

Shrinkage, absorption and high-temperature performance of concrete incorporating quarry and limestone dust as partial replacement of fine aggregate

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Abstract. Sand is considered the most consumed natural resource after water. However, the world's sand deposits are depleting day by day due to their over-extraction for different industrial uses, which is becoming another sustainability threat. Incorporating and blending industrial waste to replace some constituent materials in concrete is becoming the new norm for environmental sustainability. This practice can benefit the construction industry and the environment at large. This investigation aims to study the durability properties of concrete produced with different industrial wastes as a partial replacement material for fine aggregate. Considerably, quarry dust and limestone dust were used to substitute the fine aggregate at different percentages (5%, 10% and 15%) and cured conventionally at 7, 28, 90 and 180 days. The durability properties of concrete were examined through water absorption, drying shrinkage, chloride and sulphate attack test and elevated temperature test. The experimental result shows that the optimum content of both quarry dust and limestone dust is 15% in terms of concrete durability. The durability performance of these materials indicates a significant filling effect which was obvious in the reduction of water absorption and dry shrinkage. Therefore, it is reasonable to utilize these materials as fine aggregate to produce concrete that is durable, economically feasible and environmentally sustainable.

Keywords: concrete durability; fine aggregate; limestone dust; quarry dust; waste materials

1. Introduction

Concrete durability is an important parameter of concrete testing that is normally employed to establish concrete quality after the measurement of concrete strength (Carlos *et al.* 2010), especially when new materials are introduced as replacement materials. The study on concrete durability is expedient to understand the ability of the concrete structure to resist deterioration for a long time when exposed to harsh environmental conditions. Therefore, the durability of concrete should be meticulously conducted to avoid structural failure and other structural challenges (Arthanary *et al.* 1985). Previous studies demonstrated that incorporating industrial waste as a substitute material can enhance the strength and durability properties of concrete (Arthanary *et al.* 1985, Sunil *et al.* 2017, Binici and Aksogan 2018, Kaish *et al.* 2021a). The aforementioned benefit would be exclusively actualized only when the right replacement content or accurate

proportion is employed. Due to this fact, researchers are devising means for useful utilization of waste material for environmental sustainability and at the same time maintaining improved properties of concrete (Noufal *et al.* 2020, Odimegwu *et al.* 2021). Waste materials have been remarkably utilized to replace cement or aggregates (Carlos *et al.* 2010, Karra *et al.* 2016, Kaish *et al.* 2021b). Bederina *et al.* (2013) used limestone fine sand in concrete production. The result showed that the porosity of concrete decreased owing to the smaller particle size of limestone, which finally enhances the concrete properties by reducing the water absorption capacity. Binici and Aksogan (2018) conducted an experimental investigation on the durability of concrete containing different waste materials (waste marble powder, natural granular granite, silica sand and basalt) as fine aggregate at different replacements (up to 50%). The results inferred that the concrete showed improved and denser structure when the waste materials were introduced to the concrete mix, and with better performance in other parameters.

Previous research affirmed that concrete subjected to elevated temperature undergoes different negative changes (chemical and physical changes) causing loss of strength during and after the time of exposure (Bali and Boutemour 2016, Kodur 2014). This behaviour, as reported from past

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research, can be linked to the loss of bonding due to temperature change, which caused gradual debonding between the constituent materials (aggregate and the hydrated cement). Consequently, understanding the concrete properties after being exposed to high temperatures is reported to be necessary, to know the structural integrity of a constructed concrete structure (Hertz 2005, Arioz 2007, Salau *et al.* 2015). There has been evidence that compressive strength decreased when the temperature was elevated above 200°C at 15% limestone content (Kara 2021).

Celik and Marar (1996) affirmed that there was a decrease in water absorption rate as the waste (dust) content raised to 15%. This means that the rate of decrease in water absorption was due to the increase in the waste material. According to Chandar *et al.* (2016), sandstone can replace fine aggregate due to their similar physical properties, including fineness modulus, moisture content, and water absorption. Kaish *et al.* (2021a) utilized industrial waste material (alum sludge) as a substitute for fine aggregate in structural-grade concrete. It was affirmed that the optimum replacement content of industrial by-products to substitute fine aggregate in concrete was 10%, which improved water absorption and strength properties. Seawater and sea sand were also used in concrete production, resulting in improved early-age compressive strength (Chen *et al.*, 2021). Shrinkage of concrete produced with limestone dust was studied, and it was found that 30% limestone content showed a similar shrinkage value with the reference concrete (Carlos *et al.* 2010). However, the behaviour changed when limestone was used as a replacement material above 40%, and an obvious reduction in shrinkage was seen to this effect. Early age shrinkage was reported (Kato *et al.* 2001) and the result showed a decrease in shrinkage when the substitute material (limestone dust) was increased. In comparison, Leeuwen *et al.* (2016) confirmed that shrinkage significantly decreases at all percentage substitution and limestone filler particle sizes in all curing ages. Moreover, quarry dust employed as a substitute for fine aggregate was reported to improve concrete durability (Sai *et al.* 2016). Different industrial by-products like limestone dust, alum sludge, and quarry dust incorporated as partial substitution of fine aggregate have been reported (Kaish *et al.* 2021b), and the findings confirmed that the addition of the aforementioned by-product partially substituting fine aggregate improved the microstructure and strength of the concrete.

Furthermore, the integrity of concrete structures can be affected by sulphate and chloride attacks in the short or long-term depending on the intensity of the chemical exposure. However, this occurs when sulphate ions attack the concrete structure, by long-term penetration, whereby negatively alters the bonding strength of the cement. The mechanism of sulphate attack is owing to the forming of gypsum and ettringite, which affects the bond of cement paste significantly. Thereafter, the internal concrete structure will gradually deteriorate, hence, negatively affecting the strength and weight of concrete and ultimately causing the cracking of concrete (Hekal *et al.* 2002) as the time of exposure progresses. There has been a link to the

deterioration of concrete structures due to chloride attack (commonly experienced in the marine environment) on the concrete cement paste (Ramezani pour and Dehkordi 2017, Mangi *et al.* 2019). An experimental investigation confirmed that some substitute materials employed in concrete that were later exposed to magnesium sulphate solution showed improved properties over conventional concrete (Hekal *et al.* 2002, Aziez and Bezzar 2017). Aziez and Bezzar (2017) stated that incorporating limestone as a substitute material in concrete yields improved durability properties (magnesium sulphate attack) when compared to concrete produced with silica sand. Thus, long-time exposure to sulphate solution causes deterioration in concrete in terms of loss in weight and strength (Xie and ang 2017). Another study has shown evidence of concrete gaining strength at 56 days when subjected to 5% sodium chloride. It was further stated that after 56 days of exposure, the concrete strength started to decrease (Mangi *et al.* 2019). Another experimental investigation affirmed that up to 20% content of limestone or below, drastically enhances the concrete performance when exposed to chloride attack (Elgalhud *et al.* (2007). The risk of corrosion of reinforcing steel due to chloride ingress may lead to cracking of concrete structures (Ramezani pour and Dehkordi 2017). Therefore, rigorous investigation should be considered to examine concrete performance, especially when concrete durability is a concern against chemical attack. However, limited studies have been conducted on non-reactive industrial waste as a replacement of fine aggregate in concrete. Therefore, this study is focused on the investigation of non-reactive industrial waste (Quarry and Limestone Dust) as a replacement of fine aggregate in concrete tested to understand their behaviour in different harsh environmental conditions.

1.1 Significance/Novelty

The excess generation of some industrial waste (quarry and limestone dust) from the quarry industries is becoming alarming and needs to be addressed. Limestone and quarry dust are completely inert materials which makes them a better by-product for fine aggregate replacement. Utilizing these industrial wastes is advantageous to suppress the environmental pollution associated with their disposal. Together with that, this will also help to reduce the sustainability threat of extensive sand extraction. Some durability tests (elevated temperature, shrinkage, magnesium sulphate attack test and sodium chloride attack test) on concrete using quarry dust as a partial substitute to conventional fine aggregate for manufacturing concrete materials is limited and not intensively studied. Therefore, together with the strength and microstructure investigation, a comparative study on the durability of concrete partially utilizing quarry dust and limestone dust as fine aggregate is also required. This study is also necessary to optimize the replacement content of sand using these wastes in terms of concrete durability. Although durability studies on concrete replacing cement with limestone dust have been reported, there are limited studies on some durability properties at long-term testing using quarry and limestone dust as

replacements for sand in concrete casting. Therefore, this study aimed to investigate the durability of concrete produced with a non-reactive industrial by-product tested at long-term duration. This experiment aims to confirm the durability (shrinkage, water absorption and concrete exposure to high-temperature) properties of concrete produced with quarry and limestone dust as a partial substitute for fine aggregate. The findings will enable the industry to employ quarry and limestone dust with desirable durability properties.

2. Materials and methods

2.1 Concrete materials

Ordinary Portland Cement with a density of 1440 kg/m³ and a specific surface area of 365 m²/kg is utilized in this study as a binder conforming to ASTM C-150 (2007). Commercially available river sand of size less than 2 mm was used as fine aggregate. A crushed stone aggregate of size 10 mm was used as coarse aggregate. All the aggregates were water-saturated and surface-dried before concreting. Supplied tap water fit for drinking was used to mix the concrete. Materials employed as a substitute for fine aggregate (Fine Agg) in this investigation were limestone dust and quarry dust. These materials were characterized according to various standard specifications for their chemical and physical properties as reported and adopted from a previous study by Kaish *et al.* (2021b).

The grading curve for all the used aggregates is presented in Fig. 1 in compliance with BS 882 (1992). The microstructure images of all the fine aggregates presented in Fig. 2, were done using Scanning Electron Microscope

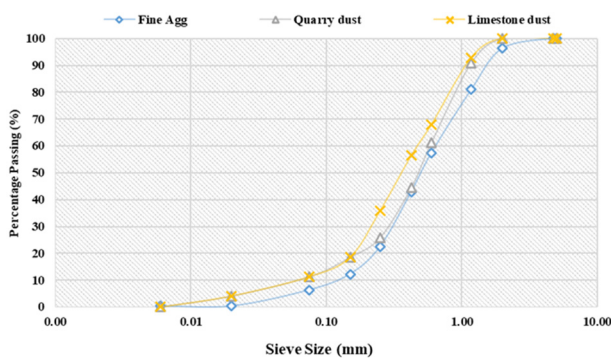
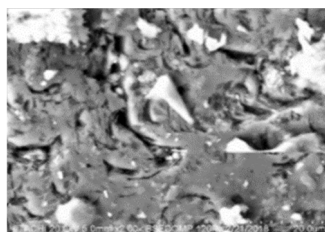
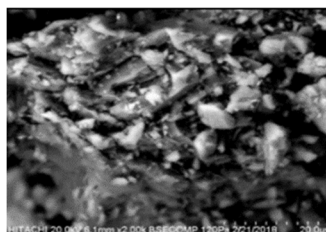


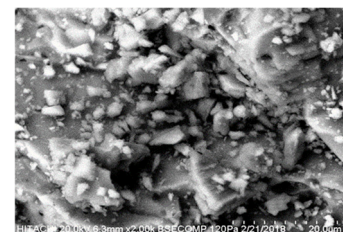
Fig. 1 Fine aggregate grading curve



Fine sand



Limestone dust



Quarry dust

Fig. 2 Microstructure of sand and replacement materials

(SEM) following the previous studies (Shuhua and Peiyu 2009, BS 8500: Part 1. 2006). Both limestone and quarry dusts have angular shape particles as presented in Fig. 2, which indicates that those can be utilized as fine aggregate substitutes.

2.2 Concrete mix design, casting, and curing

British standard mix design (BS 8500: Part 1. 2006) for normal concrete strength of 35 MPa was employed in this study. The control concrete sample contains ordinary Portland Cement, fine aggregate (natural river sand), crushed coarse aggregate with the selected slump of 30-60 mm and a constant water/cement ratio of 0.53. Industrial by-products (limestone dust and quarry dust) were employed to replace fine aggregate in 5%, 10% and 15% and mixed in different batches as shown in Table 1.

Saturated surface dry aggregates were used during concrete mixing using a drum mixer. Concrete was cast in 100 mm cube mould for all the tests. However, a prismatic steel mould with dimensions 70 × 70 × 280 mm was used to produce concrete samples for the shrinkage test. Normal water curing was adopted for different ages of up to 180 days.

2.3 Concrete durability tests

2.3.1 Water absorption test

The water absorption test was conducted as outlined in ASTM C642 (1997) with a 100 mm concrete cube and measured for samples at 28 days, 56 days 90 days and 180 days. The investigation was actualized by completely submerging all the dried samples (dried at 105°C for 24 hours) for 72 hours. The total water absorbed was calculated from the difference between the weight of wet and dry samples.

2.3.2 Drying shrinkage test

ASTM-C157 (2014) testing standard was adopted for the drying shrinkage test. The concrete samples cast were selected randomly for each mix and then allowed for 24 hours for hydration to take place. The samples produced for the test were demoulded after 24 hours of hardening and kept in the laboratory for the sample to dry under the temperature of 26 ± 2°C. Measurement of the samples was taken from 24 hours until 180 days. Differences and changes in the length of the sample were measured for 7, 28, 90 and 180 days accordingly.

Table 1 Concrete mix proportion (Kg/m³)

Marking	W/C	Cement	Coarse agg.	Fine agg.	Limestone dust	Quarry dust
CS ₃₅	0.53	425	1053	698	-	-
QUA5	0.53	425	1053	663.1	34.9	-
QUA10	0.53	425	1053	628.2	69.8	-
QUA15	0.53	425	1053	593.3	104.7	-
LD5	0.53	425	1053	663.1	-	34.9
LD10	0.53	425	1053	628.2	-	69.8
LD15	0.53	425	1053	593.3	-	104.7

*CS₃₅: Control Sample; QUA5: Quarry Dust 5%; QUA10: Quarry Dust 10%; QUA15: Quarry Dust 15%; LD5: Limestone Dust 5%; LD10: Limestone Dust 10%; LD15: Limestone Dust 15%

2.3.3 Sodium chloride attack test

The effect of sodium chloride (NaCl) attack on concrete was studied by submerging concrete cubes into a 5% NaCl solution. The concrete samples in ordinary water used for curing were used as reference samples to compare the change in weight and strength of the concrete subjected to NaCl attack. The days of exposure of concrete to NaCl attack were 28 days and 90 days, thereafter, the record of change in compressive strength and weight was noted for the desired testing days. The ability of concrete to decrease the penetration of sodium chloride through voids to the internal structure of the concrete, with the addition of industrial waste materials as a replacement for fine aggregate was studied. Hence, a durability study was important to establish the efficacy of these materials as a substitute for fine aggregate in concrete production.

2.3.4 Magnesium sulphate attack test

The chemical attack on concrete is a deteriorating process that poses a threat to the integrity of the concrete structure, affecting the concrete durability. This process is achieved by a gradual penetration of chemicals through voids or porous structures into the internal structure of concrete. Due to the process of absorption over a long period. The testing procedure was adopted from ASTM C1012 (2004) to examine concrete weight and strength losses due to MgSO₄ exposure. After a 28-day curing period of the concrete samples, 22 samples were selected from the curing tank and immersed in magnesium sulphate (MgSO₄) solution for a period of 28 days to 90 days. Meanwhile, the other 22 concrete samples were left in the curing tank as a control sample, to compare the difference in weight and strength of concrete between samples immersed in MgSO₄ and samples immersed in an ordinary curing tank.

2.3.5 Effect of elevated temperature

Weight and strength loss due to elevated temperature were considered and measured for this test. Concrete samples cured for 28 days were removed and allowed to air dry under the temperature of about $26 \pm 2^\circ\text{C}$ for 56 days to achieve complete drying and avoid sudden cracks due to loss of moisture. Concrete samples were placed into an electric furnace for testing after air drying in the laboratory. Thereafter, the air-dried samples were moved to an electric furnace to evaluate the concrete behaviour at exposure to

elevated temperatures. The selected temperature for this investigation was 200°C to 500°C at an increased rate of $5^\circ\text{C}/\text{min}$ and a total time of 2 hours for both temperatures. The temperature of 200°C and 500°C was selected after considering the temperatures studied in previous studies (Kaish *et al.* 2021a, Arioz 2007, Salau *et al.* 2015). Hence, this present study used this temperature as a benchmark to investigate concrete made with quarry dust and limestone dust as replacements for fine aggregate. After the concrete samples achieved the targeted temperature, the electric furnace was turned off and allowed to cool off (under room temperature) with the samples inside it. The cooling process was adopted to avoid any form of thermal shock that may occur due to a sudden temperature change. The samples after cooling were weighed and compressive strength was carried out and reported, then compared with samples that were not exposed to elevated temperature. It is understood that elevated temperature is not necessarily used to represent concrete durability but for evaluation of various effects (strength and deformation of concrete) and behaviour when concrete is exposed to a harsh or high-heat environment (caused by fire outbreaks). At high temperatures, concrete might experience cracks due to thermal shock, and loss of bond between the cement and the other constituent material (aggregate) that formed the concrete that might reduce the concrete strength. Thus, studying concrete response due to elevated temperature is necessary, to better understand the concrete behaviour to harsh environmental conditions, high temperature and fire. Hence, it helps the construction industry to manufacture concrete mix proportion with waste material that might withstand these harsh environmental conditions.

3. Results and discussions

This section provides a precise description of the experimental results and their interpretation.

3.1 Compressive strength test

Fig. 3 presents the result of the compressive strength behaviour of concrete with and without industrial waste. The graph shows that compressive strength increased with an increase in waste material (limestone dust and quarry

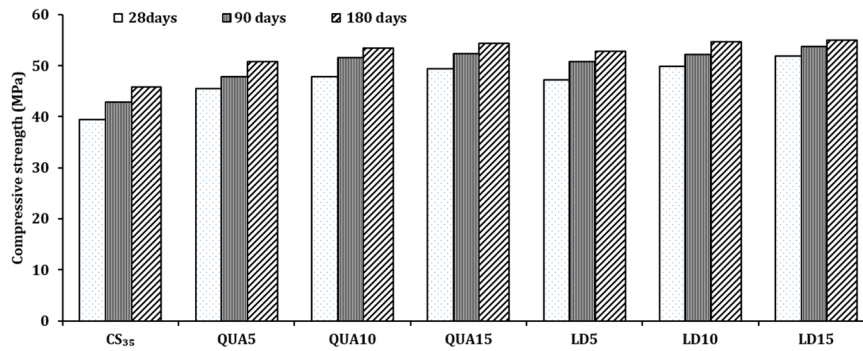


Fig. 3 Compressive strength behaviour of concrete with industrial waste materials

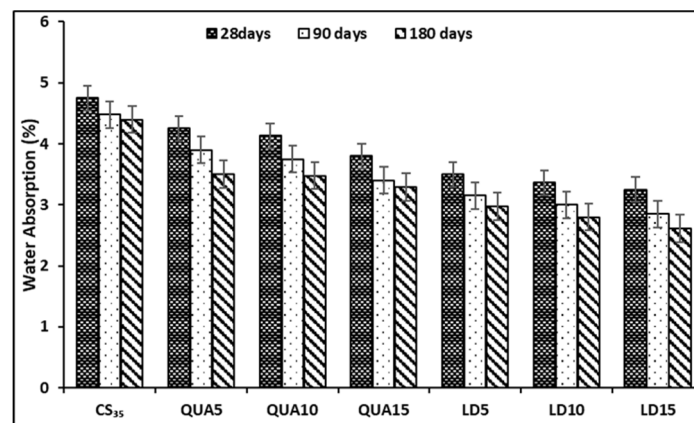


Fig. 4 Water absorption capacity of concrete

dust) respectively. The compressive strength results also reveal that concrete strength increased as the curing age progressively increased from 28 days to 180 days. This indicates that all the concrete samples at the curing age of 180 days had the highest strength compared to other curing ages (28 days and 180 days). However, it is important to highlight that all replacement content up to 15% had the highest compressive strength compared to the other replacement content (5% and 10%) and control sample (CS₃₅). The improved performance of the concrete strength due to the addition of waste material could be attributed to the fineness of the waste material which may have acted as filler to fill the concrete internal structure.

3.2 Water absorption

Fig. 4 shows the water absorption test results for reference concrete and concrete with industrial waste material as a substitute for fine aggregate. The result presented in Fig. 4 indicates that the rate of water absorption progressively reduced with curing time. The water absorption rate decreased with the replacement of sand with limestone and quarry dust in the mix.

For example, CS₃₅ at 28 and 90 days had an absorption rate of 4.75% to 4.48%, while QUA15 and LD15 had 3.8% and 3.25% for 28 days, but when the samples were left for 90 days the absorption rate decreased drastically to 3.9% to 2.85% respectively. The decrease in water absorption due to replacing fine aggregate with limestone and quarry dust could be attributed to finer particles of both materials

having a filler effect and reducing the internal void through the packing effect in the interfacial transition zone. This behaviour could be attributed to the concrete's improved performance on compressive strength as reported in Fig. 3. Hence, this observation was convincing because one major filler behaviour is filling voids between constituent materials in the concrete structure. Fig. 4 shows that water absorption is reduced with an increase in dust content. Celik and Marar (1996) also reported similar findings on the water absorption capacity of concrete. This means that adding quarry dust to replace fine aggregate greatly reduced the concrete water absorption. Furthermore, limestone dust used in this study showed better resistance to water absorption when compared to quarry dust waste and reference concrete (CS₃₅). Another observation revealed that water absorption reduced with an increase in limestone dust in all replacement content and age of curing. Water absorption also decreased with an increase in curing age at all limestone dust replacement content. Bederina *et al.* (2013) reported that this behaviour could be attributed to reducing a porous internal structure due to the addition of limestone dust. However, the lowest water absorption at ages 28, 90 and 180 days was observed for sample LD15 with percentage absorption of 3.25%, 2.85% and 2.61%, respectively. Meanwhile, it was seen that the water absorption for limestone and quarry dust used to substitute fine aggregate is below 10%, and according to BS 1881-122 (2011) it is considered as having average water absorption values ranging from 2.61 to 5.85%. This indicates that

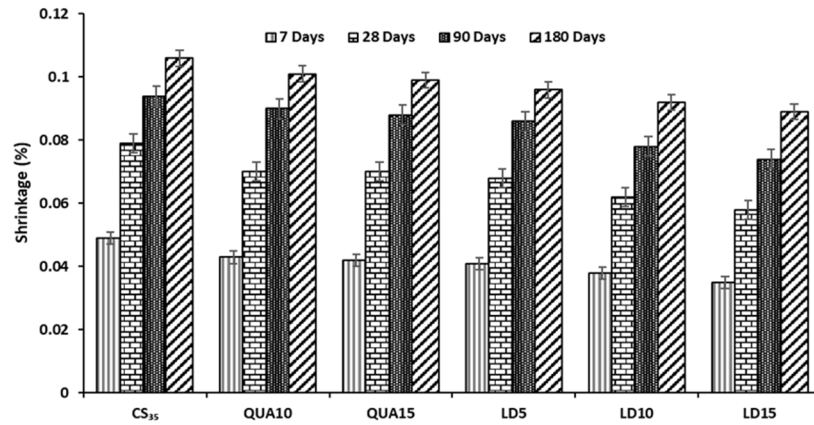


Fig. 5 Concrete drying shrinkage at 7, 28, 90 and 180 days

employing limestone dust and quarry dust to substitute fine aggregate in an optimum content for the production of concrete will yield concrete with good resistance to water absorption.

3.3 Effect of industrial waste materials on concrete drying shrinkage

Concrete shrinkage is another important parameter for establishing the durability of concrete. Shrinkage of concrete is said to be about a change in the dimension of concrete due to the evaporation of water. However, constrained shrinkage movement causes cracks especially when the shrinkage stress surpasses its tensile capacity (Rao *et al.* 2012). In this study concrete change in length was measured and recorded for both reference concrete and concrete with limestone and quarry dust used as a substitute for fine aggregate. The result from Fig. 5 shows that shrinkage reduced as the age of concrete testing advanced. This behaviour was seen in the case of reference samples, limestone dust and quarry dust employed as a substitute for fine aggregate. For example, the rate of shrinkage from 7 days to 28 days for CS₃₅ was 0.030 % and between 28 days to 90 days, the rate of shrinkage decreased to 0.015%. The aforementioned behaviour indicates that the rate of shrinkage reduced after 28 days; and at an age between 7 to 28 days, concrete showed higher shrinkage values compared to the later age. This proves that at 28 days of curing age, the concrete samples have achieved more than 70% hydration. Thus, beyond this age, there was evidence of a decrease in shrinkage.

From Fig. 5 there was a reduction in shrinkage value owing to the increase in limestone and quarry dust content used as fine aggregate. A similar finding was also reported by Arthanary *et al.* (1985). The result from Fig. 5 proves that the addition of limestone dust and quarry dust at all percentages had better resistance to concrete shrinkage when compared to the reference sample (CS₃₅). Among all concrete samples, it is seen that samples with limestone dust had the lowest shrinkage value as compared to CS₃₅ and quarry dust in all replacement content. This could be attributed to the better performance of limestone dust in filling the concrete internal void may have reduced the porous structure of the concrete Carlos *et al.* (2010) as seen

in the case of water absorption. For an increase in limestone and quarry dust used as a substitute for fine aggregate, it was observed that the percentage of shrinkage progressively decreased. However, 15% replacement content of quarry dust and limestone dust progressively decreased concrete shrinkage with the age of testing (7, 28, 90 and 180 days). Among all replacement content of fine aggregate, 15% limestone dust content had the lowest shrinkage value for all ages of testing when compared to CS₃₅ and quarry dust in all percentage replacement content. The limestone dust at all curing ages and replacement content had better resistance to concrete shrinkage when compared to the other samples in this study. This behaviour could be due to the filling effect of the industrial waste (limestone dust and quarry dust) particles that decrease the concrete shrinkage. Whereas the particles of the industrial waste materials reduced the capillary voids in the internal concrete structure. This behaviour agrees with the findings by Carlos *et al.* (2010) and Leeuwen *et al.* (2016).

3.4 Sodium chloride and magnesium sulphate attack on concrete

These experiments were conducted to determine the concrete weight loss and loss in strength because of exposure to sodium chloride and magnesium sulphate attack. Thus, concrete samples were selected for testing at ages 28 days, and 180 days and the loss of weight and strength of concrete compared with the samples immersed in the ordinary tap water of the same testing age.

3.4.1 Weight loss after exposure to sodium chloride attack

Fig. 6 presents the result of concrete exposed to NaCl and the result shows weight loss due to exposure to NaCl decreased with the addition of Limestone dust and quarry dust in the mix. The weight of concrete with limestone dust and quarry dust at 28 days of exposure was better when compared to the weight of control sample CS₃₅ at the same age. This means that an increase in limestone dust and quarry dust content decreased the weight loss of the concrete.

Concrete exposure to NaCl solution at 180 days showed a higher percentage loss in weight when compared to 28

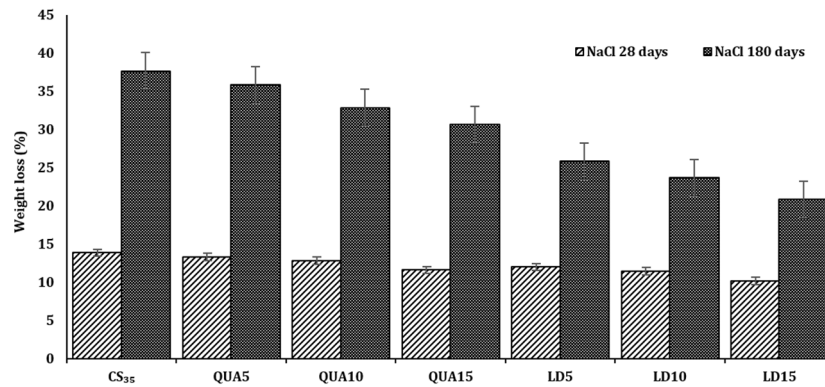


Fig. 6 Weight loss due to exposure to Sodium Chloride at 28 days and 180 days

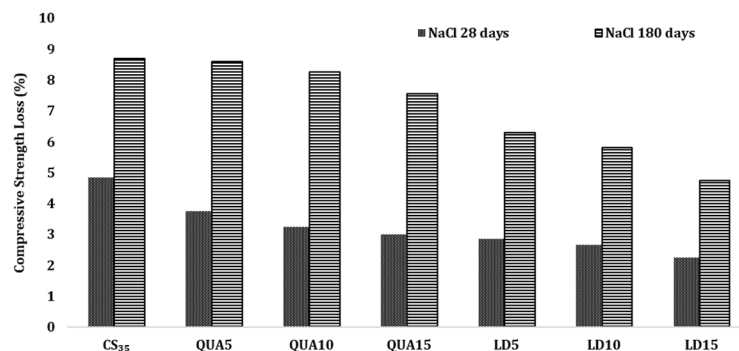


Fig. 7 Compressive strength Loss (%) after exposure to NaCl solution at 28 days and 180 days

days of exposure to NaCl. The results revealed that concrete loss of weight increases with an increase in time or age of exposure. Thus, with the addition of quarry dust and limestone dust, the loss of concrete weight due to exposure to NaCl decreased. This means that when concrete is exposed to NaCl in the long term the loss of weight tends to reduce due to the addition of industrial waste materials to the concrete. Limestone and quarry dust showed better performance on resistance to percentage weight loss compared to the reference concrete sample CS₃₅.

3.4.2 Sodium chloride solution attack on concrete strength

The behaviour of concrete, when exposed to sodium chloride, is presented in Fig. 7. It shows that compressive strength slightly decreased when exposed to NaCl compared to concrete cured in normal water. This performance shows that exposure of concrete to NaCl at 28 days and below will only result in a slight decrease in strength. However, it was observed from the result presented in Fig. 7 that the exposure of concrete to NaCl beyond 28 days (180 days) caused an increase in loss in compressive strength. It was also observed that concrete with limestone dust and quarry dust as a substitute for fine aggregate exposed in NaCl solution had better resistance to strength loss when compared with CS₃₅ at the same age of exposure. The result from Fig. 7 showed that the rate of compressive strength loss decreased with an increase in replacement content. For example, the results show that CS₃₅ exposed to NaCl at 28 days lost strength of about

4.85%, and QUD5 at 28 days lost 3.75% respectively. For concrete samples with limestone dust at 28 days of exposure to 5% NaCl solution, it was observed that LD5, LD10 and LD15 lost strength of about 2.85%, 2.65% and 2.25% respectively. Observation from Fig. 7 also indicates that limestone dust in all replacement content had good resistance to strength loss when exposed to NaCl at all ages. This was clear when compared to CS₃₅ and quarry dust concrete samples.

The resistance to strength loss by concrete with industrial waste materials might be associated with the performance of quarry dust and limestone dust on resistance to loss of weight and their performance in concrete strength as presented in Fig. 3 above. Hence, the industrial waste materials lowered the penetration of NaCl into the concrete internal structure. This can also be because of the improvement in the filling effect by the particles of limestone dust and quarry dust that filled the internal concrete structure, which may have enhanced the dense microstructure of the concrete.

However, when the age of exposure progressed to 180 days, all the samples suffered higher compressive strength loss, especially when compared with normal water-cured concrete. This behaviour affirms that the concrete was affected by chloride ions due to long-term exposure to NaCl. Thus, changing the void sizes of the cement paste in a hydrated state, and thereby causing the concrete paste to deteriorate due to the decalcification process. It was also seen from Table 5 that sample CS₃₅ and all quarry dust samples suffer more loss in strength than limestone dust

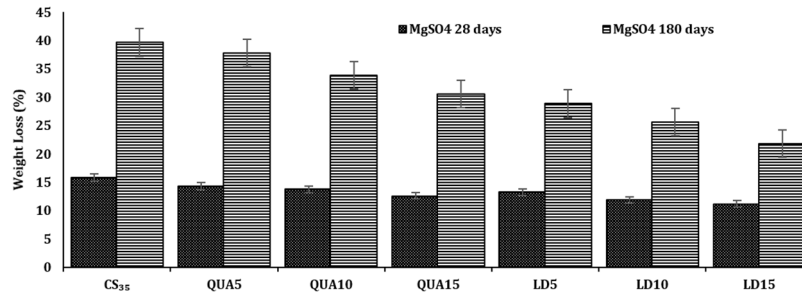


Fig. 8 Weight loss due to exposure to MgSO₄ at 28 days and 180 days

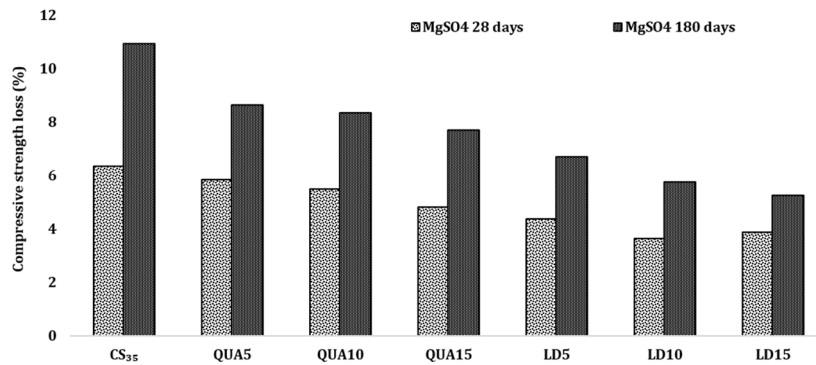


Fig. 9 Compressive strength Loss (%) after exposure to MgSO₄ solution at 28 days and 180 days

samples. This might be connected to the weak pore structure of the concrete with higher quarry dust content that affects the compressive strength of concrete (Aziez and Bezzar 2017).

3.4.3 Weight loss due to magnesium sulphate attack

Fig. 8 shows the experimental results of concrete subjected to magnesium sulphate solution and sample submerged in conventional tap water. From the result, it is seen that exposure of concrete to MgSO₄ affected the concrete weight. The effect of MgSO₄ on concrete weight was not obvious at 28 days, but more significant at 180 days. Employing limestone dust and quarry dust in the mix reduced the rate of weight loss due to MgSO₄. This was seen particularly when concrete produced with limestone dust and quarry dust as a substitute for fine aggregate was compared with the reference sample. The concrete's weight loss reported in Fig. 8 could be associated with the deterioration of the cement paste.

The results from this investigation show that the substitution of fine aggregate with limestone dust and quarry dust yields a better resistance to magnesium sulphate attack. However, the result proves that quarry dust and limestone dust decreased the rate of weight loss with an increase in replacement content. Limestone and quarry dust in all percentage replacements progressively reduced the loss in weight due to the MgSO₄ attack on concrete structure. The result also indicates that the increase in the content of quarry dust and limestone dust decreased the percentage weight loss at every tested age (28 days and 180 days). For example, CS₃₅ at 28 days and 180 days had a weight loss of about 15.86 and 39.65%, while at 5%

replacement of fine aggregate with limestone dust (LD5) had a weight loss of 13.25% at 28 days and 28.85% at 180 days. This behaviour was observed in all replacement content with quarry dust and limestone dust.

3.4.4 Magnesium sulphates effect on concrete compressive strength

The result of the compressive strength of concrete exposed to magnesium sulphate (MgSO₄) at 28 and 180 days is presented in Fig. 9. The result indicates a decrease in compressive strength when concrete was exposed to MgSO₄ for 28 days and 180 days respectively. Hence, the investigation indicates a decrease in compressive strength with increases in exposure at all ages as shown in Fig. 9. The result also discloses that strength loss decreased with an increase in limestone dust and quarry dust content when compared to the control sample. For instance, CS₃₅ at 28 days loss of 6.34%, but when 5% quarry dust (QUA5) and 5% limestone dust (LD5) were added to the mix, the strength loss for 28 days of exposure in MgSO₄ was 5.86% and 4.36%, respectively. Nevertheless, when replacement content increased to 15% for QUA15 and LD15 the strength loss decreased to 4.86% and 3.88% respectively. This indicates that the industrial waste materials as a substitute to fine aggregate improve the filling effect within the constituent materials and the cement paste. Thus, improved the microstructure of the concrete which yields a decrease in penetration and absorption of MgSO₄ to the concrete.

Additionally, when the concrete was tested for 180 days the concrete had a higher loss in strength when compared to the samples cured in ordinary water at the same age. Limestone dust at 10% to 15% replacement content had better resistance to compressive strength loss when

compared to CS₃₅ at 180 days. Hence it can be seen from the result that both quarry dust and limestone dust can be a good alternative to fine aggregate in terms of resistance to MgSO₄ attack using the appropriate replacement content for reuse in concrete. Nevertheless, limestone dust and quarry dust as a substitute for fine aggregate demonstrated more resistance to loss in strength (Aziez and Bezzar 2017) when exposed to MgSO₄ solution for 180 days. Thereby having better resistance to MgSO₄ attack when compared to CS₃₅. It can be seen that CS₃₅ had a greater strength loss because of the weakening and debonding of the cement that yielded to high penetration of magnesium sulphate solution into the concrete.

3.5 Effect of elevated temperature on concrete

3.5.1 Loss in weight after exposure to high temperature

The laboratory experiment was conducted for concrete with and without industrial waste material to understand the concrete behaviour when subjected to elevated temperature. The results of weight loss for concrete samples exposed to elevated temperatures of 250°C and 500°C are presented in Fig. 10. The result from this table confirmed that the weight of concrete reduced with an increase in temperature. There was evidence of a decrease in weight when the temperature was elevated to 500°C, for example, the percentage weight loss of CS₃₅ was 2.80% at a temperature of 250°C, but when the furnace temperature reached 500°C the concrete loss weight of about 4.13%. The result from this investigation affirms that the increases in limestone or quarry dust as a substitute to fine aggregate yield an increase in weight loss as presented in Fig. 10. The loss in weight of the concrete when exposed to high temperature may be due to the loss of free water from the cement paste within the sample. This results in a reduction of the overall weight of the concrete samples.

The behaviour of weight loss due to the elevated temperature of quarry dust and limestone dust at a temperature of about 200°C was low when compared to exposure to temperatures up to 500°C. However, at all exposure temperatures, limestone dust had better resistance to weight loss than all quarry dust concrete samples at all replacement content. For example, QUA5 lost about 2.85% at 200°C and 500°C, the weight loss increased to 4.18%. Meanwhile, LD5 lost 2.75% at a temperature of 200°C; and

at 500°C, the weight loss increased to 4.16%. This could be linked to the loss of water by evaporation from the concrete paste. Thereby losing all the absorbed water in a short period at a higher temperature. The result indicates that plain concrete (CS₃₅) had better resistance to elevated temperatures than concrete with industrial waste materials.

3.5.2 Concrete strength loss after exposure to different temperature

The residual concrete strength after exposure to high temperatures is reported in Fig. 11. It was seen from the study that the concrete strength was reduced due to exposure to high temperatures. The result also indicates a decrease with an increase in temperature for all samples tested. All the concrete exposed to elevated temperatures up to 500°C showed higher strength loss than samples exposed to a temperature of 200°C, meaning that low temperature (200°C) had little effect on concrete strength (Arioz 2007, Owaid *et al.* 2014, 2015, Kaish *et al.* 2018). At a temperature of 200°C, for CS₃₅ the resistance to strength loss was 90.21%, while at exposure up to 500°C, the resistance to strength loss was 68.21%. The result showed a decrease in resistance to strength loss with limestone and quarry dust when compared with CS₃₅. However, the resistance to strength loss is observed to be progressively decreased with an increase in industrial waste materials. Hence, the addition of limestone dust and quarry dust had less resistance to loss of strength at a temperature of 500°C and this is clear when compared to concrete without limestone dust and quarry dust (CS₃₅).

A slight difference was observed in the residual compressive strength for concrete with limestone and quarry dust when compared to the reference concrete (CS₃₅) at temperatures above 200°C. For instance, QUA5 at a temperature of about 200°C had resistance to strength loss of about 88.06%, while the strength loss progressively increased to 66.98% at a temperature of about 500°C.

3.5.3 Compressive strength loss due to elevated temperature

Fig. 12 presents the result for compressive strength loss due to elevated temperature. The result shows that the loss in compressive strength increased with an increase in temperature. It also indicates that the substitution of fine aggregate with limestone dust and quarry dust also increased the percentage of strength loss. For example, CS₃₅

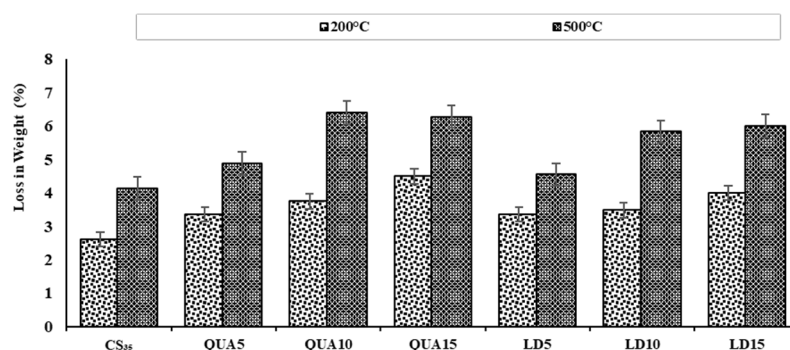


Fig. 10 Weight loss of concrete subjected to high temperature

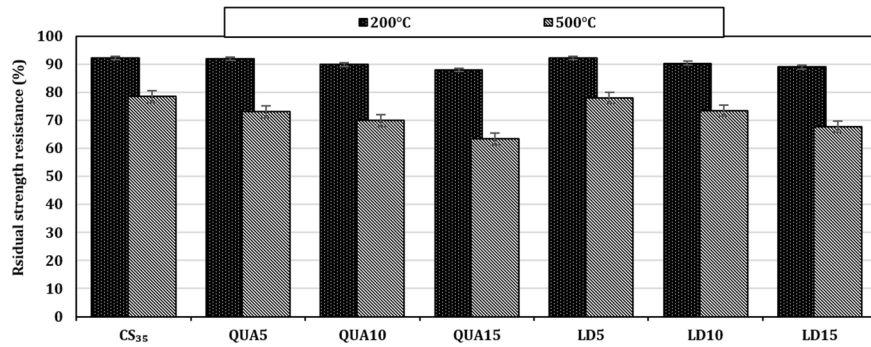


Fig. 11 Residual strength after exposure to elevated temperature

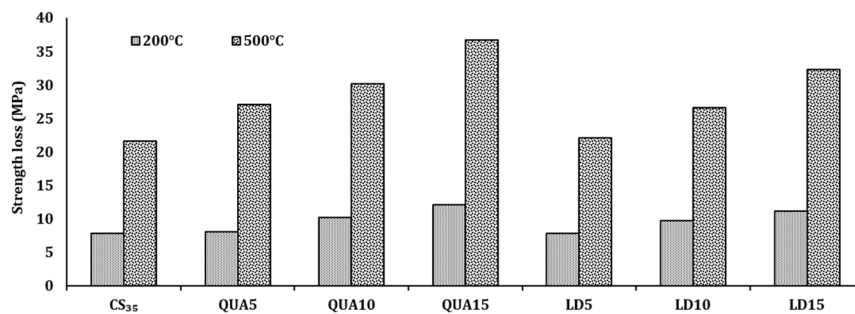


Fig. 12 Compressive strength loss of concrete at temperatures 200°C and 500°C

at temperature 200°C to 500°C had compressive strength loss from 7.87% to 21.62%, QUA5 from 8.08% to 27.05%, and LD5 from 7.87% to 22.11%. At temperatures ranging from 200°C to 500°C, and a 15% fine aggregate replacement content with quarry dust QUA15, the compressive strength loss was 12.15% to 36.69%. While LD15 lost 11.11% to 32.25% respectively. Furthermore, it was observed from the result that limestone dust at 5% replacement content (LD5) had a similar strength loss to the reference sample (CS₃₅).

After being exposed to a temperature of 500°C, the concrete changed its physical properties which resulted in noticeable surface cracking. This was caused by the intense heat that removed moisture from the concrete. The elevated temperature negatively affected the concrete structure, causing the constituent materials to de-bond, particularly the hydrated cement. This effect weakens and cracks the concrete structure and reduces its ability to resist strength loss. (Salau *et al.* 2015). The cracks could be related to shrinkage because of heat, loss of moisture caused by intense heat from the furnace and thermal stress because of the heat from the furnace. The behaviour of the concrete studied indicates dehydration and weakening of the bond between the hydrated cement paste, and other constituent materials around the concrete matrix. Similar behaviour was reported by Khodja and Hadjab (2018), Kaish *et al.* (2018).

4. Conclusions

A detailed experimental investigation on the use of limestone and quarry dust as a substitute for fine aggregate in concrete production was conducted in the laboratory.

This study involved the proper selection and optimizing the use of limestone and quarry dust as a substitute for fine aggregate, while meeting their specified standards. Nevertheless, this study specifically investigated the durability testing of normal-strength concrete. The experimental results led to the following conclusion.

- The use of limestone dust and quarry dust as a substitute for fine aggregate improved compressive strength and the water absorption properties of concrete, with an optimum replacement content of 15% among the considered replacement ratios.
- Concrete with limestone dust and quarry dust at 15% replacement content (QUA15 and LD15) yields the lowest shrinkage value for all replacement content. Hence can be utilized in the reduction of concrete shrinkage with the optimum replacement content from this study.
- The change in weight and strength for concrete cured in water is less relative to the change in weight and strength of concrete cured in both NaCl and MgSO₄ solution. Quarry dust and limestone dust at 15% substitution of fine aggregate showed better resistance to both weight loss and strength loss due to concrete exposure to NaCl solution. Quarry dust and limestone dust utilized in this investigation as a substitute for fine aggregate improved the resistance to weight loss and strength loss due to MgSO₄ attack.
- All concrete samples in this study have shown some resistance to strength loss and weight loss due to an elevated temperature at 200°C, but a significant decrease in resistance to an elevated temperature at

500°C. This indicates that higher temperatures will result in higher weight and strength loss.

- All industrial waste materials at 15% optimum replacement content showed no form of deterioration or significant reduction in volume at 180 days, hence, can be used as a substitute for fine aggregate for concrete work.

The by-product used in this study at optimum replacement content has demonstrated encouraging behaviour in terms of reduction in water absorption, concrete shrinkage, and resistance to chemical attack (sodium chloride attack and magnesium sulphate attack). This could be due to the particle size of the materials which improved the filling of voids (filler effect) in the concrete structure. Hence, limestone and quarry dust can be utilized as partial replacements for fine aggregate to produce concrete with considerable durability properties.

Supplementary materials

“Not applicable”.

Author contributions

Conceptualization, T.C.O. and A.B.M.A.K.; methodology, T.C.O.; validation, I.Z. and A.B.M.A.K.; formal analysis, T.C.O. and A.B.M.A.K.; investigation, T.C.O. and A.B.M.A.K.; resources, A.A.M., M.M.A. and A.T.; data curation, T.C.O. and A.B.M.A.K.; writing—original draft preparation, T.C.O.; writing—review and editing, T.C.O. A.A.M. and A.B.M.A.K.; visualization, A.B.M.A.K.; supervision, I.Z., M.M.A., A.A.M. and A.B.M.A.K.; project administration, A.A.M., A.T and A.B.M.A.K.; funding acquisition, A.T and A.B.M.A.K. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

“The authors declare no conflict of interest.”

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