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Sustainable Solution for Industrial Waste at the Coal Mining Site

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ABSTRACT
The environmental impact of the coal industry includes many issues, and one of them is waste management that affects human life crucially. This paper proposes the sustainable solution for the industrial waste at the coal mining site. As an example, this waste is produced with the amount of about 200 million cubic meter per year at the north-east area of Vietnam, where gathers a lot of coal mining site, and more importantly this makes the landfill becoming longer and higher. This waste can be manufactured and turned into aggregates used effectively for construction. The industrial sand, which is one of the products from the coal mining waste, is used for concrete production in this paper. Two types of concrete of strength class 30MPa, such as conventional concrete (need of vibration) and self-compacting concrete (lack of vibration), were considered. The industrial sand replaces totally natural sand that usually involved into concrete mix design. Different specimens of different types and sizes were prepared in order to determine compressive strength, flexural strength and elastic modulus. The experimental test showed that both of concretes achieved strength class as designed. The average compressive strength at 3 and 7 days was about 57% and 76% that at 28 days. Also, the average flexural strength is about 10% the corresponding compressive strength. Lastly, the average elastic modulus at 28 days showed the result of 25 GPa, which complies with the one prescribed in Eurocode for concrete of this type of strength class.

Key words: Industrial waste, coal mining, industrial sand, concrete production.

1. INTRODUCTION
Coal mining is the process of extracting coal from the ground. Coal is valued for its energy content and since the 18th century, has been widely used to generate electricity [1]. Steel and cement industries use coal as a fuel for extraction of iron from iron ore and for cement production in many countries around the world including Vietnam [2, 3]. However, coal mining can result in a number of adverse effects on the environment. For instance, surface mining of coal completely eliminates existing vegetation, destroys the genetic soil profile, displaces or destroys wildlife and habitat, degrades air quality, alters current land uses, and to some extent permanently changes the general topography of the area mined [4].
One of the environmental problem that the north-east area of Vietnam, where gathers a lot of coal mining sites, faces with is that there is a huge amount of industrial waste or by-product during coal excavation. Every year, this area normally produces about 40 million tons of coal. In general, 1 ton of coal is excavated, at least 5 cubic meters of soil and rock are transported to dumping site. The amount of soil and rock on the ground every year is proportional to the landfill becoming longer and higher, as it can be seen in Figure 1. In the recent years, the proposed solution for this issue has been to manufacture this by-product, in which consists of mainly sandstone, turning into coarse and fine aggregates used for make floor tiles, brick, and additives for precast pipes and road building as well as for other construction materials [5, 6]. The one to be used as fine aggregated is also named as industrial sand. This type of sand has shape and size similar to natural sand that will completely pass through 4.75 mm sieve [7].

When the industrial sand is used for concrete, there could be many positive outcomes. On the one hand, the industrial waste at the coal mining site causing environmental impact from the disposal area can be reduced. On the other hand, it is possible to relieve the scarcity of natural sand for concrete production. Besides, the cost of concrete using industrial sand could be more economical in comparison with the one using natural sand of high cost due mainly to high market demand [8].

Figure 1: Industrial waste “mountain” at the coal mining site

This paper reports the results of an experimental investigation on the use of industrial sand is used for concrete production. Two types of concrete of strength class 30MPa, such as conventional concrete (need of vibration) and self-compacting concrete (lack of vibration), are considered. The industrial sand replaces totally natural sand that usually involved into concrete mix design. Different specimens of different types and sizes are prepared in order to determine compressive strength, flexural strength and elastic modulus.

2. MATERIALS AND METHOD

Materials used in the experimental work are given below.

2.1. Cement

Cement used in this study is ordinary Portland blended cement PCB40 with commercial band Xuan Thanh, which is conforming to the European cement standard EN 197-1. Physical and mechanical characteristic of cement are given in Table 1.

Table 1: Physical and mechanical characteristic of cement

Parameters	Units	Test results
Specific density	g/cm^3	3.11
Bulk density	g/cm^3	1.32
Blaine fineness	cm^2/g	3320
Consistency	%	28.1
Initial setting time	min.	110
Final setting time	min.	295
Soundness of cement	mm	2.2
3 days compressive strength	N/mm^2	33.1
28 days compressive strength	N/mm^2	45.7

2.2. Fine and coarse aggregates

The industrial sand used was from the coal mining site Dong Cao Son of Thien Nam JSC, as it can be seen in Figure 2. While, natural crushed stone from the nearby area with maximum size of 20 mm was implemented for the concrete mix design. Characteristic of fine and coarse aggregates is included in Table 2. Besides, in order to obtain grading of aggregates, sieve analysis was also carried, the results are shown in Table 3.

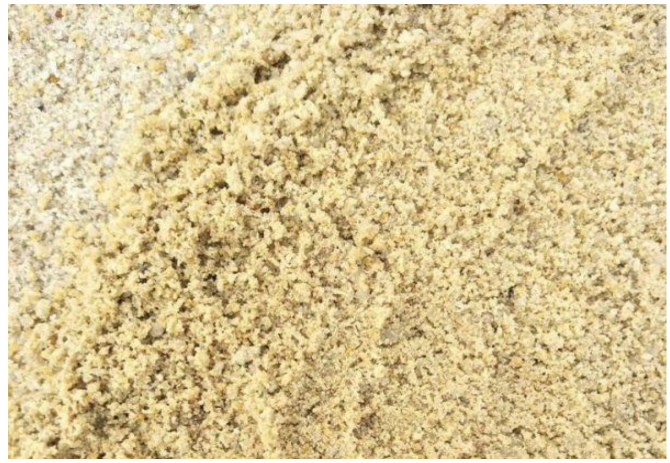


Figure 2: Industrial sand used in this study

Table 2: Characteristic of coarse and fine aggregates

Parameters	Units	Crushed stone	Industrial sand
Specific density	g/cm^3	2.71	2.7
Bulk density	g/cm^3	1.48	1.65
Water absorption	%	0.9	1.9
Clay, silt and dust content	%	1.5	1.5
Fineness modulus	-	-	3.01

Table 3: Gradation of coarse and fine aggregates by sieve analysis

Sieve size	Crushed stone	Industrial sand
	Cumulative % retained	
70	0.0	
40	1.9	
20	9.5	
10	80.3	
5	98.0	0.0
2.5		19.5
1.25		37.8
0.63		61.6
0.315		84.2
0.14		98.4
Pan	100	100

2.3. Chemical admixture and water

Chemical admixture used was a high-range water reducer admixture, which is a third generation poly carboxylate super plasticizer. Besides, in order to improve segregation resistance and cohesiveness of fresh concrete, viscosity modifying agent was also used to produce SCC mix. Water used in this study was tap water at the local area. Characteristic of chemical admixture and water is shown in Table 4.

Table 4: Characteristic of superplasticizer (SP), viscosity modifying agent (VMA) and water

Parameter	Units	SP	VMA	Water
Specific density	g/cm^3	1.075 ÷1.095	1.05	1
pH value	-	4÷ 6	7÷ 8	7

2.4. Experimental program

In this study, concrete 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 marketing demand at the local area. There were two concrete mixes prepared by using industrial sand; one is conventional mix (CVC), and the other is self-compacting mix (SCC). On the one hand, CVC was designed by using the standard mix design method [9], on the other hand the “combined-type” SCC mix design method was considered [10], apart from the increase of powder content and reduction of coarse aggregate content in accordance with SCC mix design guidelines of Professor Okamura [11]. Some “trial-and-error” were involved, the final mix proportion of CVC and SCC is presented in Table 5.

Table 5: Mix proportion of conventional concrete (CVC) and self-compacting concrete (SCC)

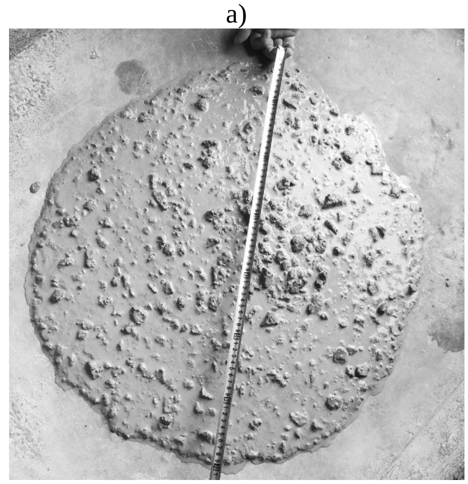
	Cement	Sand	Stone	SP	VMA	Water
	Kg	kg	kg	L	L	L
CVC	285	780	1105	-	-	180
SCC	285	955	906	4.5	2.0	180

After a proper mixing, CVC and SCC were subjected to several tests at fresh state, some of them are illustrated in Figure 3. Also, the fresh properties of CVC and SCC are provided in Table 6. Notably, it can be observed that the slump-flow value, T500, J-ring and V-funnel values of SCC mix in this study are in agreement with the recommendation for SCC mix [12]. This implies that SCC mix was properly proportioned.

Table 6: Fresh properties of conventional concrete (CVC) and self-compacting concrete (SCC)

	Slump, mm	Slump-flow value, mm	T_{500}, s	J-ring, mm	V-funnel, s
CVC	60	-	-	-	-
SCC	-	680	3.5	7	8

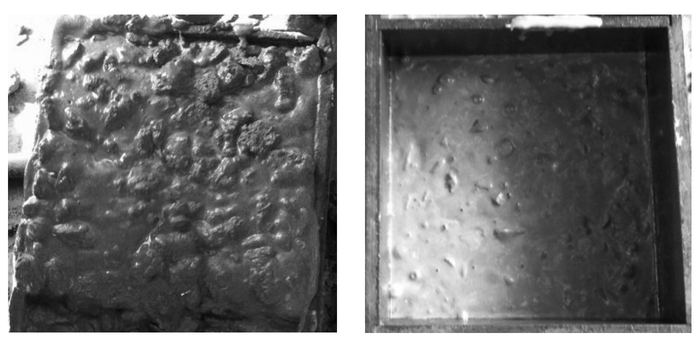
a)



b)

Figure 3: Test at fresh state of CVC a) and SCC b)

Afterward, the fresh concrete was poured into a series of metallic mould, as shown in Figure 4, in order to produce a series of standard specimens for mechanical tests. For each concrete, 9 cube specimens (150x150x150 mm^3) and 9 prism specimens (100x100x400 mm^3) were prepared for determination of compressive and flexural strength at the age of 3, 7 and 28 days. Besides, 3 cylindrical specimens (diameter 150 mm and height 300 mm) were cast to define elastic modulus at the age of 28 days.



a) b)

Figure 4: Casting CVC a) and SCC b) into the metallic mould

3. RESULTS AND DISCUSSION

Test results of compressive strength versus time evolution are shown in Figure 5. Looking into this figure, both of CVC and SCC achieved strength class of 30 MPa, as designed. From Table 7, it can be seen that the average compressive strength of CVC and SCC at 3 and 7 days was about 57% and 76% that at 28 days. Besides, it can be observed that compressive strength of SCC is slightly higher than that of CVC. The reason might be due to the use of chemical admixture in SCC that results in better rheological properties at fresh state, which in turn yields higher compressive strength at hardened state [9].

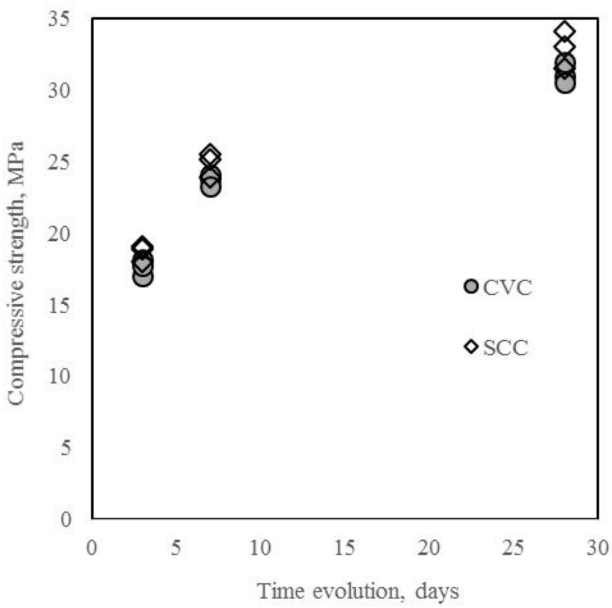


Figure 5: Compressive strength of CVC and SCC versus time

Table 7: Hardened properties of conventional concrete (CVC) and self-compacting concrete (SCC), average results

	CVC			SCC		
	3 d	7 d	28 d	3 d	7 d	28 d
Compressive strength	17.6	23.7	31.2	18.7	24.9	32.9
Flexural strength	1.68	2.25	2.96	1.78	2.36	3.11

Regarding test results of flexural strength versus time evolution, Figure 6 shows no big discrepancy between CVC and SCC at the age of 3, 7, and 28 days. In general, at different ages, the average flexural strength of CVC and SCC is about 10% the corresponding compressive strength, as it is observed from Table 7.

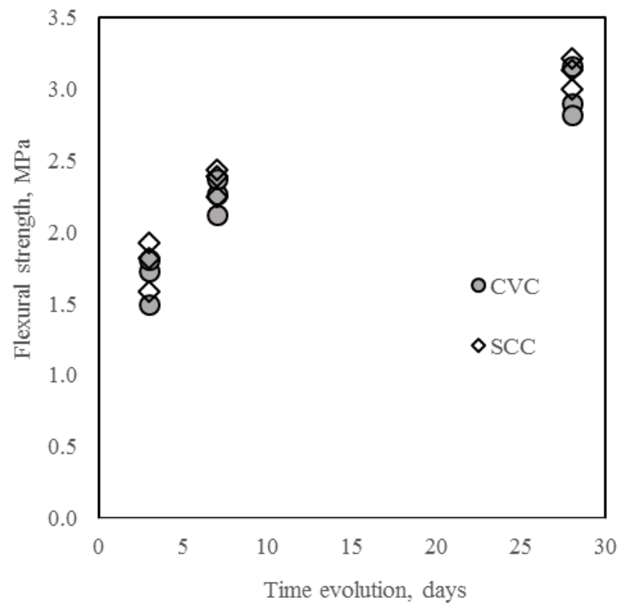


Figure 6: Flexural strength of CVC and SCC versus time

The average elastic modulus of CVC and SCC at 28 days present the similar results of 25 GPa, as shown in Figure 7. This modulus result complies with the one prescribed in Eurocode for concrete of this type of strength class [13].

The test results from compressive strength, flexural strength and elastic modulus of CVC and SCC have proved that the industrial sand can be implemented positively for concrete production.

4. CONCLUSION

The principal advantage of industrial sand usage for concrete production in this paper are twofold. Firstly, it is able to diminish the industrial waste at coal mining site, causing environmental impact from the disposal area on human life, especially surrounding area. Secondly, it is possible to relieve the scarcity of natural sand for concrete production. The industrial sand was used successfully for production of conventional and self-compacting concrete of strength class 30 MPa. Compressive strength and flexural strength of these concretes at the different ages (3, 7, and 28 days) and elastic modulus are in compliance with the one prescribed in the standard design code for this type of concrete.

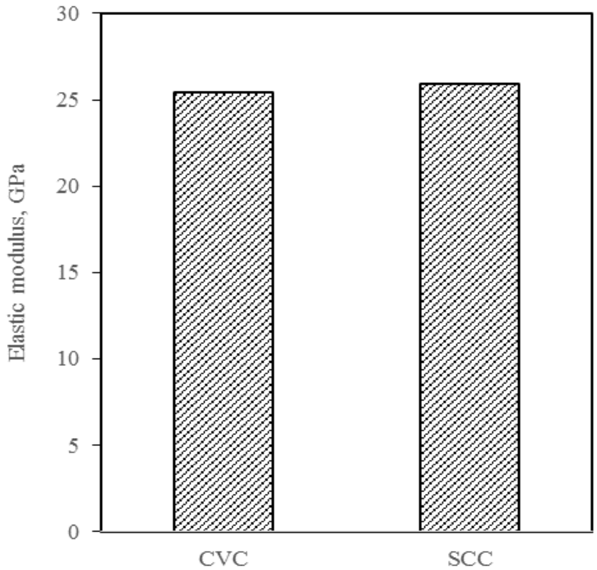


Figure 7: Elastic modulus of CVC and SCC at 28 days

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