Research Article

Influence and Possibility of Using Limestone Dust Replacement of Sand for Sustainability in Concrete Production

Nuttawut Intaboot* and Kriangkrai Chartboot
Department of Civil Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Suvarnabhumi, Nonthaburi, Thailand

* Corresponding author. E-mail: Nuttawut098@gmail.com

DOI: 10.14416/j.asep.2021.11.002
Received: 8 May 2021; Revised: 3 June 2021; Accepted: 17 June 2021; Published online: 4 November 2021

Abstract

This paper aimed to assess the potential of using limestone dust to replace sand at levels of 0, 20, 40, 60, 80, and 100% by weight. Concrete mix design for cement fine aggregate coarse aggregate was 1: 2 4 and 0.40, 0.50, 0.60 water cement ratios were used. The study started by testing the basic properties of the material. The compressive strength test was done with curing for 7, 14, 21, and 28 days and modulus of elasticity of concrete at 28 days, after which the microstructural properties of concrete modified with limestone dust, were investigated. The study found that the concrete had better workability when increasing the limestone dust content. The incorporation of 40% limestone dust, at water cement ratios of 0.50, were found to improve the compressive strength of the concrete and resulted in the maximum compressive strength. However, high levels of replacement lead to porous microstructures. Moreover, the use of limestone dust in concrete production tends to be more cost-effective. Therefore, the results of this research seemingly provide confirmation and support for the utilization of these waste materials by reducing the use of natural resources. Further, it is a goal of local governments to help promote the value of limestone dust for future use.

Keywords: Limestone dust, Modulus of elasticity, Economics analysis, Water cement ratios, Workability

1 Introduction

At present, concrete has a vital role in national development. Construction requires the use of concrete for critical components. Because concrete is a material that can be designed to support the weight of a building, it must be durable and have a long service life. In addition, the researcher identified new technologies and methods that could be easily used to save money, while also maintaining the strength of the concrete [1]. Concrete mixtures typically consist of rock, gravel, and coarse sand, known as aggregate. The aggregate must be inert materials that do not react with the cement paste. The aggregate is inserted into the cement paste at approximately three-quarters of the concrete content, which must be cheaper than cement. Therefore, the aggregate must contribute to a cheaper concrete price while maintaining the same properties [2].

In Thailand, there are a large number of stone mill industries, resulting in waste products from industrial processes. Limestone dust is a waste material that is less useful but more plentiful. Limestone dust is a by-product of the stone milling or stone production process. The dust from this process will be very small size and cannot pass through a sieve, but it will instead be blown out and falls to the mill floor. Normally, it will be carried out and discarded. According to data from the Department of Mineral Resources of Thailand, it has a production capacity of approximately 90,000 cubic meters per day [3]. This is a reflection of nature's destruction and results in a significant amount of waste. The dust stone has physical characteristics similar to sand but has a price of just 1/8 of sand [4]. From the research, it was found that limestone dust can be used in the concrete industry by using limestone dust as a mixture to replace partially or fully to sand, which provides the compressive strength of concrete similar to normal concrete [5]–[7].

In the past, many researchers studied the development of industrial wastes, such as quarry dust, alum sludge, granite sludge, marble dust, and limestone dust, all of which could be recycled by using technological innovation in concrete. These industrial wastes have partially or completely replaced sand in concrete production [8]. In addition, these waste materials used to replace sand can also be used as a replacement for cement to reduce the use of cement. Ahmed *et al.* [9] used granite sludge to replace cement in mortar for the production of concrete blocks and used a constant w/b ratio. The results indicated that up to 20% of the granite sludge replaces cement, resulting in better properties of a concrete block including resistance to abrasion, freezing, and thawing, and sulfate attack. In addition, Li *et al.* [10] used granite dust mixed with additional cement instead of fly ash to study behaviors such as workability, durability and shrinkage performance, and the mechanical properties of concrete. It was found that the optimum granite dust content was 20% of the total cement. Moreover, A. Danish *et al.* [11] compiled a review of the use of these waste materials to replace some of the cement in concrete materials such as mortar, normal concrete, high-performance concrete, self-compacting concrete, and cement paste, etc. It is aggregated from the study of researchers from around the world. It was concluded that these waste materials could be substituted for cement without compromising the engineering properties of concrete. They could also reduce environmental pollution and costs, and boost the value of these waste materials.

Besides these industrial waste materials being partially substituted for cement, they can also be used as a paste replacement to improve the durability and stability of concrete materials. China has the second largest of the marble manufacturing industries in the world [12], so a significant amount of marble dust waste material is generated. Therefore, it is necessary to study to increase the value of the waste products [13]. For this reason, the researchers in the country studied the potential use of these waste materials to replace cement or aggregate. There would be some limitations, such as increasing the limestone dust content makes the concrete have high water requirements, thus diminishing the properties of the concrete. Increasing the limestone dust content to replace aggregate is only a reduction in the use of natural resources. It does not reduce the carbon footprint from the cement obtained from the manufacturing process to help protect the environment. Therefore, Li *et al.* [14] proposed a new method by using these wastes material to produce mortar and concrete, which is called the paste replacement method. In this way, wastes materials are added to replace the same amount of cement mixture (cement material and water) without changing the mix composition or water/cementitious materials ratio of the paste. Based on this method, it was found that adding a limestone dust paste replacement could greatly improve the carbonation and water resistance as well as reduce the heat content in the concrete curing process [15], reduce shrinkage and water permeability, [16], [17] and also improves tensile strength, compressive strength, and durability [18], [19].

In addition to both the previously mentioned methods, another factor that researchers have studied is the use of limestone dust by replacing sand. From testing the physical and chemical properties of limestone dust, it was found that limestone dust has the same properties as sand. Therefore, a trial mix was conducted to examine the properties of compressive strength, pumping, and water absorption. It was found that concrete could be produced to the desired properties with no impact on concrete quality [20]. For that reason, Kaish *et al.* [21] studied the effects of several kinds of waste in the industrial sector, including quarry dust, limestone dust, and alum sludge to replace sand in concrete production. The research also shows that the optimum replacement content of limestone dust at 15% improves the density of concrete compression, bending, and tensile strength. The influence of limestone dust on concrete strength depends on the particle size and replacement percentage. Therefore, it also influences a significant increase in strength on later days for replacement in small quantities [22]. In addition to replacement, limestone dust will increase the concrete water requirements. However, the strength of the concrete diminishes as the water content in the mixture increases. Still, the compressive strength of limestone concrete is higher compared to that of normal concrete [23], [24].

From the literature review above, there is a way to utilize the waste materials from industrial processes. The three methods for concrete production that were used in this study consisted of sand substitution, cement replacement, and paste replacement. The last two methods focused on reducing the use of cement to reduce the cement production process and enhance environmental responsiveness. However, the reduction of cement in large quantities to increase the limestone dust in large quantities is not yet possible because it will greatly reduce the strength. On the other hand, using limestone dust in large amounts can be a replacement for sand. The concrete also can gain strength. It also helps to reduce the use of natural resources and lowers the costs of concrete production. It also adds value to the limestone dust.

For the above reasons, this research aimed to study the possibility of using limestone dust to replace sand in the production of concrete. The limestone dust from Nakhon Sawan Province in Thailand was used as a case study because it is a resource close to a laboratory or test site, which helps to reduce transportation costs and allows operational budget control. Limestone dust was used for grading the size to have a grain size distribution equivalent or close to the distribution of the grain size of sand. Compressive strength of concrete with different water cement ratios and addition ratio of limestone dust were tested. The microstructural properties of concrete were studied in order to present the ecological and economic aspects of limestone dust concrete. The results could serve as a guideline for development by government agencies to promote value in the future and the use of limestone dust, which is a waste material from various industries.

2 Materials and Methods

2.1 *Materials*

Portland cement type I, river sand (natural fine aggregate, NFA), water, and 5–19 mm. Crushed rock coarse aggregates were used for the concrete formulation. The limestone dust (LSD) from stone processing was obtained from a local stone-crushing quarry in Thailand (Figure 1.) The physical properties of the fine aggregates are shown in (Table 1.) The sieve analysis of both NFA and stone processing dust is presented in (Figure 2.) The fine aggregate satisfied the ASTM C-136-95 specification requirements [25]. Limestone dust particles have a higher amount of fine particles and also exhibit rougher and more angular features than river sand (Figure 3.) The size distribution of dust stone is shown in (Figure 4.) and D50 was 127 µm.

Figure 1: Limestone dust (LSD) from a local stone-crushing quarry in Thailand.

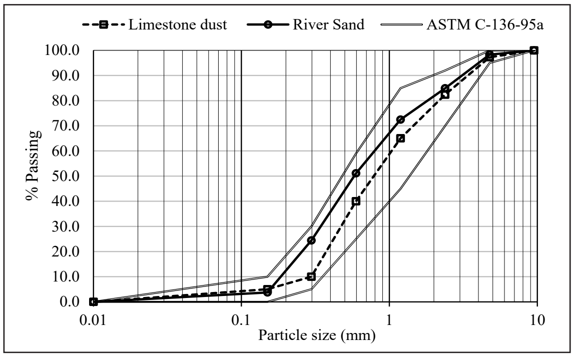


Figure 2: Gradation curve of river sand and dust stone.

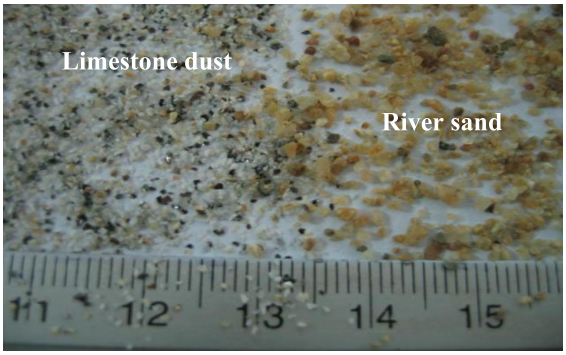


Figure 3: Particle size of river sand and limestone dust.

2.2 *Mix proportion and preparation*

The ratio of cement: fine aggregate: a coarse aggregate of 1:2:4 was used in the concrete mix design. This concrete mixed design is a local mix used for construction in

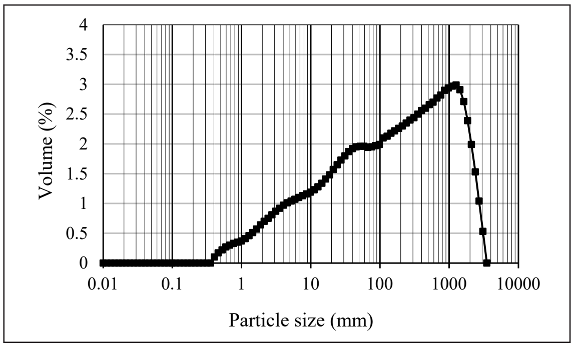


Figure 4: Size distribution of limestone dust.

Thailand. It has been determined that it is suitable for general concrete structures such as floors, columns, beams, and piers. The natural fine aggregate (NFA) was replaced by limestone dust up to 100% (Increments of 20%). The concrete mix was designed to have a near-constant slump in the range of 80–120 mm. The three water-to-cement ratios of 0.40, 0.50, and 0.60 were used for testing and without superplasticizer because the high water consumption can control workability within the specified criteria. The list of concrete design mix proportions is shown in (Table 2.) First, the cement and aggregate were mixed in a mixing pan. Water was then added and mixing was continued until a uniform and homogenous matrix was obtained. The mix for each sand replacement level of a particular concrete grade was casted in 150 × 150 × 150 mm [26] and compacted with a tamping rod in three layers. The specimens were de-molded after 24 h. and cured by immersion in water for 7, 14, 21, and 28 days.

2.3 *Test procedure*

To study the effect of limestone dust replacement of river sand on the mechanical strength development of the concrete mixtures, cubes of size 150 × 150 × 150 mm were cast as per BS EN 12390-Part 3 [26]. Compressive strength measurements were performed

Table 1: Physical properties of fine aggregate

Fine Aggregate	Bulk Density (kg/m^3)	Specific Gravity	Water Absorption (%)	Fineness Modulus	Moisture Content (%)
Limestone dust	1,762.82	2.69	2.60	2.65	0.55
River sand	1,678.85	2.65	0.85	3.00	3.85

Table 2: Concrete mix proportions

Mix No.	Cement (kg/m^3)	River Sand (kg/m^3)	Limestone Dust (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)	Slump (cm)
Conwc40	331	662	0	1324	132.4	8.5
LSD20wc40	331	529.6	132.4	1324	132.4	8.5
LSD40wc40	331	397.2	264.8	1324	132.4	9
LSD60wc40	331	264.8	397.2	1324	132.4	9
LSD80wc40	331	132.4	529.6	1324	132.4	9.5
LSD100wc40	331	0	662	1324	132.4	10
Conwc50	321	642	0	1284	160.5	9
LSD20wc50	321	513.6	128.4	1284	160.5	10
LSD40wc50	321	385.2	256.8	1284	160.5	11
LSD60wc50	321	256.8	385.2	1284	160.5	11
LSD80wc50	321	128.4	513.6	1284	160.5	11
LSD100wc50	321	0	642	1284	160.5	11
Conwc60	315.7	631.3	0	1263	190	10
LSD20wc60	315.7	505.04	126.26	1263	190	11
LSD40wc60	315.7	378.78	252.52	1263	190	12
LSD60wc60	315.7	252.52	378.78	1263	190	12
LSD80wc60	315.7	126.26	505.04	1263	190	12
LSD100wc60	315.7	0	631.03	1263	190	12

at curing ages of 7, 14, 21, and 28 days. The samples were water cured at a temperature of 27 ± 2 °C and relative humidity of 70–90%, which is common for Thailand. Representative compressive strength was taken as an average of three specimens. The static modulus of elasticity (28 days) was tested on standard ASTM C 469 [27] by cylinder sample of size 150 × 300 mm. The microstructures of concrete were tested by scanning electron microscopy (SEM).

3 Results and Discussion

3.1 *Effect of limestone dust and water to cement ratio on workability*

Figure 5. presents the concrete workability by slump test. The results show that the slump value is between 8 and 12 cm, which is a suitable slump value for construction in Thailand. The influence in affecting slump value included water content and limestone dust content. From the experiment, it was found that the slump value increased with the increase of limestone dust content when the water ratio was 0.40. This is consistent with a study by Kaish *et al.* [21], which found that the slump value increased with increased limestone dust. With higher water content (w/c = 0.50, 0.60), the slump value will increase with the amount of limestone dust at 20 and 40%. However, when the amount of limestone dust is higher (more than 40%), the slump value is almost the same. When comparing the slump values of each w/c value, it was found that the higher w/c, the fresh concrete had better properties and better workability in all mixtures of limestone dust content. Since limestone dust is added to the mixture, limestone dust will absorb a large of water, causing the concrete with less water content to have a dry appearance effect to slump value decreasing. When more water is added, the saturation of limestone dust will result in the concrete containing water to help the slump value increase. Therefore, the optimum water content for the w/c ratio in this experiment was not more than 0.60 because it makes the concrete has a suitable slump value.

3.2 *Effect of water-to-cement ratio on compressive strength*

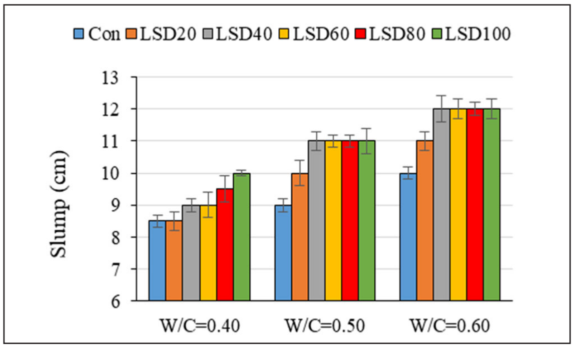


Figure 5: Workability of concrete.

Compressive strength testing focused on the influence of the water-to-cement ratio and curing time. Three water-to-cement ratios were used including 0.40, 0.50, and 0.60 at curing times of 7, 14, 21, and 28 days. The compressive strengths at different water-to-cement ratios are shown in Figure 6. Compressive strength of all mixing and air curing ages of 7, 14, 21, and 28 days were between 14.46–21.16 Mpa, 16.07–24.33 Mpa, 17.26–26.37 Mpa, and 18.23–28.33 Mpa, respectively. The compressive strength in the absence of limestone dust mixture (LSD 0%) revealed that a water to cement ratio of 0.40 provided the highest compressive strength. As the water to cement ratio increases, the compressive strength decreases as a result of the free water, while porosity increase results in strength decrease [28]. However, when 20% and 40% of limestone dust replaced sand, it was found that, with a curing time of 14 days or more, water to cement ratio of 0.5 gave the highest compressive strength. This is because the water demand will increase when the amount of limestone dust increases, because the limestone dust has a rough surface and is more porous than natural sand [29], thus needing more water than natural sand, which is consistent with the water absorption test results in Section 2.3. The additional water will be in the gaps of the limestone dust. Therefore, water will be used to complete the hydration reaction with cement as the curing time increases, resulting in dense concrete that has more compressive strength [30].

When increasing the limestone dust content by 60–100%. However, concrete has a higher water requirement. A water-cement ratio of 0.6 resulted in the concrete having the highest compressive strength due to the increase in limestone dust content. The water demand of concrete was higher, which water absorption of the limestone dust was higher than at of

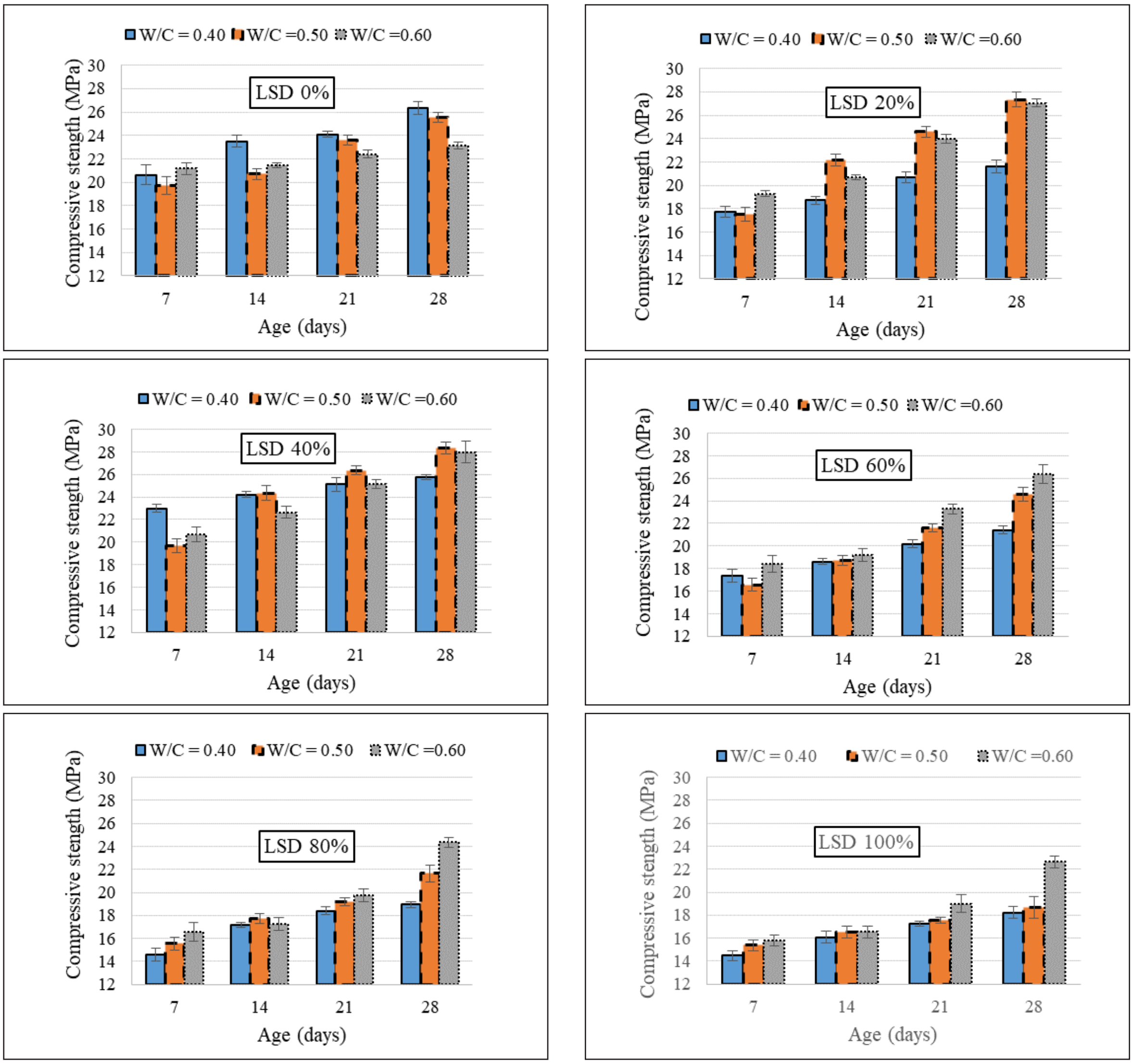


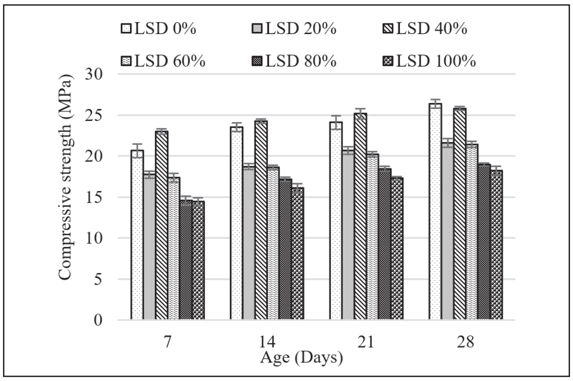
Figure 6: Compressive strength of concrete containing limestone dust.

the sand in the previous test. Therefore, with the ratios of limestone dust more than 40%, the ratio of water to cement at 0.6 is the ratio that makes the concrete compactness results in the maximum compressive strength.

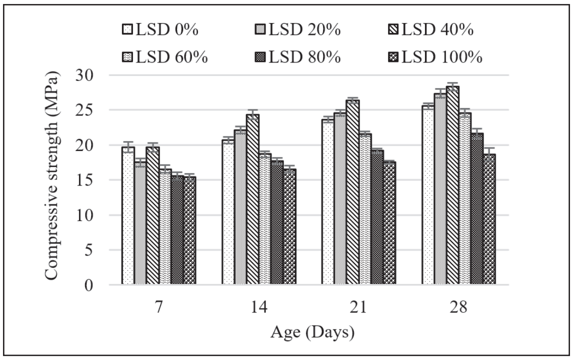
3.3 *Effect of limestone dust on compressive strength*

Compressive strength at different limestone dust in concrete mixing is shown in Figure 7. The maximum compressive strength was obtained with the 40% limestone dust replacement of river sand. For 28 days, the compressive strength of the LSD 40% increase more than control concrete. The compressive strength of the LSD 40% mixing was maximum at 21% and was higher than control concrete water-cement ratio 0.6. The limestone dust could not be in excess of 60% replacement because the compressive strength was lower than control concrete by more than 30%.

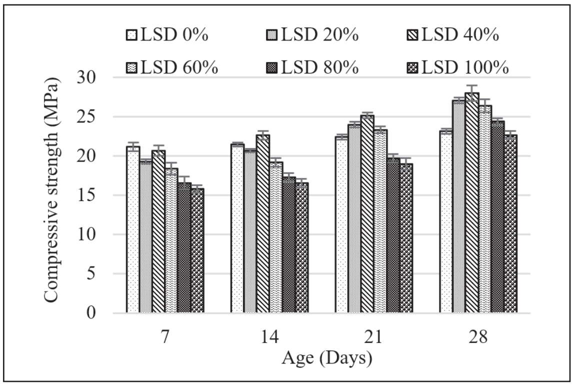
The concrete strength is improved by mixing limestone dust to replace sand because the finer particle



(a) 0.40 of water to cement ratio



(b) 0.50 of water to cement ratio



(c) 0.60 of water to cement ratio

Figure 7: Compressive strength of concrete with different limestone dust.

of limestone dust will fill the gap and reduces the void in concrete. The dense concrete matrix is exhibited the best mechanical performance [31]. Strength characteristics is transferred by the higher compactness. Fine particles improve the packing density for hardened concrete [21]. The hardened concrete is densely packed by fine particles. However, the higher limestone dust increases the voids due to the amount of fine higher left after filling the cement paste to particle ratio resulting in the lower compressive strength. Additionally, increases in limestone dust caused the angular nature to increase and the surface area was covered by cement paste that increase the voids [31]. The increasing of the void is resulting in low compressive strength due to the voids have a weaker plane. Furthermore, the increasing of inter-particle friction and the angularity of limestone dust is resulting lowers the compactness of concrete [31].

The concrete containing limestone dust replacement river sand was analyzed using scanning electron microscopy (SEM) of all mixtures at a curing time of 28 days. The study of microstructures used the broken pieces of concrete generated from compressive strength tests. The examination was carried out at three points in a specimen. The microstructures of concrete mixing limestone dust showed that the structure was not as homogeneous. Figure 8 shows the scanning electron microscopy (SEM) of concrete at 0, 20, 40, 60, 80, and 100% limestone dust replacement river sand at 0.50 water cement ratio.

The intensity of the porous area increased when using limestone dust as a replacement for river sand. In case-control concrete sample is compact and has some little voids and a dense matrix. The control concrete is fully matured and voids are filled up. In case of 20 and 40% of LSD replacement, the void, and lose matrix has decreased. In the case of 60, 80, and 100% LSD replacement, the void and loose matrix increase significantly. The particles have a loose matrix, resulting in a compressive strength decrease. Compressive strength test results for these concrete samples also confirmed the formation of the less dense microstructures when using limestone dust in concrete. Therefore, the higher voids and loose and dense matrix in concrete might have affected their compressive strength [32].

3.4 *Static modulus of elasticity for concrete containing limestone dust*

In Figure 9. shows the elastic modulus of concrete at 28 days. It was found that 40% replacement was the highest among all ratios of water to cement. This proportion is

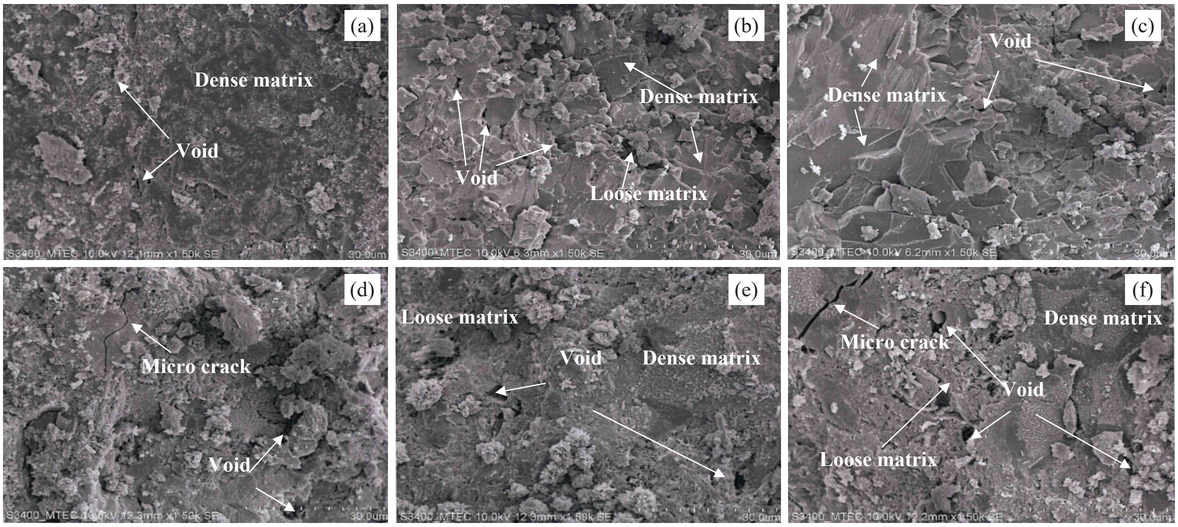


Figure 8: SEM images of concrete containing limestone dust at water-to-cement ratio of 0.50, (a) 0%LSD, (b) 20% LSD, (c) 40%LSD, (d) 60% LSD, (e) 80% LSD, (f) 100% LSD.

made to compact concrete, in accordance as described above. The modulus is reduced significantly with more limestone dust replacement in the water-cement ratios of 0.4 and 0.5, but slightly reduced for a ratio of 0.6. This is because the higher ratio of limestone dust will cause the concrete to have a higher water requirement, which is the result of the strength as described previously.

The modulus depends on the type of coarse aggregate, mortar strength, bonding force between aggregates and mortars, and void or porosity of the concrete [33]. In this study, the coarse aggregates remained the same throughout the study. The remaining 3 factors determine the modulus in this study. Adding fine particles makes the microstructure of concrete become denser (Figure 8.) As a result, there is a better adhesion between the aggregate and mortar matrix. The dense concrete matrix, due to the filler action of fine particles of stone dust, presents higher stiffness for mortar paste, increasing the elasticity modulus of concrete. With a minor replacement of limestone dust (less than 40%), the roughness of the limestone dust improves the adhesion force between cement and aggregate. These factors lead to uniform stress distribution and lower dimensional deformation. Similar behavior was observed by Shen *et al.* [34] when utilizing different types of stone processing dust in concrete. In the case of increased limestone dust greater than 40%, the angularness of the aggregates in large quantities leads to an increase in voids, which decreases the elastic modulus. Similar behavior was observed by different authors utilizing rough and angular aggregates [33], [35].

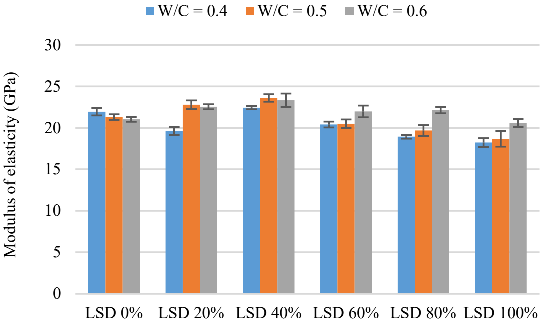


Figure 9: Static modulus of elasticity for concrete containing limestone dust.

Considering to the relationship between the elastic modulus and square root of the compressive strength of the manufactured limestone dust concrete, it was found that the modulus of concrete was higher than concrete strength increased and tended to be linear. However, comparing the modulus of normal concrete in accordance with ACI 318 [36] and ACI modified standard proposed by Charles *et al.* [37] revealed that the modulus of concrete with limestone dust replacement of sand was close to both standards (Figure 10.) Further, it tends

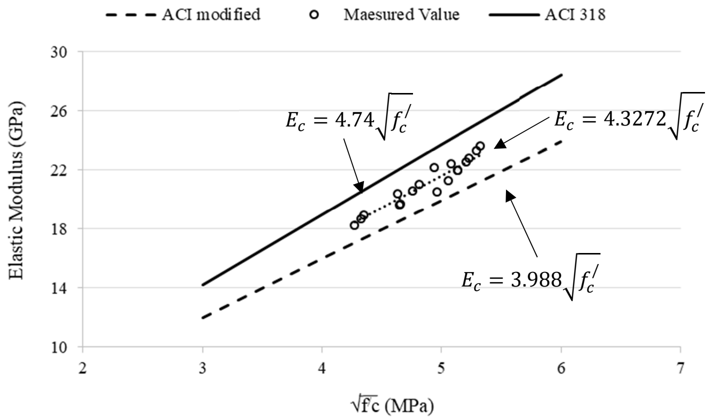


Figure 10: Relationship between static modulus of elasticity and square root for compressive strength of manufactured limestone dust concrete.

Table 3: Cost analysis of limestone dust concrete

Materials	Per Unit Cost (Baht/kg)	Cost (Baht/m^3)					
		LSD 0%	LSD 20%	LSD 40%	LSD 60%	LSD 80%	LSD 100%
OPC	2.6	860.60	860.60	860.60	860.60	860.60	860.60
River sand	0.463	306.51	245.20	183.90	122.60	61.31	0.00
Limestone dust	0.065	0.00	8.61	17.21	25.82	34.42	43.03
Coarse aggregate	0.23	304.52	304.52	304.52	304.52	304.52	304.52
Water	0.013	1.72	1.72	1.72	1.72	1.72	1.72
Total		1,473.35	1,420.65	1,367.96	1,315.26	1,262.57	1,209.87

in a linear line in the same direction. As a result of this relationship, an equation can be used to calculate the elastic modulus of concrete using aggregate from limestone dust replacement of sand, as shown in Equation (1).

$$E_c = 4.3272\sqrt{f_c^{/}} \qquad (1)$$

Where E_c is concrete modulus (GPa), $f_c^{/}$ is concrete compressive strength (MPa) and precision $R^2 = 0.928$. Thus, the resulting modulus is suitable for use in the approximation of the elastic modulus of the limestone dust replacement of sand concrete mix used.

3.5 *Economics analysis for concrete containing limestone dust*

In this study, the cost of concrete mixed with limestone dust, the price per kilogram (Bath/kg) is based on the Thailand price in 2021. Cost price consists of cement, sand, limestone dust, coarse aggregate, and water, excluding any admixtures and labor costs. The above prices are inclusive of shipping in the operator service area. The limestone dust is in Nakhon Sawan Province, which is close to the experiment site. Therefore, the price of limestone dust is cheap because a shipping cost is not applicable. Table 3 shows the cost per unit volume (Bath/m^3). It was found that the normal concrete price was 1473.35 Baht/m^3. When reducing the sand content but adding limestone dust, (it will lower the concrete price. The price of concrete with 100% limestone dust mix is 1209.87 Bath/m^3, which is 17.88% lower than the normal concrete price. Therefore, when analyzing the decrease in concrete cost price compared to normal concrete, it was found that the price of the mixture at LSD20%, LSD40%, LSD60%, LSD80%, and LSD100%, decreased by 3.58%, 7.15%, 10.73%, 14.31%, and 17.88%, respectively. It shows that the use of concrete with a limestone dust mixture can significantly reduce costs because it is necessary to use a lot of concrete in each construction. Likewise, it will also help limestone dust be a valued economic material in the future since it is a non-valued material at present.

4 Conclusions

Limestone dust is a waste material obtained from the stone mill industry. The results from this study provide a guideline for developing these materials to be beneficial by using them in the process of concrete production. The results of this study can be summarized as follows.

The limestone dust contributes to the improvement of the workability of concrete. The increasing limestone dust content will result concrete to obtain a better flow. However, limestone dust concrete has higher water requirements to improve the flow. The optimum water content for the slump value within the specified criteria in this study was w/c = 0.60.

The compressive strength of normal concrete is the highest at w/c = 0.40, but limestone dust concrete compressive strength is lower. Further, when water is increased, the compressive strength of limestone dust concrete will increase in all proportions. In contrast, the compressive strength of normal concrete is reduced.

At the w/c ratio at 0.50, concrete with limestone dust content 20–40% increased the compressive strength with an increase of limestone dust, and 40% limestone dust gave the highest strength. Moreover, the compressive strength will decrease as the amount of limestone dust increases for concrete with 60–100% limestone dust content. However, the compressive strength of the limestone dusted concrete was higher than at w/c ratio at 0.50, but the compressive strength of concrete with 20–40% limestone dust content is less than that of w/c ratio at 0.50.

The amount of limestone dust is another factor that causes a change in the compressive strength of concrete. Limestone dust content of 20 and 40% will increase the compressive strength. In contrast, the limestone dust content of 60–100% will decrease the compressive strength. The maximum compressive strength is 40% of limestone dust content and is also higher than that of normal concrete.

Concrete mixed with limestone dust at 40% with w/c ratio at 0.50 results in the concrete having the highest compressive strength because the mixture can reduce voids and improve bonding between cement paste and the aggregate due to the improvedment of modulus of elasticity. The modulus value obtained from this limestone dust concrete meets the standard and is higher than normal concrete for all mix proportions. Therefore, it can be applied for design and support in various works.

Concrete with limestone dust content will reduce overall costs because limestone dust is a relatively inexpensive material. Therefore, it is appropriate to develop these waste materials for use in economical building materials in some countries in the future.

From the above conclusion, it is very possible to develop the use of limestone dust in concrete production. It seems apparent that a suitable amount of water and limestone dust content gives concrete the best properties and it also makes the cost cheaper. Although some concrete mixed with limestone dust has been used, it is not yet widespread. Therefore, this research is a part of the confirmation and support effort for the widespread utilization of these waste materials to help reduce the use of natural resources. Such determination is also a part of local government efforts to help promote the value of limestone dust for the future.

Acknowledgements

The researcher would like to thank the Rajamangala University of Technology Suvarnabhumi for its support in the publishing of this research. Thanks also are due to the teachers, students and staff in the Civil Engineering Program, who facilitated the use of laboratories. Gratitude also goes to the Faculty of Engineering and Architecture, Rajamangala University of Technology Suvarnabhumi for its support of this research in the form of materials and equipment.

References

[1] T. Thapprom, "The study of compressive strength of concrete by using silt stone instead of sand for fine aggregate; A case study on silt stone from Narathiwat stone mine," *Princess of Naradhiwas University Journal*, vol.1, no. 2, pp. 28–41, 2009.

[2] C. Choosakul and K. Yongsata, "Compressive strength of mortar using the mineral dust partial replacement in sand," *Rajamangala University of Technology Srivijaya Research*, vol. 10, no. 2, pp. 324–332, 2018.

[3] W. Arckarapunyathorn, "Slump and compressive strength of concrete containing recycled aggregate and lime stone dust," *Journal of Engineering RMUTT*, vol. 17, no. 1, pp. 149–161, 2019.

[4] G. Aditya and M. T. S. Lakshmayya, "Effective utilization of various industrial waste in concrete for rigid pavement construction—A literature review," *International Journal for Innovative Research in Science & Technology*, vol. 3, pp. 65–73, 2016.

[5] S.-C. Kou and C.-S. Poon, "Properties of concrete prepared with crushed fine stone, furnace bottom ash and fine recycled aggregate as fine aggregates," *Construction and Building Materials*, vol. 23, pp. 2877–2886, 2009.

[6] R. Siddique, "Effect of fine aggregate replacement with class F fly ash on the mechanical properties of concrete," *Cement and Concrete Research*, vol. 33, pp. 539–547, 2003.

[7] H. Li, F. Huang, G. Cheng, Y. Xie, Y. Tan, L. Li, and Z. Yi, "Effect of granite dust on mechanical and some durability properties of manufactured sand concrete," *Construction and Building Materials*, vol. 109, pp. 41–46, 2016.

[8] Y. Aggarwal and R. Siddique, "Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates," *Construction and Building Materials*, vol. 54, pp. 210–223, 2014.

[9] A. O. Mashaly, B. N. Shalaby, and M. A. Rashwan, "Performance of mortar and concrete incorporating granite sludge as cement replacement," *Construction and Building Materials*, vol. 169, pp. 800–818, 2018.

[10] H. Li, F. Huang, G. Cheng, Y. Xie, Y. Tan, L. Li, and Z. Yi, "Effect of granite dust on mechanical and some durability properties of manufactured sand concrete," *Construction and Building Materials*, vol. 109, pp. 41–46, 2016.

[11] A. Danish, M. A. Mosaberpanah, M. U. Salima, R. Fediuk, M. F. Rashid, and R. M. Waqas, "Reusing marble and granite dust as cement replacement in cementitious composites: A review on sustainability benefits and critical challenges," *Journal of Building Engineering*, vol. 44, p. 102600, 2021.

[12] S. Singh, R. Nagar, and V. Agrawal, "A review on properties of sustainable concrete using granite dust as replacement for river sand," *Journal of Cleaner Production*, vol. 126, pp. 74–87, 2016.

[13] H. Hebhoub, H. Aoun, M. Belachia, H. Houari, and E. Ghorbel, "Use of waste marble aggregates in concrete," *Construction and Building Materials*, vol. 25, no. 3, pp. 1167–1171, 2011.

[14] L. G. Li, Z. H. Huang, Y. P. Tan, A. K. H. Kwan, and F. Liu, "Use of marble dust as paste replacement for recycling waste and improving durability and dimensional stability of mortar," *Construction and Building Materials*, vol. 166, pp. 423–432, 2018.

[15] J. J. Chen and A. K. H. Kwan, "Adding limestone fines to reduce heat generation of curing concrete," *Magazine of Concrete Research*, vol. 64, no. 12, pp. 1101–1111, 2012.

[16] A. K. H. Kwan, M. McKinley, and J. J. Chen, "Adding limestone fines as cement paste replacement to reduce shrinkage of concrete," *Magazine of Concrete Research*, vol. 65, no. 15, pp. 942–950, 2013.

[17] J. J. Chen, A. K. H. Kwan, and Y. Jiang, "Adding limestone fines as cement paste replacement to reduce water permeability and sorptivity of concrete," *Construction and Building Materials*, vol. 56, pp. 87–93, 2014.

[18] L. G. Li and A. K. H. Kwan, "Adding limestone fines as cementitious paste replacement to improve tensile strength, stiffness and durability of concrete," *Cement and Concrete Composites*, vol. 60, pp. 17–24, 2015.

[19] L. G. Li, J. J. Chen, and A. K. H. Kwan, "Roles of packing density and water film thickness in strength and durability of limestone fines concrete," *Magazine of Concrete Research*, vol. 69, no. 12, pp. 595–605, 2017.

[20] C. Weerayot, S. Apirak, and K. Supaporn, "Use of limestone dust for concrete in xayaburi hydroelectric power project," *Journal of Thailand Concrete Association*, vol. 4, no. 1, pp. 40–51, 2016.

[21] A. B. M. A. Kaish, T. C. Odimegwu, I. Zakaria, and M. M. Abood, "Effects of different industrial waste materials as partial replacement of fine aggregate on strength and microstructure properties of concrete," *Journal of Building Engineering*, vol. 35, 2021, Art. no. 102092.

[22] K. Slaiai, “Use of Limestone Powder (LSP) in Concrete in GCC Region,” 2016. [Online]. Available: https://www.linkedin.com/pulse/use-limestone-powder-lsp-concrete-gcc-region-khaldoon-slaiai.

[23] A. Carlos, I. Masumi, M. Hiroaki, M. Maki, and O. Takahisa, “The effects of limestone aggregate on concrete properties,” *Construction and Building Materials*, vol. 24, pp. 2363–2368, 2010.

[24] Z. Makhloufi, T. Bouziani, M. B´ ed´ erina, and M. Hadjoudja, “Mix proportioning and performance of a crushed limestone sand- concrete,” *Journal of Building Material and Structure*, vol. 2014, no. 1, pp. 10–22, 2014.

[25] *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*, ASTM C136-95a, 1996.

[26] *Testing Hardened Concrete- Part 3: Compressive Strength of Test Specimens*, BS EN 12390-3, 2001.

[27] *Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression*, ASTM C469, 2014.

[28] A. Hawa, W. Prachasaree, and D. Tonnayopas, “Effect of water-to-powder ratios on the compressive strength and microstructure of metakaolin based geopolymers,” *Indian Journal of Engineering & Materials Sciences*, vol. 24, pp. 499–506, 2017.

[29] S. Ramjan, W. Tangchirapat, and C. Jaturapitakkul, “Effect of finenesses of fly ash and rice husk ash on compressive strength and expansion of mortar in accelerated mortar bar method,” *Journal of Thailand Concrete Association*, vol. 5, no. 1, pp. 1–13, 2017.

[30] T. Ji, C. Y. Chen, Y. Z. Zhuang, and J. F. Chen, “A mix proportion design method of manufactured sand concrete based on minimum paste theory,” *Construction and Building Materials*, vol. 44, pp. 422–426, 2013.

[31] T. Gupta, S. Kothari, S. Siddique, R. K. Sharma, and S. Chaudhary, “Influence of stone processing dust on mechanical, durability and sustainability of concrete,” *Construction and Building Materials*, vol. 223, pp. 918–927, 2019.

[32] K. Vardhan, S. Goyal, R. Siddique, and M. Singh, “Mechanical properties and microstructural analysis of cement mortar incorporating marble powder as partial replacement of cement,” *Construction and Building Materials*, vol. 96, pp. 615–621, 2015.

[33] S. Siddique, S. Shrivastava, S. Chaudhary, and T. Gupta, “Strength and impact resistance properties of concrete containing fine bone china ceramic aggregate,” *Construction and Building Materials*, vol. 69, pp. 289–298, 2018.

[34] W. Shen, Y. Liu, Z. Wang, L. Cao, D. Wu, Y. Wang, and X. Ji, “Influence of manufactured sand’s characteristics on its concrete performance,” *Construction and Building Materials*, vol. 172 pp. 574–583, 2018.

[35] A. Halicka, P. Ogrodnik, and B. Zegardlom, “Using ceramic sanitary ware waste as concrete aggregate,” *Construction and Building Materials*, vol. 48, pp. 295–305, 2013.

[36] *Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete*, ACI 318, 2008.

[37] K. Charles, M. Bismark, S. Gnida, and B. Thomas, “Stress-strain characteristics of concrete containing quarry rock dust as partial replacement of sand,” *Case Studies in Construction Materials*, vol. 7, pp. 66–72, 2017.