine the adhesion force between concrete and steel reinforcement

The experimental specimen to determine the adhesion force was designed according to the instructions of Rilem 7-II-128 [23]. Accordingly, the experimental specimen was designed to include a ϕ14 steel bar anchored for a length of 5ϕ = 7 cm in a 15 × 15 × 15 cm cube concrete specimen (Fig. 7). One end of the steel bar was left about 5 cm out of the concrete specimen to measure the displacement of the steel bar during the test. The other end of the steel bar was inserted into a plastic tube to prevent adhesion to the concrete. The experiment to determine the adhesion force between concrete and steel reinforcement was conducted 28 days after casting the specimen. There were a total of 6 specimens for the experiment for the two types of concrete.

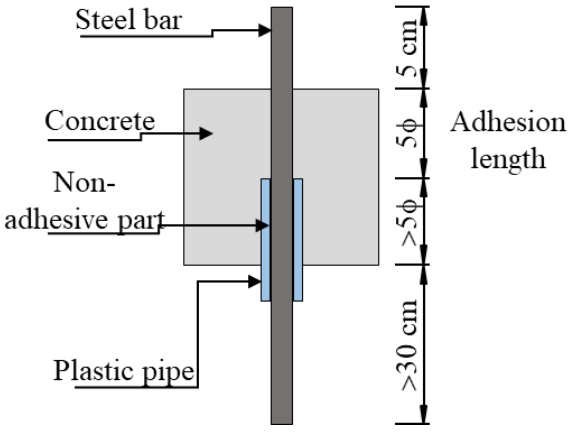


Fig. 7 - Experimental model of adhesion force of steel to concrete

2.5 Testing of reinforced concrete beams under bending

In this section, the author conducts experiments on two beam samples. Beam sample 1 uses 100% natural sand as fine aggregate, and beam sample 2 uses 50% natural sand + 50% crushed stone dust as fine aggregate. The reason for choosing fine aggregate for the second beam sample as above is that the sand/crushed stone dust ratio satisfies the Vietnam standard grading conditions; at the same time, the above ratio also increases the workability of concrete when using crushed stone as fine aggregate. This increases the possibility of applying crushed stone dust as fine aggregate in practice.

The experimental reinforced concrete beam is designed as follows:

- Reinforced concrete beam 1200x100x150mm (Fig. 8)
- Concrete beam of strength level B15, the beams are poured together at the same time to ensure uniformity in concrete strength for the test samples.

The beam is arranged with 6mm diameter stirrups, and 2 branches with a distance of a = 200mm. The included 2 beam samples, denoted as M1 (small aggregate using natural sand) and M2 (small aggregate using 50% natural sand and 50% crushed stone dust), with 2ϕ6 reinforcement at the top and 2ϕ10 reinforcement at the bottom. The cast beam samples are cured with water in the mold for three days, then removed from the mold and placed in the laboratory air to closely resemble the actual construction conditions at the construction site.

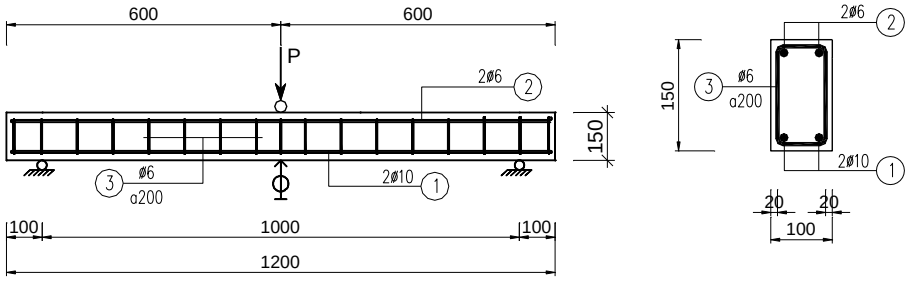


Fig. 8 - Experimental beam diagram



Fig. 9 - Failure state of beam specimen M1



Fig. 10 - Failure state of beam specimen M2

3 Results and discussion

3.1 Grain composition

The grain composition of river sand, crushed stone, and a mixture of 50% sand + 50% crushed stone all meet ASTM standards. However, the grain composition of crushed stone does not.

3.2 Slump of concrete

Table 1 shows the slump test results of the concrete mixes CM1-CM4. The slump of CM2 has decreased significantly compared to CM1, which indicates that the use of crushed stone reduces the plasticity of fresh concrete. To increase the plasticity of concrete when using crushed stone, the CM3 additive can be used, or sand can be combined with crushed stone CM4.

Table 1. Measured slump of concrete types

Concrete types	CP1	CP2	CP3	CP4
Slump (mm)	75	45	95	65

3.3 Compressive strength of concrete

Table 2 and Fig. 11 show the results of the cubic concrete specimens' compression test.

Table 2 - Results of compression test of concrete cube sample

Compressive strength (MPA)	Concrete mix			
	CM1	CM2	CM3	CM4
0 day	0	0	0	0
3 days	16,2	17,92	20,3	18,65
7 days	18,.9	20,56	23,92	21,45
28 days	24,3	26,2	27,8	27,4

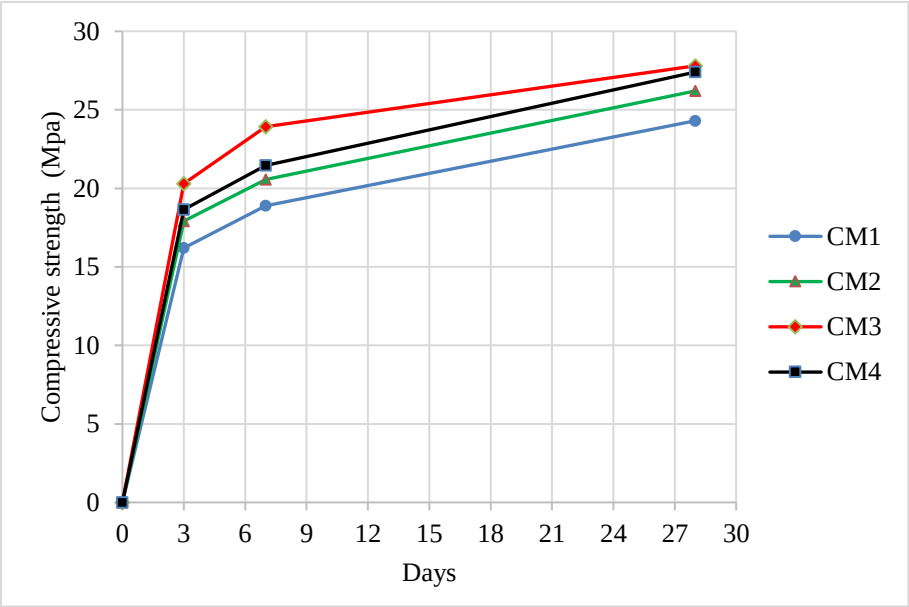


Fig. 11 - Increase in compressive strength over time of concrete samples

From the above results, we can see in Table 2 that all four CM1-CM4 concrete mixes reach the B15 strength level at 28 days. The use of crushed stone dust in CM2, CM3, and CM4 increased the strength at 28 days by about 7,2-12,6% compared to the use of natural sand. In all mixes, it can be seen that the compressive strength of concrete at 7 days is above 70% compared to the compressive strength of concrete at 28 days. Meanwhile, in CM3 mixed with a plasticizer, the compressive strength of concrete at 7 days is about 86% compared to that of concrete at 28 days. This can be explained by the fact that the use of additives increases the plasticity and ease of pouring of fresh concrete, thereby the compressive strength of concrete develops earlier (7 days). However, the compressive strength of CM3 concrete at 28 days is not much different from other mixes. Note that, due to the limitations of the instrumentation, all mixtures exhibit the same peak strain in Fig. 3.

3.4 Adhesion force between concrete and steel

The results of the steel-concrete adhesion test are given in Table 3.

Table 3. Results of measuring the adhesion force between steel and concrete using SN and SD

Result	Concrete type	
	Natural Sand (SN)	Crushed Stone dust (SD)
Rebar pull-out force, P (KN)	60,7	64,9
Adhesion, τ_{tb} (MPa)	19,7	21,1

The results showed that the adhesion between the steel and the two types of concrete was quite similar: concrete using SD crushed stone gave a higher adhesion force than SN natural sand concrete by about 6.6% (Table 3). This proves that the

rough surface properties of SD and the solidity of the crushed stone concrete mix with the river sand increased the adhesion between the concrete layer and the surface of the steel bar.

3.5 Bending compression results of two beam specimens

The bending test results of two beam specimens are given in Table 4 and Fig. 12.

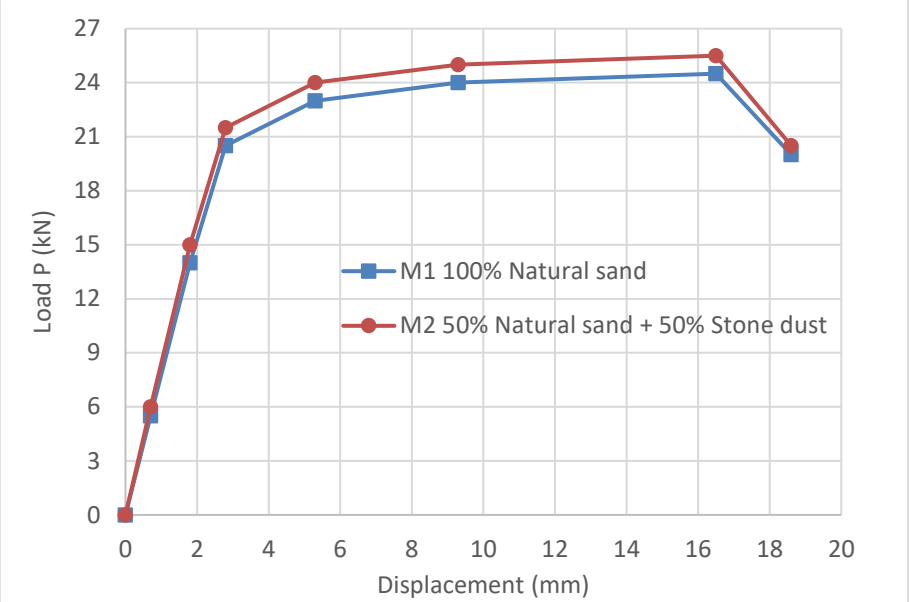


Fig. 12 - Comparison chart of experimental loads of beam M1 and beam M2

Table 4. Comparison table of experimental compressive loads of beam M1 and beam M2

Loading order	Reading value on measuring device (Mpa)	Displacement (mm)	Conversion value (kN)		ΔP_{max} (%)
			M1	M2	
1	0	0	0	0	0
2	2	0,7	5,5	6,0	+8,33
3	4	1,8	14,0	15,0	+6,67
4	5	2,8	20,5	21,5	+4,65
5	6	5,3	23,0	24,0	+4,17
6	7	9,3	24,0	25,0	+4,00
7	8	16,5	24,5	25,5	+3,92
8	9	18,6	20,0	20,5	+2,44

The results of steel yield strength and theoretically calculated Pmax force are given in Table 5.

Table 5. The steel yield strength and the theoretically calculated P_{max} force

Beam model	Yield strength of steel ϕ10 (MPa)	Yield strength of steel ϕ6 (MPa)	P_{max} determined according to TCVN	P_{max} determined experimentally	ΔP_{max} (%)
M1	355	282	16,14	24,5	+34,12
M2	355	282	18,5	25,5	+27,45

From the above results, we can see that with beam model M1, the first crack appeared in the middle of the beam at a load value of P = 5,5 kN. As the load increased, oblique cracks formed, and the crack widened at a load of P = 20,5 kN and a displacement of 2.8mm. When the load P = 24,5 kN, the crack widened to more than 1mm and the beam was damaged; the corresponding displacement at this load was 16,5 mm (Table 4). With beam model M2, similar to beam M1 at a load value of P = 7 kN, the first straight crack appears. As the load increased, oblique cracks formed, and the crack widened at a load of P = 21,5kN, and a displacement of 2,8mm. Continuing to load, the crack extends to the load point, forming additional cracks on both sides close to the load point. When the load reaches Pmax = 25,5 kN, the corresponding displacement at the middle of the beam span is 16,5mm.

Through the experiment, we see that the bearing capacity of the beam using fine aggregates of 100% natural sand and fine aggregates of 50% natural sand + 50% crushed stone dust are almost equivalent, the beam using fine aggregates of 50% natural sand + 50% crushed stone dust has a slightly greater bearing capacity. Specifically, with the same deflection of 2,8mm, P1 = 20,5 kN, while P2 = 21,5 kN. Or, the destructive load P1max = 24,5 KN, P2max = 25,5 KN. This increase in strength may be due to the better friction of the crushed stone and pore structure of the crushed stone concrete mix with the river sand, or it may be due to the microstructural bonding of this type of concrete, thus increasing the adhesion between the concrete and the steel. From the experimental results to determine the compressive strength of concrete samples, we also see that the strength of cubic concrete samples using crushed stone dust is higher than that of concrete samples using 100% natural sand.

4 Conclusion

The experimental study to evaluate the possibility of replacing natural sand with artificial sand crushed from natural stone (a by-product of the production of large aggregates) has achieved the following results:

- The experimental results of slump of concrete mixes with corresponding small aggregates in mixes CM1 (using 100% natural sand), CM2 (using 100% crushed stone dust), CM3 (using 100% crushed stone dust + plasticizer), CM4 (using 50% natural sand + 50% crushed stone dust). We can see that the slump of CM2 has decreased significantly compared to CM1, which can be seen as the use of crushed stone dust reduces the plasticity of fresh concrete. To increase the plasticity of concrete when using crushed stone dust, it is possible to use additional additives of sample CM3 or combine sand with crushed stone dust of sample CM4.
- The experimental results of compressive strength at 28 days of concrete using crushed stone dust exceeded 7,2-12,6% compared to concrete using natural sand. Thus, when coarse sand (a material that is scarce in some areas) is replaced with crushed stone dust in the composition of sand concrete, the compressive strength is significantly improved.

In addition, the paper also tested two beam models with dimensions of 100x150x1200 mm. Beam model M1 used 100% natural sand as small aggregate, Beam model M2 used 50% natural sand + 50% crushed stone dust as small aggregate, both beams were designed with concrete with durability level B15. Through the experimental results, although the number of samples was limited, it showed that the bearing capacity was almost the same, the beam using small aggregate of 50% natural sand + 50% crushed stone dust had a slightly greater bearing capacity than the reinforced concrete beam using 100% natural sand, the difference was 6%. This increase in strength may be due to the better friction of the crushed stone and pore structure of the crushed stone concrete mix with the river sand, or it may be due to the microstructural bonding of this type of concrete, thus increasing the adhesion between the concrete and the steel. Thus, from this result, we can see that crushed stone dust can be used to replace part of natural sand for concrete used in beam structures, in particular, and civil structures in general. Currently, stone quarries discharge about 25% ÷ 40% crushed stone dust. If this crushed stone dust resource is utilized, it can bring economic and environmental benefits.

Some limitations of this study: the number of test samples was limited, and the test period was short (only 28 days). In addition, the durability, abrasion resistance, water absorption, corrosion, and life cycle of crushed stone concrete were not analyzed.

In future work, we will study further compressive-strength monitoring to 56 days and 90 days, conducting durability screening (ASR, chloride penetration), performing economic and environmental assessments, and exploring implications for Vietnamese code updates.

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