International Journal of GEOMATE, Jan., 2023, Vol.24, Issue 101, pp.126-133
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.101.s8548
Geotechnique, Construction Materials and Environment

DURABILITY PERFORMANCE OF CONCRETE WITH DIMENSION LIMESTONE WASTE AS FINE AGGREGATES REPLACEMENT

*Jasmin Panganiban[1] and Mary Ann Adajar[2]

[1]University of Rizal System, Philippines; [2] De La Salle University, Philippines

*Corresponding Author, Received: 13 June 2022, Revised: 20 Nov. 2022, Accepted: 05 Jan. 2023

ABSTRACT: Quarrying and production of dimension limestone produced a considerable amount of solid and slurry waste. Because of its great potential to be used as an alternative material in concrete, these dimension limestone waste (DLW) have been the interest of many researchers. Several studies focus its investigation on the effect of DLW addition on concrete particularly on its mechanical properties. Although review of related literatures suggested the used of DLW in concrete because of its positive effect on concrete's mechanical properties, there remains doubt on its acceptability due to the lack of studies regarding its durability performance. Thus, this study aimed to assess the durability performance of concrete made with DLW as a fine aggregate replacement. The investigation included test for sorptivity and resistance to sulfate attack using specimens with DLW replacements of level of 0%, 20%, 40% and 60%. Sorptivity test reveals that incorporation of up to 60% of DLW as sand replacement reduces the permeability of concrete. In terms of sulfate resistance, it was found that the addition of DLW reduces length expansion and mass change due to sulfate attack. Furthermore, change in compressive strength test showed that after 15 weeks of sodium sulfate immersion, DLW concrete exhibited a less than 25% reduction in compressive strength. Based on the findings of this study, it has been concluded that replacement of sand by DLW can result to concrete having comparable durability performance.

Keywords: Durability performance, Sorptivity, Sulfate resistance, Limestone waste

1. INTRODUCTION

In a global scale, the construction industry is in great demand for raw materials particularly sand which is one of the components in making concrete. According to the United Nations Environmental Programme, the demand for sand has tripled over the last two decades as a result of the ballooning population, expanding urbanization, infrastructure development and ever-changing consumption patterns [1]. The estimated global sand consumptions have reached a volume of more than 20 billion tons annually, 75% of which is used in concrete production. Because of this huge consumption, many regions around the world is bound to face an increased rate of resource depletion.

In the Philippines, because of the current trend in infrastructure development, both public and private, the demand for fine aggregates or sand remains high and is expected to continuously grow. The country is rich in natural resource for raw materials such as river sand, stone and boulders, however over-exploitation of these non-renewable resources will eventually lead to its depletion causing sand scarcity in the country. The construction industry is therefore compelled to search for an alternative to natural fine aggregate.

Similar to sand, dimension stone also has an increasing domestic and international demand. Limestone is one of the most used dimension stone by the construction industry. It is often cut into blocks and slab panel that are used for flooring, cladding, stair thread and many other applications. The quarrying and processing of these materials produced considerable amount of solid and slurry waste which are quite often left dumped in the quarry site. In one of the local manufacturing plant in the Philippines, it was reported that an average of 280 cu.m filtered sludge and 112 cu.m solid waste were collected every month. Figure 1 shows the plant's accumulated limestone waste. These wastes are considered a big problem from the aspects of disposal, environmental pollution, and health hazards. Given that we cannot totally reduce the amount of waste, neither at the quarrying stage nor at the dimension limestone production, the industry is therefore obligated to find a way to utilize these industrial wastes, in order to reduce landfills and avoid severe problem associated with its disposal.

Useful application of solid waste particularly as substitute for fine aggregates in concrete is a promising solution to avoid severe problem associated with solid waste disposal and help construction industry in finding solution to the onset shortage of sand. Solid waste from aggregate quarry was found to be a viable substitute for fine aggregates in concrete mix [2]. Alternative concrete was made by using high density polyethylene pellets as replacement for sand with class F fly ash as substitute for cement [3]. Earlier studies showed that limestone waste exhibits properties that is nearly comparable to that of the natural river sand [4]–[5]. Because of this, utilization of dimension limestone waste (DLW) as fine aggregate replacement becomes a viable solution to address the problem of both the sand and dimension limestone industry.

a.) slurry waste

b.) solid waste

Fig. 1 Dimension limestone waste from a local manufacturing plant

Review of the literature on the technical properties of concrete with limestone concludes that, in general, incorporation of an appropriate amount of limestone as fine aggregate replacement enhances the compressive strength [5], flexural strength [4] and splitting tensile strength [6]. Several researchers have also reported that limestone aggregate could reduce the total shrinkage, water permeability and sorptivity coefficient of concrete [7]. Evaluation of sulfate resistivity, however, has contradicting results. Therefore, this study further investigated the durability performance DLW concrete exposed to sulfate-rich environment which is common in the Philippines being an archipelagic country where seawater is abundant. Specifically, this study aims to assess the effect of using DLW as fine aggregate replacement in the sorptivity and sulfate resistance of concrete. It is hoped that the result of this study will be a valuable input in the development of local standards for the utilization of waste limestone as fine aggregates to gain widespread acceptance and deployment of DLW concrete.

2. RESEARCH SIGNIFICANCE

This study is of high significance to the resource intensive construction sector in the Philippines. With the increasing demand for concrete, the country is bound to face problems in the scarcity of raw materials for concrete production. To address this problem, the effectiveness of DLW as sand replacement was evaluated to promote its use as an alternative to conventional fine aggregate in concrete.

Furthermore, the utilization of DLW in the concrete industry could help abate the demand for additional landfill sites and alleviate the environmental problem associated with it. Thus, for the dimension limestone industry, this might serve as an attractive alternative to waste disposal thereby increasing their economic competitiveness whilst decreasing the environmental pollution around the limestone plants and quarries.

3. EXPERIMENTAL PROGRAM

3.1 Materials

DLW concrete test specimens were prepared using locally available materials. For cementitious materials, Ordinary Portland Cement Type 1, complying with PNS 7:2005, was used. Well graded crushed gravel with a maximum size of 20mm (3/4in) were used as coarse aggregates, while fine aggregates consist of a combination of sand and DLW. The mixing water were free from organic material and any deleterious minerals.

The DLW used as a partial replacement for sand was dry limestone waste in slurry form collected from the dump yard of a local dimension stone manufacturing plant and was sieved for particle size ranging from 75μm to 4.75mm. A comparative analysis of sand and DLW fine aggregate was conducted in terms of specific gravity, absorption and fineness modulus.

3.1.1 Properties of dimension limestone waste

The physical properties of DLW and sand were determined in accordance with ASTM test standards and the results are presented in Table 1. The specific gravity and absorption of DLW fall within the range for normal weight aggregates specified in ACI standard. The specific gravity of DLW is slightly lower whereas their water absorption is roughly 75% higher as compared with sand. Water absorption of aggregate is one of the key factor that influence the workability and strength of concrete.

The particle size distribution of sand and DLW was measured through sieve analysis in accordance with ASTM C136. Figure 2 summarizes the gradation of DLW and sand.

Table 1 Physical properties of fine aggregates

Property	DLW	Sand
Specific Gravity (SSD)	2.58	2.72
Absorption (%)	1.42	0.81
Fineness Modulus	1.54	2.44

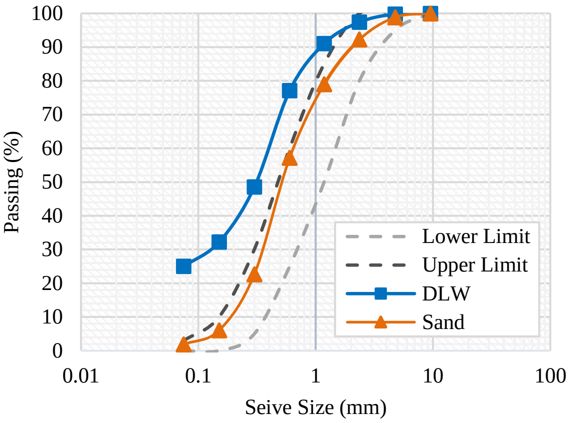

Fig. 2 Particle size distribution curves

As shown in the figure, both sand and DLW exhibited a uniform grading. Sand shows a grading that fits within the limit whereas the fineness of DLW exceeded the upper limit set forth in ASTM C33. DLW has a fineness modulus of 1.54 which is 37% lower compared to the 2.44 fineness modulus of sand, indicating that DLW is a finer material compared to sand. The visual representation for the light and fine DLW samples is shown in Fig. 3.

Fig. 3 DLW fine aggregate

Based on ASTM C33, the fineness modulus of fine aggregates generally ranges from 2.0 to 3.3. In some cases, however, aggregates with a fineness modulus less than 2.0 are used, an example of which is manufactured fine aggregates which contain finer natural sand [8].

3.2 Mix Proportion

A total of four (4) concrete mixtures were used in order to evaluate the effect of dimension limestone waste as sand replacement on the durability performance of concrete. Design mix proportion of concrete without DLW, designated as C-L0, as per ACI specification for a target strength of 20 MPa normal weight concrete and slump in the range of 50-90mm were used as reference or control mixture. DLW concrete mixtures were then determine by partially replacing sand with DLW. The replacement level investigated were 20%, 40% and 60% by weight thus each DLW concrete mixture were correspondingly designated as C-L20, C-L40 and C-L60, respectively. In all four mixes, no chemical admixture has been added and the water-to-cement ratio used was 0.65. Except for the ratio of dimension limestone waste and sand, the amount of other materials such as cement, coarse aggregate and mixing water were kept constant.

Preliminary tests were conducted to pre-assessed if the design mix is suitable for the experimental program. Initial compressive strength test has been carried out on C-L0 mixture to determine if the design strength of 20MPa were achieved after 28 days of curing. Simultaneously, slump test for C-L60 was also conducted to check if the workability is within acceptable limit. After the initial test, resulting to C-L0 having achieved the design strength and C-L60 yielding slump above tolerance level of 25mm, the design mix proportions were adopted for the purpose of this study. Table 2 summarizes the details of the concrete mix proportion used.

Table 2 Details of concrete mix proportion

Mix Proportion in kg/m^3				
Material	C-L0	C-L20	C-L40	C-L60
Cement	316	316	316	316
Gravel	1007	1007	1007	1007
Sand	853	682.4	511.8	341.2
DLW	0	170.6	341.2	511.8
Water	205	205	205	205

3.2 Methodology and Test for the Study

Durability of DLW concrete in terms of sorptivity and sulfate resistance was evaluated through series of laboratory experiments in accordance with ASTM standards. For each durability test, five replicate samples per mixture were tested.

To determine the sorptivity (rate of absorption), the standard test method in accordance with ASTM C1585 was followed. The test was carried out on concrete specimens having diameter of 100 mm and height of 50 mm after 28 days and 90 days of curing periods.

Sulfate resistance of DLW concrete was evaluated in terms of change in length, mass and compressive strength. For the change in mass and compressive strength, 100mm concrete cube specimens were fabricated while for length change evaluation, 25mm by 25mm by 285mm mortar prism specimens were used as established by ASTM C157M. After the initial 28-day curing, each concrete specimens were subjected to sulfate attack by immersing it in a sodium sulfate solution with a concentration of 5% by mass. The volume proportion of sulfate solution to concrete specimens was maintained at 4±0.5 to ensure full immersion. The sulfate solution was stirred every week and replenished each month to maintain the same concentration throughout the study.

Compressive strength test in accordance with ASTM C39 was performed on concrete cube specimens at the end of 28 days curing period and after 2, 4, 8, 13 and 15 weeks of sulfate immersion. Concurrently, for a set of concrete cube specimens, weight in saturated surface dry condition were measured and recorded as basis for mass change evaluation. Parallel to this, length change measurement of mortar prisms specimens was carried out in accordance with ASTM C1012. The initial length measurement was taken before sulfate immersion and then length change measurement was taken after 1, 2, 3, 4, 8, 13, 15, 19, 24 weeks of sulfate immersion.

4. TEST RESULTS AND DISCUSSION

Durability performance measures the concrete ability to resist the damaging effect of weathering, chemical attack and other deterioration process. It is the ability of concrete to withstand induced damages over a long period of time [9]. In this study, durability was assess based on sorptivity and resistance to sulfate attack.

4.1 Sorptivity

Durability of concrete is largely dependent on its ability to absorb water. Sorptivity is widely used to characterize the concrete's ability to absorb water and transmit it via capillary action. It provides indications of pore structure and connectivity which is an important factor that influences the concrete's resistance to attack of aggressive substance when exposed to severe environment [10]. Increased sorptivity potential can lead to rapid concrete deterioration.

Figure 4 presents a typical absorption curve of DLW concrete. Notice that absorption was more intense during the first 6 hours of the test, and then tends to gradually decreases afterwards. The rate of absorption during the first 6 hours is known as the initial sorptivity which is equal to the slope of the line that is the best fit to absorption plotted against the square root of time and was determined through linear regression analysis using all the points from 1 minute to 6 hours. On the other hand, the secondary sorptivity was taken as the slope of the line that best fitted the plot of absorption versus square-root of time using all points from day 1 to day 8.

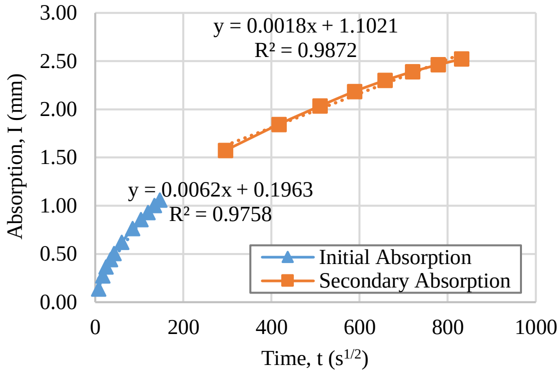

Fig. 4 Typical absorption curve of DLW concrete

The results of sorptivity tests are summarized in Table 3 and illustrated in Figure 5. Comparison of the results recorded at test age of 28 days and 90 days shows that the addition of DLW generally reduces the sorptivity values.

Table 3 Sorptivity of DLW concrete

Sample ID	28 days		90 days	
	S_i	S_s	S_i	S_s
C-L0	0.0068	0.0017	0.0061	0.0022
C-L20	0.0050	0.0014	0.0062	0.0018
C-L40	0.0054	0.0015	0.0061	0.0018
C-L60	0.0057	0.0022	0.0056	0.0016

Note: S_i *– initial sorptivity in mm/s*$^{1/2}$*;* S_s *– secondary sorptivity in mm/s*$^{1/2}$

At 28 days, concrete with 20%, 40% and 60% DLW exhibits 27%, 20% and 17% reduction, respectively, in initial sorptivity as compared to control concrete. For secondary sorptivity, 14% and 10% reduction were observed for replacement level of 20% and 40%, respectively, which is contrary to the 32% increase noticed when replacement level is 60%. At 90 days testing age, the effect of DLW on sorptivity is more defined. A consistent reduction in both initial and secondary sorptivity with increasing DLW content was observed. The initial sorptivity of all mixes are comparable, with C-L60 having a slightly noticeable reduction of 9%. In terms of secondary sorptivity, 19%, 20% and 28% reduction relative to control concrete was recorded when replacement level is 20%, 40% and 60%, respectively. The reduction in sorptivity was more pronounced in the 20% replacement level at 28 days and 60% replacement level at 90 days. It is important to note that, all concrete mixes are considered acceptable in terms of sorptivity property since any value less than 0.10 mm/s$^{1/2}$ indicates an excellent quality concrete.

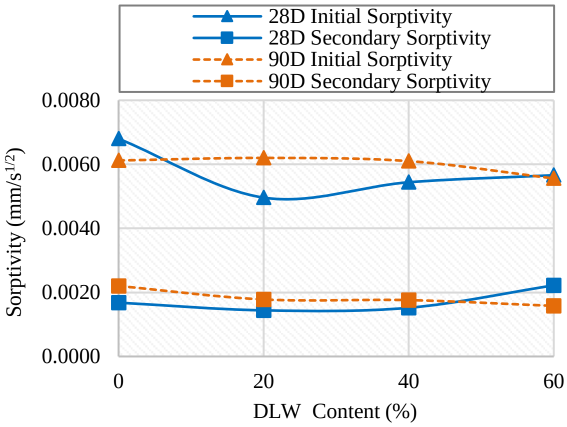

Fig. 5 Sorptivity of DLW concrete

Through Analysis of Variance (ANOVA), an overall look at the sorptivity results reveals that there is no significant variation in both initial and secondary sorptivity values due to percent replacement and curing period. The variation, however small, indicates that incorporation of up to 60% DLW as sand replacement improves the sorptivity. The improvement signifies a denser concrete microstructure making them more impermeable compared to control concrete. This could be attributed to the filler effect of the much smaller and finer particles of DLW blocking the interstitial and capillary pores of the binder phases of the mixture [11].

4.2 Resistance to Sulfate Attack

Sulfate resistance is one of the main concerns in terms of durability performance of concrete containing limestone. It has been previously reported that addition of limestone in concrete resulted to its poor performance under sulfate exposure. Some studies confirmed that expansion of concrete increased significantly when limestone is incorporated while other scholars found that the presence of limestone improves sulfate resistance [7]. In this study, the sulfate resistance of DLW concrete is evaluated by the examination of changes in length, mass, and compressive strength.

4.2.1 Change in length

The resistance to sulfate attack is commonly evaluated through expansion measurements. In this study, where mortars bars have been subjected to very severe sulfate exposure (Class S3), ACI stipulated an expansion limit of 0.10% after 18 months of exposure. Figure 6 presents the average expansion of 5 mortar bars immersed in sodium sulfate solution measured after 1, 2, 3, 4, 8, 13, 15, 19 and 24 weeks of immersion as per ASTM C1012. During the test, increased expansion was observed in all mortar samples. Considering the expansion after 6 months, all tested mixes expanded less than specified limit. Among the studied mixes, control samples exhibited the highest expansions.

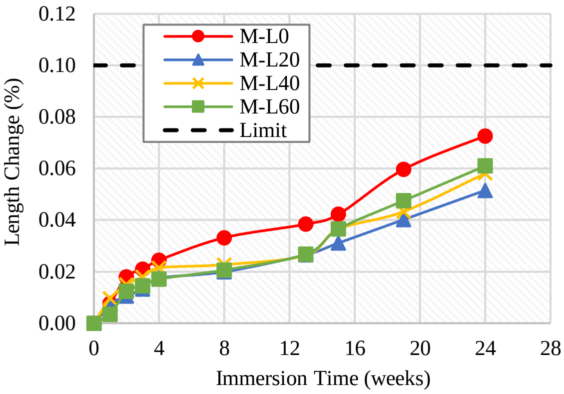

Fig. 6 Length change of DLW mortar prism

Statistical analysis revealed a significant decrease in length change between each DLW mortar samples and control samples. The percent decrease in length change were 29%, 19.9% and 16% for M-L20, M-40 and M-60, respectively. This indicates that incorporating DLW does in fact reduces the length expansion caused by sulfate attack. Nevertheless, it is important to note that although samples prepared with DLW have expanded less than the control concrete, expansion increases as the amount of DLW increases. This is because adding limestone in higher quantity increases the calcite content which also increases the possibility of ettringite and gypsum formation that leads to length expansion [12].

4.2.2 Change in mass

Mass loss is another indicators of concrete deterioration. The curve shown in Fig. 7 presents the percent change in mass measured after immersing concrete cube sample in sodium sulfate solution for a period of 1, 2, 3, 4, 8, 13, and 15 weeks. All samples demonstrate a similar trend. In the first week of immersion, a slight drop in mass was observed, then followed by a gradual increase in the subsequent immersion time.

The initial drop in mass can be attributed to the leaching of hydration products into the solution while the succeeding increase in mass was caused by the formation of expansive compound during the sulfate attack [13].

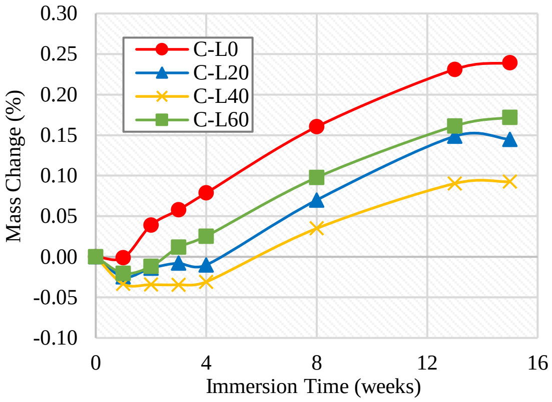

Fig. 7 Mass change of DLW concrete

ANOVA showed a significant difference in mass change of DLW concrete and control concrete. The concrete incorporated with DLW showed a lower mass change at the increasing stage compared with control concrete. After 15 weeks of exposure, mass increase was 39.5% lower for C-L20, 61.3% for C-L40 and 28.1% for C-L60. By inspection, concrete with 40% DLW has more pronounced effect in reducing mass change. Though the change in mass is relatively small, the resulting increase in mass indicates a formation of expansive compounds due to continuous exposure to sulfate. This indication was confirmed by the length change test conducted in which continuous length change was also observed throughout the test duration. Evidently, from the mass and length change test, concrete incorporated with DLW has improve resistance to sulfate attack. This can be attributed to the effective reduction in sorptivity due to the filler effect of DLW. The reduced sorptivity decreases the change of sulfate ions ingress inside the hydrated cement matrix which consequently improves the resistance to sulfate attack.

4.2.3 Change in compressive strength

Prior to sodium sulfate immersion the average 28th day compressive strength was determined and the results are shown in Table 4. The compressive strength of all mixes satisfactorily exceeded the designed value of only 20MPa. Furthermore, it is obvious that as the DLW content increases, compressive strength gradually increases until the maximum compressive strength was developed at a replacement level of 40%. On the other hand, even though concrete specimen containing 60% DLW presents a compressive strength lower than the maximum recorded value, its compressive strength is still higher than the control specimen.

The compressive strength of concrete after immersion in sodium sulfate solution for a period of 2, 4, 8, 13, and 15 weeks were also determined and the corresponding change in compressive strength were recorded. As depicted in Fig. 8, all concrete mix experienced a continuous compressive strength development in the first 8 weeks of exposure to sodium sulfate solution. After that, decrease in compressive strength related to increase in immersion time was observed. It can therefore be concluded that sulfate attack affects the compressive strength of concrete whether or not DLW were incorporated, particularly when exposed for a longer duration. The initial development of compressive strength even after sulfate exposure may be attributed to the continuous formation of hydration products and the formation of expansive product from the reaction of sulfate ions with hydrated cement components [13]. As this reaction product was formed, it filled the pores and strengthened the concrete. But, later on, when the formation of expansive product becomes more dominant, it induced cracking, spalling and loss of strength.

Table 4 Compressive strength of DLW concrete

Sample ID	% DLW	28th-day Compressive Strength (MPa)
C-L0	0	24.84
C-L20	20	25.00
C-L40	40	27.59
C-L60	60	27.03

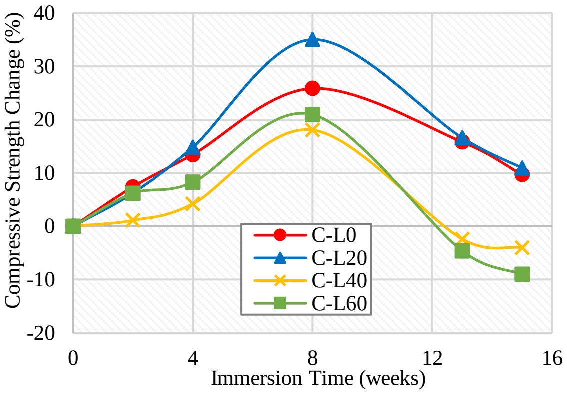

Fig. 8 Compressive strength change of DLW concrete due to sulfate attack

At the end of testing, 15 weeks after immersion, C-L0 and C-L20 maintained a compressive strength 9.7% and 10.9% higher, respectively, compared to their respective compressive strength prior to immersion. On the other hand, mixture with 40% and 60% DLW substitution rate showed an initial compressive strength reduction of 2.4% and 4.6%, respectively, after 13 weeks of exposure. After 15 weeks of exposure, C-L40 and C-L60 retained only 96% and 91% of their compressive strength prior to immersion, respectively. Considering the 25% limit in strength loss recommended for sulfate resistance concrete [14], it can still be concluded that all concrete mixes exhibited good performance on sulfate resistance despite the observe decrease in compressive strength change.

5. CONCLUSION

Durability performance measures the concrete ability to resist the damaging effect of weathering, chemical attack and other deterioration process. In this study, the effect of utilizing DLW as fine aggregates in durability performance of concrete was investigated through examination of sorptivity and resistance to sulfate attack. Based on the finding of this study the following conclusions were established.

Replacement of sand by DLW shows good durability potential. In terms of sorptivity, it was concluded that incorporating up to 60% DLW fine aggregates slightly improved the permeability of concrete. All DLW concretes has sorptivity values less than 0.10 $mm/s^{1/2}$, hence DLW concretes can be classified an excellent quality concrete in terms of sorptivity.

The reduced sorptivity of DLW concrete gives way to the improvement of its resistance to sulfate attack. In terms of expansion, significant decrease in length change was observed in all DLW concrete as compared to the control concrete. Similarly, all DLW concretes showed lower mass change compared with control concrete. With regards to compressive strength loss, 20% DLW concrete retained a compressive strength higher than control concrete while a slight reduction in compressive strength was observed in 40% and 60% DLW concrete. Generally, it was inferred that DLW concrete has better sulfate resistance than conventional concrete. This was particularly evident from the evaluation results of length and mass change after immersion in sulfate solution.

Hence, based on the test results it can be concluded that dimension limestone waste (DLW) can be used as sand replacement to produced concrete with improved durability performance, reduce depletion of our non-replenishable aggregate deposits and alleviate environmental problems associated with DLW disposal. However, appropriate ratio of DLW replacement must be considered to achieve an optimum durability performance without any detrimental effect on strength and workability. SEM-EDX analysis of DLW concrete before and after sulfate exposure is recommended to get an idea about the reactive products formed due to exposure. Furthermore, other durability parameters such as chloride permeability, carbonation resistance and corrosion resistance should also be investigated.

6. ACKNOWLEDGMENTS

The authors would like to express their sincerest gratitude to DOST-Engineering Research and Development for Technology Program for funding this research and Teresa Marble Corporation for their kind support and assistance.

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