The Effect of Chemical Composition of Quartzite and Limestone Aggregates on Concrete Characteristic Due to ASR

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Abstract. Quartzite (QS) and Limestone (LS) in the Coastal area of District Pati and Blora have not been utilized optimally as coarse aggregate [1]. Physical of coarse aggregate and chemical composition utilized to obtain the characteristic of quartzite and limestone concrete. A total of 26 (twenty-six) cylindrical concrete specimens with a coarse aggregate ratio of quartzite 70%:30% limestone under two curing conditions were prepared. 18 specimens were submerged in water at 20°C and the rest for 80°C ASR environmental conditions. Compressive strength test, split tensile strength test, and modulus elasticity test of concrete were carried out. The CaO and SiO_2 of coarse aggregate and their correlation to the compressive strength were evaluated. While Lost In Compressive Strength (LICS) test was carried out on 6 specimens in ASR environment. Replacement of 30% QS coarse aggregate with LS showed compressive strengths of 19.69 Mpa and 29.85 Mpa for w/c ratios of 0.61 and 0.47 respectively. There is relatively tenous negative correlation mids the CaO content on the compressive strength and the density of concrete. Concrete with a w/c of 0.47 and 0.61 had compressive strengths of 25.76 Mpa and 20.86 Mpa, respectively, under ASR circumstances. LICS occurred respectively of -4.7% and 13.7% which showed an increase in concrete compressive strength with a w/c ratio of 0.61 and a decrease in concrete compressive strength with a w/c ratio of 0.47 at 28 days of age in an ASR environment. Henceforth, recommends to apply w/c ratio of 0.61 for utilizing QS coarse aggregate in concrete production

Keywords: Chemical Composition, Quartzite Coarse Aggregates, Limestone Coarse Aggregates, Concrete Characteristics, ASR

1. Introduction

It is possible to evaluate the chemical bonds of minerals in coarse aggregate of quartzite and limestone by understanding the chemical composition of coarse aggregate[1]. Alkali-silica reaction (ASR) is a worldwide issue that causes loss of strength, elasticity, and durability of concrete [2]. To determine the effect of ASR on concrete, the physical properties of the aggregate were tested in the form of specific gravity, porosity, absorption, moisture content, and reactivity of the alkali silica aggregates. Quartzite aggregates were found to be highly reactive in the alkaline environment of Portland cement concrete, Limestone with low content of siliceous minerals is good for preventing the alkali silica reaction [3]. Quartz sandstone, which is a mine waste, can be used as aggregate for a high-strength, greenest concrete [4].

To estimate the compressive strength of concrete made with either NA or RA, the influence of the geological nature and physical quality cannot be ignored [5].

For rigid pavements, three properties of concrete are very important to be considered which are the tensile strength, the shrinkage, and the fatigue behavior [5]. The most significant impact on compressive strength according to concluded empirical equation has the strength of an aggregate, W/C ratio remains significant as well [6]. With a W/C ratio of 0.3, high-strength concrete is obtained for the use of limestone coarse aggregate and quartzite coarse aggregate respectively [7]. High-strength concrete may have different elastic modulus depending on the type of coarse aggregate [8]. the higher the w/c ratio, the lower the compressive strength [9].

The quick chemical test (ASTM C289) can be used to identify potentially reactive siliceous aggregates [10] has been extensively evaluated, many aggregates are not adequately identified using this test [11]. The chemical composition and crushing process jointly dominate the properties of aggregates [12]. Kosmatka, et.al stated that replacing about 30% of reactive sand-gravel aggregate with crushed limestone can minimize alkali reactivity [10]. ASR susceptibilities from the aggregate source can be tested by AASHTO T303, ASTM C289, C1260, or C1293 a long-duration test [13]. There has been virtually unanimous agreement among researchers on the relationship between compressive strength and alkali–silica reactivity [14]. Previous studies for mitigating Alkali-Silica Reaction with examination of coarse aggregates which although results can be obtained in a short time, have not reflected their application in concrete, many aggregates are not adequately identified using this test [15]. Excessive crushing may alter the availability of reactive silica within the aggregate matrix, this may lead to different aggregate reactivity during testing [15].

Considering that the coarse aggregate must first go through a crushing procedure to approach the fine aggregate size, the ASR evaluation on concrete for a brief test period does not accurately represent the performance of the aggregate. This research uses a combination of rapid and performance-based ASR testing using coarse aggregate by examining the loss in compressive strength of concrete QS 70%:30% LS aged 28 days. The chemical composition of the aggregate was examined and analyzed using JASP V 0.17 statistical software to obtain a correlation with concrete characteristics due to the ASR environment.

2. Methods

Material

The object of the research was quartzite coarse aggregate stone material, hereinafter referred to as QS, obtained from a quarry in Jairaj Village, Jepon District, Blora Regency, Central Java. The limestone material, hereinafter referred to as LS, was obtained from the quarry of Weigl Village, Suko Lilo District, Pati Regency, Central Java (Figure 1). Bangka sand fine aggregate was used from a local material store. The cement was used Portland composite cement (PCC) type II. The water comes from a network of fresh water wells at the UMB civil materials laboratory.

(a)

(b)

Figure 1. (a) Blora regency quartzite, (b) Limestone of Pati regency.

Aggregative test

Manual crushing is carried out on Quartzite (QS) and Limestone (LS) to obtain QS and LS coarse aggregate raw materials according to C33/C33M – 18 Standard Specification for Concrete Aggregates[1] [16] Aggregative testing was carried out at the Laboratory of Materials Testing, Faculty of Engineering, Department of Civil Engineering, Mercu Buana University, Jakarta on QS and LS coarse aggregates and also fine aggregates as described in Table 1.

Table 1. Characteristic of fine aggregate.

Properties	Results	unit /Ref.
Spesific gravity	2.593	ASTM C 188
Absorption	2.79	%
Fineness modulus	2.677	ASTM C 136
Bulk density	1.201	ASTM C 29
Water content	8.022	%

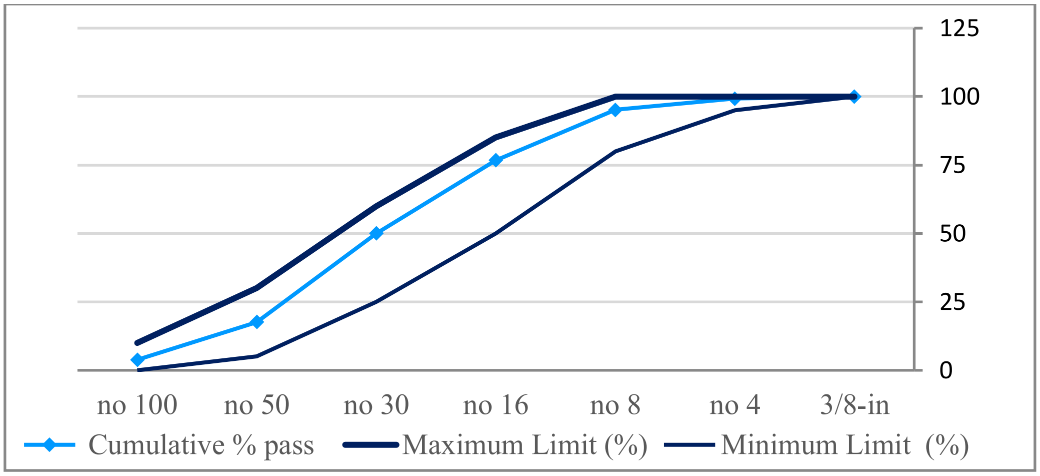

Figure 2. Gradation curves for fine aggregate.

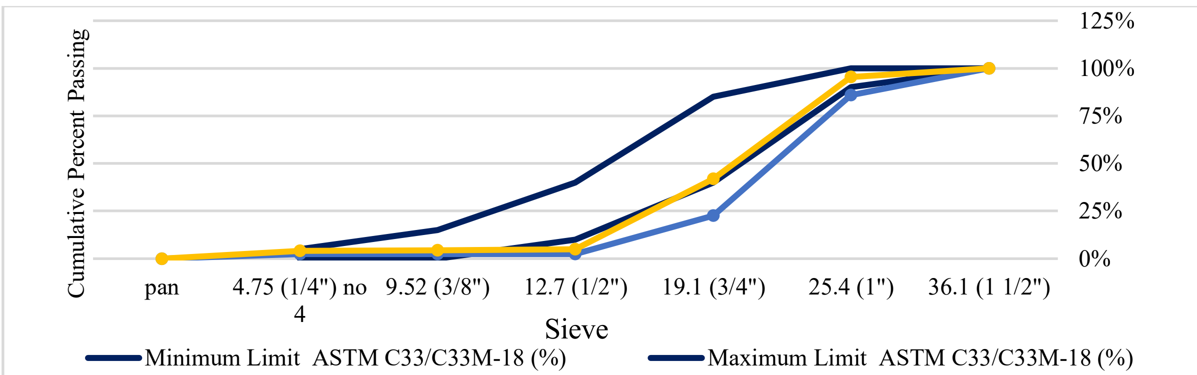

Figure 3. Gradation curves for coarse aggregate

Chemical composition

The chemical composition of QS and LS aggregates were carried out at Balai Besar Bahan dan Barang Teknik (B4T) referring to ASTM C 25 standards shown in Table 2.

Table 2. Chemical composition of aggregates

Parameter (%)	**QS** [17]	**LS** [18]
Silica Oxide (SiO_2)	2.874	1.517
Iron Oxide (Fe_2O_3)	3.250	0.241
Aluminum Oxide (Al_2O_3)	3.816	0.836
Calcium Oxide (CaO)	49.293	54.462
Magnesium Oxide (MgO)	0.313	0.419
Potassium Oxide (K_2O)	0.277	0.227
Sodium Oxide (Na_2O)	0.164	0.172
Loss on Ignition (LOI)	39.378	41.221
Manganese Oxide (MnO)	0.005	0.013
Titanium Oxide (TiO_2)	n.a.	n.a.
Phosphorus Oxide (P_2O_5)	0.355	0.723

Alkali-aggregate reactivity

The alkali-aggregate reactions (AAR) test was carried out at Balai Besar Bahan dan Barang Teknik (B4T) referring to ASTM C 289 – 03 shown in Table 3.

Table 3. Alkali-aggregate test result

Parameter	**QS** [19]	**LS** [20]
Dissolved Silica (Sc) mmol/L	8.63	4.65
Reduction in Alkalinity (Rc)	162.00	72.00

Concrete Mix Proportion

This concrete is prepared by replacing 30% of quartzite aggregate over limestone which is expected to minimize alkaline reactivity. Workability that is suitable for construction works is generally also expected to be fulfilled [21]. The water-cement ratio was kept at 0.47 according to previous research from Ahmed, Et. Al [22] and Jóźwiak, Et. Al [3]. The slump value is specified maximum of 100mm and a minimum of 75 mm [21]. The quantity of the required mixing water per cubic yard of concrete by multiplying the net mixing-water content of the trial batch [23] considering aggregate absorption as well as moisture content. No superplasticizers were used for the mixes studied in this research to keep the final cost of the produced concretes acceptable [5]. For the laboratory trial batch, it is found convenient to scale the masses down to produce 3 cylinders of concrete. The first estimate of mixture proportions already confirmed and, adjusted with trial batches in the lab as described in Table 4.

Table 4. Concrete Mix Proportion

Material	w/c 0.61	w/c 0.47	Unit
Water	205.189	215.768	liter
Cement	336.376	353.718	kg
Coarse Agg. QS	579.707	582.606	kg
Coarse Agg. LS	265.652	266.98	kg
Fine Aggregate	996.103	964.178	kg

3. Results And Discussion

3.1. Compressive Strength

Based on the compressive strength result of concrete cylinders aged 28 days, the correlation between compressive strength to w/c ratio and deviation to ACI standard was obtained in Table 5.

Table 5. Correlation w/c ratio with compressive strength

Properties	Compressive strength (Mpa)	ACI 211 Compressive strength (Mpa) [24]	Decrease of Compressive strength in comparison to ACI (%)
Fc' w/c 0.61	19.69	25	21.25
Fc' w/c 0.47	29.85	35	14.72

3.2. Tensile strength

Splitting tensile strength is used to evaluate the shear resistance provided by concrete and to determine the development length of reinforcement [25]. Splitting tensile test performed on water-cured cylinders aged 28 days obtained tensile strength of 4.6 MPa and 11.13 MPa for w/c ratio 0.61 and w/c ratio 0.47 respectively

3.3. Effects of SiO_2 and CaO of Coarse Aggregate

The proportion of coarse aggregates in this study used 70% quartzite and 30% limestone so that the combined chemical content of coarse aggregates for SiO_2 2.467% and CaO 50.844% was obtained. Statistical analysis was carried out on the systematic literature review (SLR) of the content of SiO_2 - CaO aggregates coarse for Absorption, Density and Compressive Strength of Concrete QS 70%: 30% LS in Table 6 and Figure 4.

Table 6. SiO_2 - CaO Coarse Aggregate for Absorption-Density and Concrete Compressive Strength QS 70%:30% LS

Researchers	Coarse Agg. SiO_2	Coarse agg. CaO	Absorption	Density kg/m^3	Fc' 28-day (Mpa)
Gunasekaran et al, 2016. [4]	94.32	0.560	0.09	1413	35.40
Gunasekaran et al, 2016. [4]	94.32	0.560	0.09	1413	34.10
Gunasekaran et al, 2016. [4]	94.32	0.560	0.09	1413	46.30
Gunasekaran et al, 2016. [4]	94.32	0.560	0.09	1413	46.80
Shuraim et al, 2016. [26]	42.08	18.510	1.53	1665.46	74.84
Shuraim et al, 2016. [26]	65.94	3.240	1.43	1683	73.19
Islam & Ghafoori, 2015. [14]	0.74	30.740	0.4	1630.68	41.04
Islam & Ghafoori, 2015. [14]	17.19	43.400	1.4	1509.90	39.46
Islam & Ghafoori, 2015. [14]	13.5	32.550	1.7	1595.44	29.61
Islam & Ghafoori, 2015. [14]	65.35	2.910	1.4	1510.54	38.75
Islam & Ghafoori, 2015. [14]	1.83	30.600	1.3	1705.97	37.32
Islam & Ghafoori, 2015. [14]	63.09	6.920	1.09	1673.93	36.82
Islam & Ghafoori, 2015. [14]	60.82	4.340	2.05	1492.92	34.22
Islam & Ghafoori, 2015. [14]	10.91	41.000	0.96	1510.54	37.72
Islam & Ghafoori, 2015. [14]	56.66	5.330	2.9	1508.94	32.32
Ahmed et al, 2022 [22]	56.92	9.890	2.2	1307.42	28.00
Ahmed et al, 2022 [22]	54.13	12.116	2.2	1307.42	28.00
Ahmed et al, 2022 [22]	51.33	14.341	2.2	1307.42	35.00
Ahmed et al, 2022 [22]	48.54	16.567	2.2	1307.42	40.00
Ahmed et al, 2022 [22]	45.74	18.792	2.2	1307.42	42.00
Ahmed et al, 2022 [22]	42.95	21.018	2.2	1307.42	31.00
Ahmed et al, 2022 [22]	40.15	23.243	2.2	1307.42	30.00
Ahmed et al, 2022 [22]	34.56	27.694	2.2	1307.42	26.00
Wang et al, 2021 [27]	89.05	0.280	9.7	1070	74.00
This research	2.47	50.844	0.47	1169.11	29.85
This research	2.47	50.844	0.61	1169.11	19.92

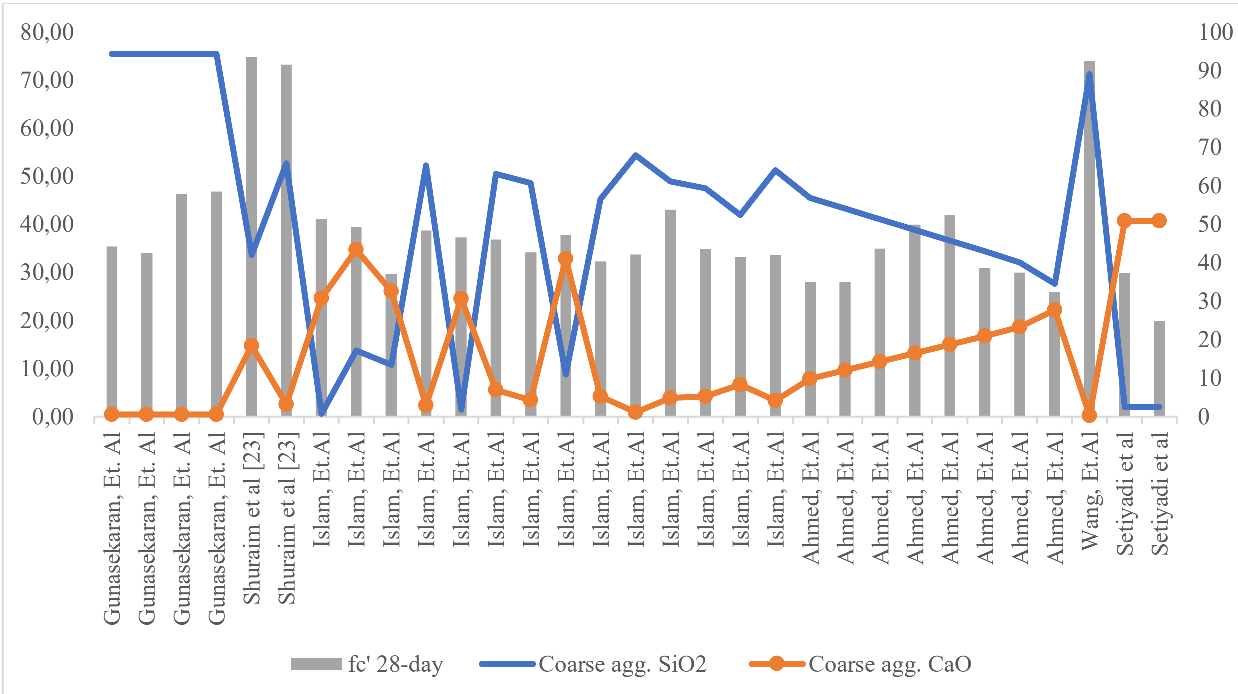

Figure 4. Correlation of Coarse aggregate SiO_2-CaO to compressive strength of QS 70%:30% LS concrete

Statistical analysis was carried out using JASP software (Version 0.17) regarding the correlation between SiO_2 and aggregate CaO content on the compressive strength of QS 70%:30% LS concrete in Table 7.

Table 7. Pearson's Correlations of Coarse Aggregate SiO2-CaO content for Absorption, Density and Compressive Strength of Concrete Aggregate QS 70%:30% LS

			Pearson's r		p
CaO coarse aggregate	-	SiO_2 coarse aggregate	-0.925	***	< .001
CaO coarse aggregate	-	Compressive strength 28 day	-0.374		0.060
CaO coarse aggregate	-	absorption	-0.212		0.299
CaO coarse aggregate	-	Density kg/m^3	-0.095		0.645
SiO_2 coarse aggregate	-	Compressive strength 28 day	0.339		0.090
SiO_2 coarse aggregate	-	absorption	0.173		0.398
SiO_2 coarse aggregate	-	Density kg/m^3	-0.126		0.540
Compressive strength 28 day	-	absorption	0.386		0.051
Compressive strength 28 day	-	Density kg/m^3	0.248		0.222
absorption	-	Density kg/m^3	-0.416	*	0.034

a) There is a very large negative correlation between the SiO_2 content and the coarse aggregate CaO content, which implies that the higher the SiO_2 concentration, the lower the CaO content,

b) The content of coarse aggregate SiO_2 correlates positively with compressive strength, suggesting that the higher the SiO_2 concentration, the greater the compressive strength obtained,

c) The content of coarse aggregate CaO has a negative correlation with 28 days compressive strength, implying that the greater the CaO concentration, the lower the compressive strength obtained.

3.4. Lost In Compressive Strength (LICS) due to ASR

Previous research on the loss in compressive strength (LICS) of concrete due to ASR environmental is still quite limited. Analysis and statistical correlation of previous research for alkali-aggregate reaction (AAR) with the content of aggregate SiO_2 and CaO for LICS concrete maintained conditions under normal conditions and ASR environment aged 28 days are shown in Table 8.

Table 8. AAR correlation with SiO_2 and CaO aggregates for normal concrete compressive strength, compressive strength due to ASR conditions and concrete LICS age 28-days.

Researcher	W/C rasio	Reactivity aggregate due to ASR	SiO_2 Coarse agg. (%)	CaO Coarse agg. (%)	Compressive strength at 28 days (Mpa)		LICS at 28 days (%)
					Water-cured cylinders at 20 °C	Alkali-cured cylinders at 80 °C	
Islam, Et.Al[14]	0.45	innocuous	0.74	30.74	41.04	43.99	(7.19)
Islam, Et.Al[14]	0.45	innocuous	17.19	43.40	39.46	41.09	(4.13)
Islam, Et.Al[14]	0.45	Reactive	13.5	32.55	29.61	31.56	(6.59)
Islam, Et.Al[14]	0.45	innocuous	65.35	2.91	38.75	42.93	(10.79)
Islam, Et.Al[14]	0.45	innocuous	1.83	30.60	37.32	41.28	(10.61)
Islam, Et.Al[14]	0.45	Reactive	63.09	6.92	36.82	40.97	(11.27)
Islam, Et.Al[14]	0.45	Reactive	60.82	4.34	34.22	35.64	(4.15)
Islam, Et.Al[14]	0.45	innocuous	10.91	41.00	37.72	45.68	(21.10)
Islam, Et.Al[14]	0.45	innocuous	56.66	5.33	32.32	34.63	(7.15)
Islam, Et.Al[14]	0.45	Reactive	68	1.14	33.72	38.75	(14.92)
Islam, Et.Al[14]	0.45	innocuous	61.17	4.88	43.01	48.26	(12.21)
Islam, Et.Al[14]	0.45	Reactive	59.33	5.30	34.86	27.16	22.09
Islam, Et.Al[14]	0.45	Reactive	52.5	8.36	33.14	34.65	(4.56)
Islam, Et.Al[14]	0.45	Reactive	64.14	4.16	33.62	39.49	(17.46)
Ahmed, Et.Al[22]	0.47	Reactive	56.92	9.89	28	26.71	4.60
Ahmed, Et.Al[22]	0.47	Reactive	54.13	12.12	28	26.32	6.00
Ahmed, Et.Al[22]	0.47	Reactive	51.33	14.34	35	31.50	10.00
Ahmed, Et.Al[22]	0.47	Reactive	48.54	16.57	40	34.00	15.00
Ahmed, Et.Al[22]	0.47	Reactive	45.74	18.79	42	37.59	10.50
Ahmed, Et.Al[22]	0.47	Reactive	42.95	21.02	31	29.14	6.00
Ahmed, Et.Al[22]	0.47	Reactive	40.15	23.24	30	28.80	4.00
Ahmed, Et.Al[22]	0.47	Reactive	34.56	27.69	26	25.35	2.50
This research	0.61	Non Reaktif	2.4669	50.84	19.92	20.86	(4.71)
This research	0.47	Non Reaktif	2.4669	50.84	29.85	25.76	13.70

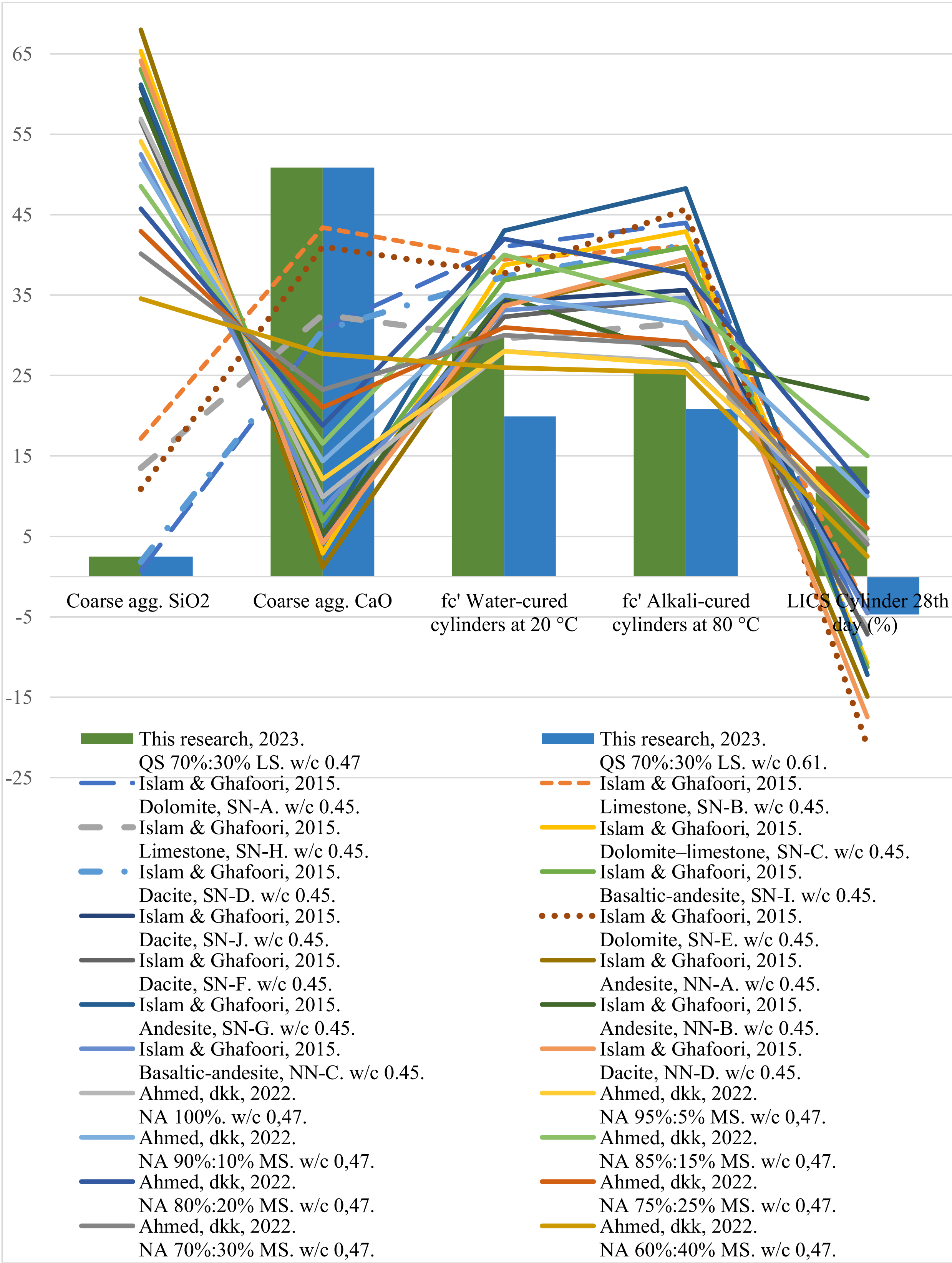

Figure 5. Correlation of coarse aggregate SiO_2-CaO composition for compressive strength and LICS

Analysis of AAR correlation with SiO_2 and CaO aggregates for normal concrete compressive strength, compressive strength due to ASR conditions and concrete LICS age 28-days is carried out using JASP software (Version 0.17) is produced in Table 9.

Table 9. Correlation Study of Coarse Aggregate SiO_2–CaO Composition with Compressive Strength and LICS

			Pearson		Spearman		Kendall	
			r	p	rho	p	tau B	p
Coarse Agg. CaO	-	fc’ 28-day (Mpa) Water-cured cylinders at 20 °C	-0.264	0.213	-0.182	0.395	-0.131	0.372
Coarse Agg. CaO	-	W/C Ratio	0.460 *	0.024	0.402	0.052	0.336 *	0.050
Coarse Agg. CaO	-	fc’ 28-day (Mpa) Alkali-cured cylinders at 80 °C	-0.227	0.286	-0.252	0.234	-0.200	0.172
Coarse Agg. CaO	-	LICS silinder 28-day(%)	0.059	0.783	0.240	0.259	0.160	0.275
Coarse Agg. CaO	-	Coarse Agg. SiO_2	-0.937 ***	< .001	-0.952 ***	< .001	-0.855 ***	< .001
fc’ 28-day (Mpa) Water-cured cylinders at 20 °C	-	W/C Ratio	-0.614 **	0.001	-0.462 *	0.023	-0.390 *	0.023
fc’ 28-day (Mpa) Water-cured cylinders at 20 °C	-	fc’ 28-day (Mpa) Alkali-cured cylinders at 80 °C	0.847 ***	< .001	0.820 ***	< .001	0.672 ***	< .001
fc’ 28-day (Mpa) Water-cured cylinders at 20 °C	-	LICS silinder 28-day(%)	-0.162	0.450	-0.200	0.349	-0.124	0.399
fc’ 28-day (Mpa) Water-cured cylinders at 20 °C	-	Coarse Agg. SiO_2	0.152	0.477	0.111	0.606	0.102	0.487
W/C Ratio	-	fc’ 28-day (Mpa) Alkali-cured cylinders at 80 °C	-0.566 **	0.004	-0.751 ***	< .001	-0.636 ***	< .001
W/C Ratio	-	LICS silinder 28-day(%)	0.155	0.469	0.651 ***	< .001	0.519 **	0.002
W/C Ratio	-	Coarse Agg. SiO_2	-0.332	0.113	-0.311	0.139	-0.267	0.119
fc’ 28-day (Mpa) Alkali-cured cylinders at 80 °C	-	LICS silinder 28-day(%)	-0.658 ***	< .001	-0.684 ***	< .001	-0.454 **	0.002
fc’ 28-day (Mpa) Alkali-cured cylinders at 80 °C	-	Coarse Agg. SiO_2	0.088	0.684	0.173	0.419	0.156	0.286
LICS silinder 28-day(%)	-	Coarse Agg. SiO_2	0.043	0.842	-0.206	0.334	-0.102	0.487

* p < .05, ** p < .01, *** p < .001

Correlation interpretation referring to Mukasa, 2012 [28], can be explained ;

a) There is a very high negative correlation between the SiO_2 content and the CaO content in coarse aggregate, the higher the SiO_2 content, the lower the CaO content, and vice versa.

b) A low negative correlation exists between W/C ratio and 28-day compressive strength in 20°C water curing cylinders. The higher the W/C Ratio in the design concrete mix, the lower the compressive strength of the concrete obtained at 28 days.

c) The compressive strength (Mpa) of cylinders cured in 20°C water for 28 days and the compressive strength (Mpa) of cylinders cured in 80°C water for 28 days are significantly positively correlated. The higher the fc’ 28 days (Mpa) of the cylinder cured with water at a temperature of 20 °C, the higher the fc’ of the concrete in the cylinder cured with alkali at a temperature of 80 °C for 28 days.

d) There was a high negative correlation between the W/C ratio and 28-day compressive strength in alkali-cured cylinders at 80 °C. The higher the W/C Ratio in the design concrete mix, the lower the compressive strength of the concrete obtained in cylinders cured with alkali at a temperature of 80 °C for 28 days.

e) Based on Spearman Rho analysis, there is a high positive correlation between the W/C ratio and the loss in compressive strength at 28 days. Concrete with a higher W/C ratio will experience a greater loss of compressive strength (LICS).

f) There was a high negative correlation between 28-day compressive strength in alkali-cured cylinders at 80 °C and LICS cylinder 28-day (%). The higher fc' 28-day (Mpa) alkali-cured cylinders at 80 °C achieved, the lower LICS cylinder 28-day(%) obtained.

4. Conclusions

The mechanical characteristics of limestone coarse aggregate and quartzite coarse aggregate were tested in an experimental study on QS 70%:30% LS concrete for w/c ratios of 0.47 and 0.61. Research findings were obtained ; a. There is no correlation between the CaO content nor the SiO_2 content of coarse aggregate to the compressive strength of QS 70%:30% LS concrete. b. Replacing 30% of the coarse quartzite aggregate with limestone resulted in compressive strengths of 19.69 MPa and 29.85 MPa, for a w/c ratio of 0.61 and 0.47, respectively. According to ACI 211.1-91, compressive strength decreases by 21.25% for w/c ratio of 0.61 and 14.72% for 0.47. c. Concrete QS 70%:30% LS with w/c 0.47 experienced a loss in compressive strength of 13.7% due to environmental conditions ASR. while for concrete with a w/c ratio of 0.61 LICS was obtained -4.7%, meaning there was an increase in compressive strength at environmental conditions ASR of 4.7%. Provided recommendations for the use of a QS 70%:30% LS ratio with w/c 0.61 in concrete production as a mitigation of the alkali-silica reaction.

Further studies are needed on the effect of the alkaline content of Portland cement on the loss in compressive strength (LICS) concrete due to ASR conditions.

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