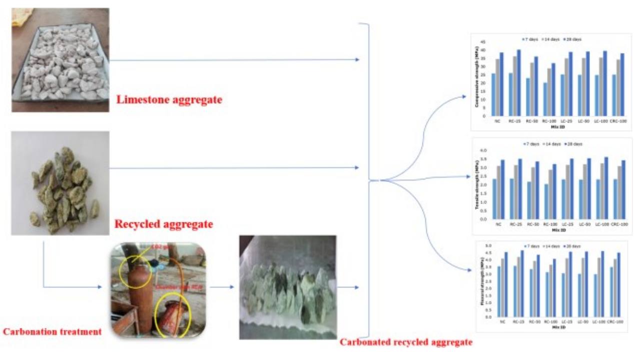
Global NEST Journal, Vol 26, No 4, 05743

Sustainable approach of utilization of limestone and treated construction wastes as aggregates in the production of high temperature resistant green concrete

Loganathan S.[1*], Nirmalkumar K.[2] and Sivakumar A.[3]
[1]Department of Civil Engineering, Government Polytechnic College, Karur-621301, Tamil Nadu, India
[2]Department of Civil Engineering, Nandha Engineering College, Erode-638052, Tamil Nadu, India
[3]Department, Excel Engineering College, Komarapalayam, Namakkal-637303, Tamil Nadu, India
Received: 17/01/2024, Accepted: 02/03/2024, Available online: 10/03/2024
*to whom all correspondence should be addressed: e-mail: gptckarur@gmail.com
https://doi.org/10.30955/gnj.005743

Graphical abstract



Abstract

Natural gravel used as aggregates in the construction had a severe impact on the environment leading to scarcity in recent times. Furthermore, the resistance of such natural aggregates to crack at higher temperature zones was less. This paper investigates the above concerns on scarcity and meagre high-temperature resistance with the use of sustainable waste materials such as recycled aggregates and limestone as aggregates in the concrete. The natural aggregates were replaced with different proportions of limestone aggregates (LA), recycled aggregates (RA) and carbonation treated recycled aggregates (CRA) to investigate their hardened properties and thermal properties at 200, 400, and 800°C. The strength of recycled aggregate concrete (RAC) and carbonated RAC (CRAC) was reduced by 16.67% and 1.32%, while the strength of limestone aggregate concrete (LAC) was enhanced by only 2.3%. The RAC and LAC show better resistance to elevated temperature compared to control concrete and the residual temperature was observed between 200 to 400°C.

Keywords: Natural aggregate, recycled aggregate, limestone aggregate, carbonation treatment, elevated temperature, hardened properties

Abbreviations

LA – Limestone aggregates	NA – Natural aggregates
RA – Recycled aggregates	CS – Compressive strength
CRA – Carbonation treated recycled aggregates	TS – Tensile strength
RAC – Recycled aggregate concrete	EM – Elastic Modulus
CRAC – Carbonated RAC	TC – Thermal Conductivity
LAC – Limestone aggregate concrete	FS – Flexural strength

1. Introduction

Generally, aggregate occupies 65-70% of the concrete volume and it becomes phenomenal to understand its behaviour in the concrete (Sivamani *et al.* 2021). Such a higher volume of materials depends on its source from natural raw materials which on surplus utilization leads to scarcity. Such serious concerns about the scarcity of raw materials in construction and the surplus utilization of natural sources have to be addressed with alternative sustainable materials to ensure environmental integrity (Sivamani *et al.* 2022). Limestone aggregates (LA) and recycled aggregates (RA) will be viable options under such circumstances to ensure sustainability in the construction. In India, the production of limestone rose from 262.88 million metric tons (2012) to 392.76 million metric tons (2023) (Statista 2023). Also, the generation of construction wastes rose to 150 MT of which only 1% was recycled (Wastewise 2023). Limestone is an alluvial deposit composed of $CaCO_3$ formed through mechanical and chemical means, while RA is obtained through the recycling of construction wastes specifically the concrete fractions.

Several studies encompass the utilization of limestone either as a replacement for cement or aggregates in the concrete. (Carlos *et al.* 2010) replaced sand with LA at different w/c ratios and found that strength and elastic modulus were enhanced with an increase in the LA, however, the increment was comparatively smaller. Also, the shrinkage was observed to be lower in LA than in conventional aggregates. (Singh *et al.* 2021) used limestone dust and observed that its higher water absorption capacity affects the workability of the concrete. The strength was enhanced by 11.6% and chloride penetration was lowered by 13.5% with 20% of LA. (Bederina *et al.* 2011) used LA and limestone fillers (0 to 40%) and found a decrease in the workability with an increase in the LA. The strength was lowered by 14.92% and the shrinkage tends to increase. (Tanijaya *et al.* 2021) used LA in high strength concrete and observed a strength of 59 MPa at 28 days and an elastic modulus of 46.96 GPa. The properties of LAC enhance with decrease in the w/c ratio.(Bentz *et al*. 2015) used 10% of LA and found that strength was enhanced with an increase in the curing ages but eventually lower compared to control concrete. The chloride penetration and resistivity tend to increase with increase in the LA. (Yasar *et al.* 2004) used LA of different sizes at different w/c ratios and the strength was lowered with increase in the particle size and increase in the w/c ratios. The optimization of 0.3 w/c ratio and particle size (0-5 mm) enhanced the strength by 20%.

Various studies were performed with recycled materials such as rubber tyre, recycled water or recycled aggregates as a suitable replacement in the concrete (Varga *et al.* 2010, Mavroulidou & Figueiredo 2010, Arunkumar *et al.* 2023, Sivamani 2022b). (Liu *et al.* 2021) discussed the outlooks on utilizing CO_2 seizure technologies and observed that early carbonation refines the microstructure in enhancing the mechanical and durability properties and the rate of carbonation was determined through CO_2 diffusion. (Hamada *et al.* 2023) suggested that solid wastes are suitable alternative for binder/aggregates in ultra-high-performance concrete, however improvement techniques should be proposed with suitable design and testing methods. Few studies were proposed with the use of fibres and eco-friendly materials in the development of composites to investigate the mechanical properties (Karthik *et al.* 2022, Fayaz *et al.* 2022, Murali *et al.* 2023, Ramesh *et al.* 2023a, Ramesh *et al.* 2023b, Ahmed *et al.* 2017). Similar studies were performed with the RA as a replacement to aggregate in the concrete. (Karthikeyan *et al.* 2023) observed that optimizing RA to 30% enhanced the strength by 3.9% while 100% RA lowered the strength by 20.06%. The higher water absorption of RA (6.3%) resulted in lowering the strength of RAC. (Saravanakumar *et al.* 2021) observed that only 72% and 73% of strength was attained in RAC at 28 days and 90 days with reference to control concrete. Also, the alkalinity of RAC was below 12, ensuring inferior corrosion resistance properties. (Sivamani *et al.* 2022a) also used RA as fine aggregate and observed 22.06% reduction in the strength owing to the higher porosity. It is observed that decrease in the particle size affects the concrete properties owing to the higher water absorption. Fewer other studies conducted with RA show inferior concrete properties stating its higher porosity ensuing from the voids as a result of recycling stages (Jagan *et al*. 2022b, Jagan *et al.* 2023, Sivamani *et al.* 2021a). So, several treatments such as acid, carbonation, microbes, polymers etc. were proposed to enhance the quality of RA. For instance, (Malathy *et al.* 2023) treated RA with acids and CO_2 and observed 9.7% and 16.44% enhancement in the strength of RAC with acids and CO_2 and 28-34% decrease in the water absorption of RAC. (Kothari and Abhay 2016) used scrubbing technique and observed 32% enhancement in the strength of the RAC.

Moreover, concrete material apart from strength and durability should withstand elevated temperature, but eventually conventional concrete tends to show deprived mechanical properties upon subjecting it to elevated temperatures. At high temperature, cracks develop and propagate owing to rise in pore pressure ensuing from Water evaporation. The concrete tends to expand, condense, evaporate, diffuse and as a result weakening occurs. Conventional aggregates can withstand up to 350°C beyond which spalling occurs (Tufail *et al.* 2017). Researchers are in the experimentation with suitable alternative eco-friendly materials with better structural and fire resistance properties. (Savva *et al.* 2005) subjected concrete with limestone and silica aggregate and found that the critical temperature for strength reduction between 300 to 750°C. However, with the addition of pozzolanic materials, the resistance to elevated temperature was better irrespective of the w/b ratios and aggregate type. (Tufail *et al.* 2017) subjected concrete with granite, quartzite and limestone aggregate and observed that granite aggregate concrete show better resistance to elevated temperature than other two. (Chen *et al.* 2021) found that heating RAC to a residual temperature of 200 to 300°C show minimum reduction in the strength and positive impact on initial cracking length. (Sivamani *et al.* 2023a) investigated thermal behaviour of bio-deposited and carbonated RAC and found that residual strength at 500°C with strength reduction of 7 to 30% and also the thermal conductivity was lowered by 43%. From the series of literatures, it could be observed that conventional aggregate does not withstand elevated temperature and also scarcity has been the major concern in recent times. This study discusses the suitability of alternative materials such as limestone and recycled aggregate under control room temperature and elevated temperatures (200, 400 and 800°C) and the investigates its hardened properties and thermal conductivity.

2. Materials and methods

2.1. Concrete materials

ASTM type I cement with properties specified in ASTM C150-07 was used in this study. River sand was used as fine aggregates in the study and gravel was used as natural aggregates (NA) in the study. The NA was replaced with recycled aggregate (RA) and carbonated recycled aggregate (CRA) in the study. Figure 1 shows the visuals of aggregates used in the study. All the aggregates except CRA was pre-saturated before its use in the concrete. The properties of NA, LA, RA & CRA is shown in the Table 1. It could be observed that the density of LA was lower compared to RA and NA and also the water absorption of RA was 87% higher compared to NA. Through carbonation to RA, the water absorption of CRA was 38% lower than RA. The CO_2 interacts with $Ca(OH)_2$ to produce $CaCO_3$ that lids the micro-cracks on the RA. Figure 2 shows the oxide composition of RA, LA and CRA. The LA used in the study was primarily composed of Ca, Si and Fe and RA and CRA show Ca as their major compound owing to the presence of $Ca(OH)_2$ and $CaCO_3$ on its surface. The peak diffraction angle for RA was observed between 60° and 70°, peak diffraction angle for CRA was observed between 20° and 30° and the peak diffraction angle for LA was observed between 30° and 40°. Figure 3 shows the SEM images of LA, RA & CRA. The angularity of LA was lower compared to NA, RA and CRA. In RA, cracks are visible owing to the micro-cracks on the adhered mortar on RA resulting from crushing and in CRA visible calcite deposition was observed resulting the deposition of $CaCO_3$ (Malathy *et al.* 2023).

Figure 1. Visual (a) LA (b) RA (c) CRA

Table 1. Properties of aggregates

Properties	Aggregates			
	NA	LA	RA	CRA
Specific gravity	2.71	2.41	2.32	2.63
Water absorption (%)	0.82	1.93	6.13	3.81
Density (kg/cu.m)	1572	1539	1426	1561

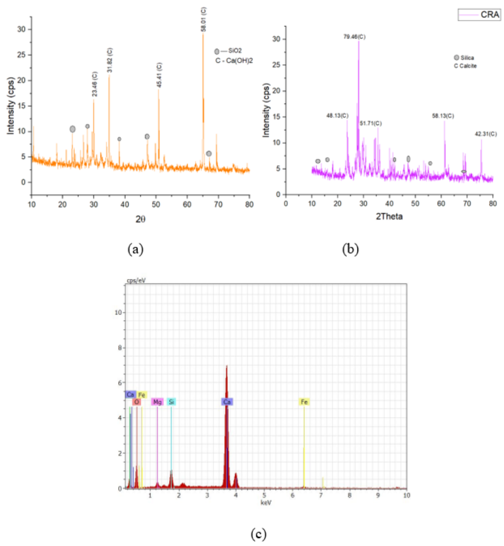


Figure 2. Oxide composition (a) XRD of RA (b) XRD of CRA (c) EDAX of LA

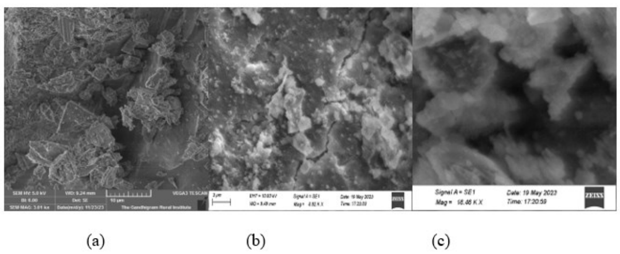


Figure 3. SEM image (a) LA (b) RA (c) CRA

2.2. *Carbonation treatment to RA*

The RA was initially pre-saturated to attain surface saturated density (SSD) and placed in a chamber connected to a 99.5% pure CO_2. The set up was placed under room temperature and at 60% R.H and CO_2 gas was supplied at a pressure of 0.3 MPa for 24 hours. After carbonation pressure, the RA were removed from the chamber and cooled under laboratory temperature. The surfaces of RA were washed to remove the scrambles of precipitate and used as CRA in the concrete. The set up for carbonation to RA is shown in the Figure 4.

Figure 4. Carbonation treatment to RA

2.3. *Preparation of samples*

The concrete mix was prepared to attain a target strength of M30 grade at 28 days (IS 10262 – 2009). The proportion of 1:1.93: 2.49 of cement, sand and aggregate with 0.45 w/c ratio was obtained and used throughout the study as shown in the Table 2. In this study, 8 different concrete mixes were prepared with 25%, 50% and 100% percentages of LA and RA and with 100% of CRA to assess the hardened concrete properties at 7, 14 and 28 days. The concrete mixes were prepared using conventional mixing technique and fabricated into cubes (150 mm on each side), cylinders (150 mm x 300 mm) and prisms (500 mm x 100 mm x 100 mm) under laboratory conditions. The samples were allowed to set for hardening and cured at room temperature for respective ages to assess their properties. For each mix, 3 samples were prepared to assess for each hardened property. To assess the thermal properties, cylinders (150 mm x 300 mm) were fabricated for four concrete mixes with 100% of NA, RA, LA and CRA and cured at room temperature for 30 days.

Table 2. Concrete mix proportions

Mix No	Mix detail	(Kg/m³)					
		Cement	FA	CA	RA	LA	CRA
M1	NC	413	799	1029	-	-	-
M2	RC-25	413	799	771.75	257.25	-	-
M3	RC-50	413	799	514.5	514.5	-	-
M4	RC-100	413	799	0	1029	-	-
M5	LC-25	413	799	771.75	-	257.25	-
M6	LC-50	413	799	514.5	-	514.5	-
M7	LC-100	413	799	-	-	1029	-
M8	CRC-100	413	799	-	-	-	1029

**NC – Normal concrete; RC – Recycled concrete; RC-25 – Recycled concrete with 25% of RA; RC-50 – Recycled concrete with 50% of RA; RC-100 – Recycled concrete with 100% of RA; LC-25 – Limestone concrete with 25% of LA; LC-50 – Limestone concrete with 50% of LA; LC-100 – Limestone concrete with 100% of LA and CRC-100 – Carbonated recycled concrete with 100% of CRA.*

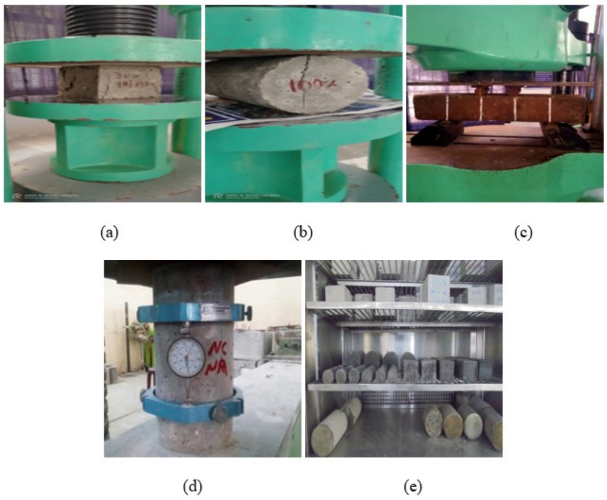


Figure 5. Experimental set up (a) CS (b) TS (c) FS (d) EM (e) Elevated temperature

2.4. *Testing of samples*

The concrete samples (cubes, cylinders and prisms) with different percentages of RA, LA and CRA were assessed for their hardened properties such as compression, tension, flexure and elastic modulus (Figure 5). The cubes were placed with the surface perpendicular to tamping and loaded axially in a 200T universal testing machine to assess the compressive strength (CS) as per ASTM C39. To assess the tensile strength (TS), the cylinders were placed transverse and loaded in UTM as per ASTM C1583. To assess the elastic modulus (EM) as per ASTM C496, 2 LVDT are affixed on either side of the sample and loaded at 0.2 MP/s wherein the stress and strain of the samples are determined. To assess the flexural strength (FS), prisms were loaded under three-point condition as per ASTMC78. To assess the behaviour at elevated temperature, the cylindrical samples were cured for 30 days and placed in oven attached with thermocouples and exposed to high temperatures of 200°C, 400°C and 800°C. The samples were then cooled at room temperature and the drop in CS, TS and EM were assessed. The thermal conductivity (TC) was evaluated with a conductivity meter wherein the samples were dried after curing in oven at 50°C and cooled down slowly. The surfaces of the specimen are wiped clean and 1V drop was supplied to the specimen to assess the thermal conductivity (Sarhat & Edward 2013).

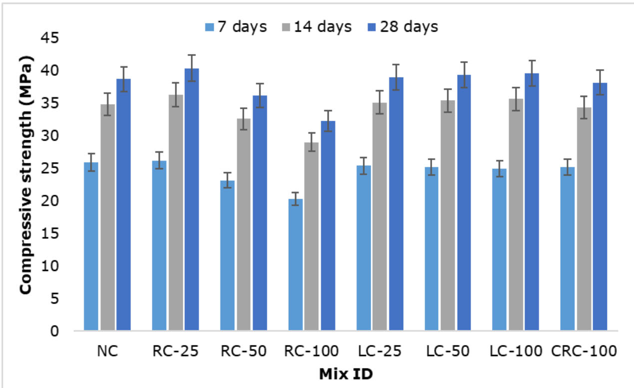


Figure 6. Compressive strength

3. Results and discussions

3.1. *Compressive strength*

Figure 6 shows the CS of the mixes. The RA was optimized to 25% past which lowers the strength of the RAC. The CS of RC-25 was 1.12% higher than NC at 7 days and 4.07% higher than NC at 28 days. The grading and better particle packing enhance the strength of RAC (Sivamani *et al.* 2023b, Jagan *et al.* 2021). However, the CS of RC-50 and RC-100 was lowered by 10.63% and 21.65% at 7 days and 6.44% and 16.67% at 28 days. The reduction in the CS of RAC was attributed to the attached mortar on RA with micro-voids that absorb more water than NA (Jagan *et al.* 2020, Kothari *et al.* 2016). So, carbonation treatment was done to RA and so enhancement in the CS of RAC was observed. The CS of CRC-100 was 20.59% and 15.55% higher than RC-100 at 7 days and 28 days and 2.79% lower at 7 days and 1.32% lower at 28 days than NC. The $CaCO_3$ deposition through the interaction amid $Ca(OH)_2$ and supplied CO_2 reduces the porosity of RA and thus better CS was observed (Malathy *et al.* 2023, Sivamani *et al.* 2023a). However, the mechanism is different with the LA compared to RA. There was no reduction in the CS of the concrete, but the enhancement was very marginal. The CS of LC-25, LC-50 and LC-100 was 0.87%, 1.58% and 2.30% higher than NC at 28 days, while the CS of LC-25, LC-50 and LC-100 was lowered by 2.13%, 2.94% and 3.75% at 7 days. The initial strength gain with LA was less compared to NA owing to its low-density characteristics. The marginal gain in the CS at 28 days was ascribed to the development of nucleation sites for $Ca(OH)_2$ and C-S-H formation and quicken the hydration of C_3S and also the formation of carbo-aluminates through the interaction between LA and C_3A (Li *et al.* 2009, Bonavetti *et al.* 2001).

3.2. Tensile strength

Figure 7 shows the TS of the mixes. Similar to CS, no improvement in TS was observed beyond 25% replacement of RA. The TS of RC-25 was 0.92% higher than NC at 7 days and 1.64% higher than NC at 28 days. Conversely, the TS of RC-50 and RC-100 was 6.92% and 12.50% lower than NC at 7 days and 2.62% and 7.03% lower than NC at 28 days. The justification for variation in the TS of RAC was equivalent to that of CS, however the percentage reduction in TS was less compared to CS. The carbonation treatment to RA tends to enhance the TS of RAC also. The TS of CRC-100 was 12.03% and 6.53% higher than RC-100 at 7 days and 28 days, while the TS of CRC-100 was lowered by only 1.93% and 0.53% at 7 days and 28 days compared to NC. Similar to CS, the TS of LAC also tend to improve marginally at 28 days. The TS of LC-25, LC-50 and LC-100 was 1.97%, 2.80% and 4.68% higher than NC at 28 days. However, the TS of LC-25, LC-50 and LC-100 was 0.98%, 1.25% and 1.65% lower than NC at 7 days. The hydration of C_3S and the formation of carbo-aluminates characterize the enhancement in the TS of the concrete (Singh *et al.* 2021, Tanijaya *et al.* 2021).

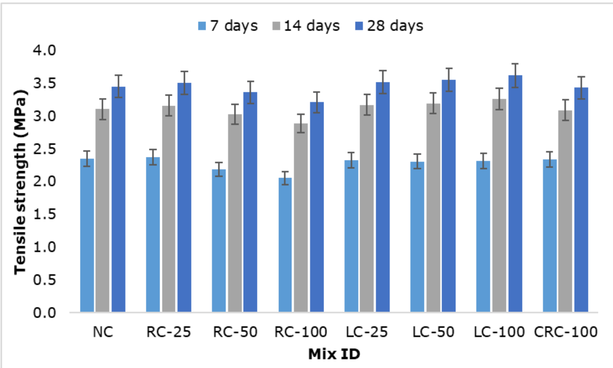


Figure 7. Tensile strength

3.3. Flexural strength

Figure 8 shows the FS of the mixes. Similar to CS &TS, no improvement in FS was observed beyond 25% replacement of RA. The FS of RC-25 was 0.56% higher than NC at 7 days and 2.50% higher than NC at 28 days. Conversely, the FS of RC-50 and RC-100 was 5.46% and 11.48% lower than NC at 7 days and 3.98% and 10.52% lower than NC at 28 days. The carbonation treatment to RA tend to enhance the FS of RAC also. The FS of CRC-100 was 10.21% and 9.80% higher than RC-100 at 7 days and 28 days, while the FS of CRC-100 was lowered by only 1.41% and 0.81% at 7 days and 28 days compared to NC. The FS of LC-25, LC-50 and LC-100 was 0.53%, 0.97% and 1.41% higher than NC at 28 days. However, the FS of LC-25, LC-50 and LC-100 was 13.89%, 14.81% and 15.72% lower than NC at 7 days. The effect of LS on FS is on filler and dilution phenomenon and thus shows enhancement in the FS of the concrete. The hydration of C_3S and the formation of carbo-aluminates also characterize the enhancement in the FS of the concrete (Bentz *et al.* 2015, Varga *et al.* 2010).

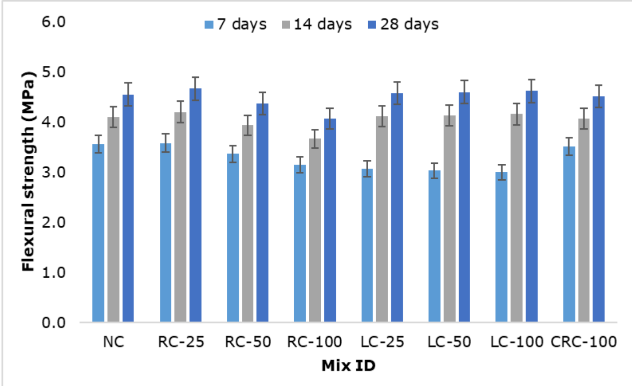


Figure 8. Flexural strength

3.4. Elastic modulus

Figure 9 shows the EM of the mixes. The EM of RC-25 was 1.34% higher than NC at 7 days and 2.74% higher than NC at 28 days. The stiffness of the aggregates is highly dependent on the EM of the concrete and thus enhancement was observed with marginal replacement of RA. However, the EM of RC-50 and RC-100 was 7.48% and 14.07% lower than NC at 7 days and 3.27% and 8.71% lower than NC at 28 days. The carbonation treatment to RA tends to enhance the EM of RAC also. The EM of CRC-100 was 13.43% and 8.10% higher than RC-100 at 7 days and 28 days, while the EM of CRC-100 was lowered by only 0.93% and 0.66% at 7 days and 28 days compared to NC. The carbonation treatment to RA coats the micro-voids in the smeared mortar, enhancing the stiffness of the RA and thus improvement in the EM was observed. The EM of LC-25, LC-50 and LC-100 was enhanced by 2.72%, 4.37% and 6.59% compared to NC at 28 days. The addition of LS blocks the voids and enhances the packing density of the LAC (Wang *et al.* 2018)

3.5. Effect of elevated temperature on the properties of concrete

Figure 10 shows the variation in the CS of the concrete at elevated temperatures. It was observed that the CS was lowered with increase in the temperature and the percentage variation in RAC and LAC was lower compared to NAC and CRAC. The residual temperature was observed between 200 to 400°C for RAC. The CS for NAC was lowered by 19.10%, 30.09% and 63.93% at 200°C, 400°C and 800°C. At 100°C, excess water starts evaporating and between 100 to 170°C, desiccation of ettringite and disintegration of gypsum °Ccurs and beyond 300°C, bond water evaporates resulting in lowering of CS. Beyond 400°C, disintegration of C-S-H and CH occurs resulting in maximum strength loss. The CS of RAC was lowered by 15.84%, 7.76% and 48.46%.The reduction in CS tends to increase till 200°C, decreases in the range between 200 to 400°C and further increases beyond 400°C indicating its residual temperature between 200 to 400°C. The equivalency in the coefficient of thermal expansion between smeared mortar on RA and new cement paste exhibits better thermal characteristics than NAC (Sarhat *et al.* 2013, Salahuddin *et al.* 2019, Sivamani *et al.* 2023a). The carbonation treatment to RA could not show any substantial enhancement in thermal characteristics. The CS of CRAC was lowered by 19.30%, 29.61% and 62.38% at 200°C, 400°C and 800°C. The coating of adhered mortar with $CaCO_3$ decreases the equivalency in thermal expansion between adhered mortar and new cement paste and thus no substantial enhancement in thermal characteristics was observed. The CS of LAC was lowered by 11.05%, 2.35% and 45.91% at 200°C, 400°C and 800°C. Similar to RAC, for LAC also reduction in CS tends to increase till 200°C, decreases in the range between 200 to 400°C and further increases beyond 400°C indicating its residual temperature between 200 to 400°C.

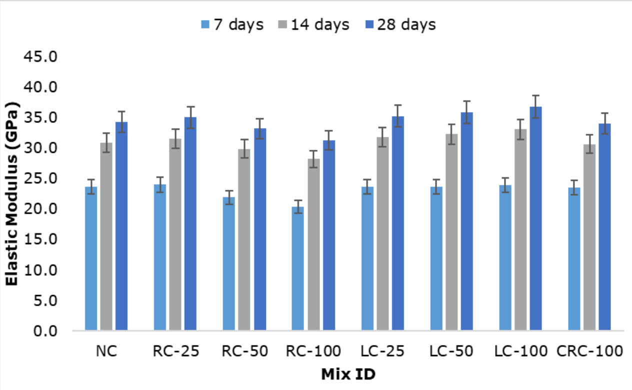


Figure 9. Elastic Modulus

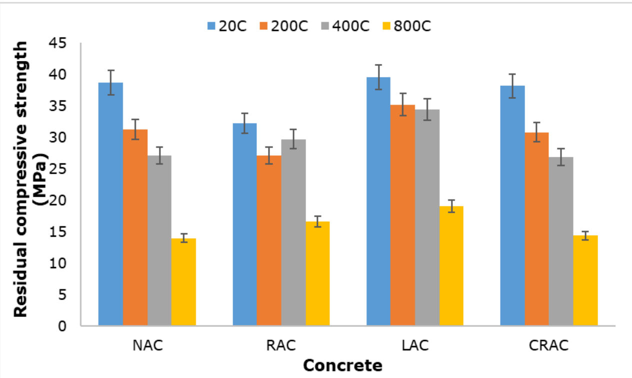


Figure 10. Variation in CS upon elevated temperature

Figure 11 shows the variation in the TS of the concrete at elevated temperature. The TS for NAC was lowered by 27.83%, 38.27% and 65.80% at 200°C, 400°C and 800°C. The TS of RAC was lowered by 20.18%, 12.08% and 56.04%. Similar to CS, the reduction in TS tends to increase till 200°C, decreases in the range between 200 to 400°C and further increases beyond 400°C indicating its residual temperature between 200 to 400°C. The TS of CRAC was lowered by 9.67%, 15.21% and 34.44% at 200°C, 400°C and 800°C. The $CaCO_3$ deposition of RA upon carbonation treatment reduces the thermal equivalency of adhered mortar on RA with new mortar. The residual temperature is varying in case of TS, wherein the TS of LAC was lowered by 22.09%, 26.24% and 58.01% at 200°C, 400°C and 800°C.

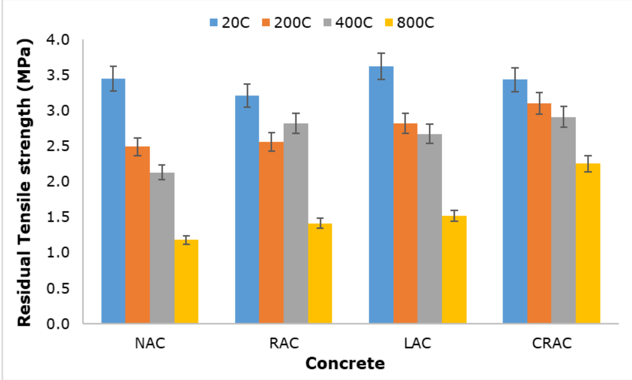


Figure 11. Variation in TS upon elevated temperature

Figure 12 shows the variation in the EM of the concrete at elevated temperatures. The EM for NAC was lowered by 34.24%, 74.14% and 92.01% at 200°C, 400°C and 800°C. The EM of RAC was lowered by 37.05%, 66.02% and 88.62%. The EM of CRAC was lowered by 37.70%, 79.07% and 92.34% at 200°C, 400°C and 800°C. The EM of LAC was lowered by 26.87%, 61.14% and 85.86% at 200°C, 400°C and 800°C. The reduction in EM was lower in LAC than RAC and CRAC.

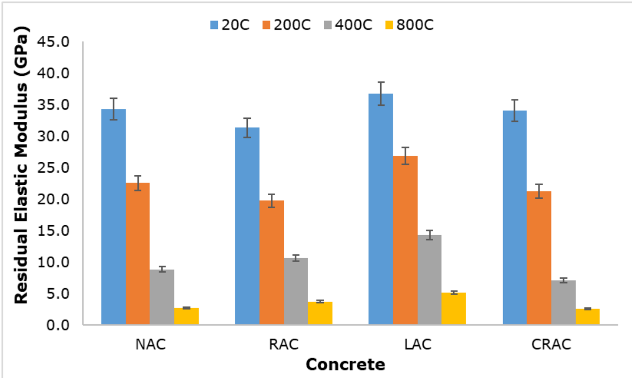


Figure 12. Variation in EM upon elevated temperature

3.6. *Thermal conductivity*

Figure 13 shows the TC of the concrete. The TC of NAC was lowered by 21.97%, 34.12% and 69.68% at 200°C, 400°C and 800°C. The TC of RAC was lowered by 18.28%, 9.03% and 53.95% at 200°C, 400°C and 800°C. The TC of LAC was lowered by 12.81%, 15.21% and 57.52% at 200°C, 400°C and 800°C and the TC of CRAC was lowered by 22.20%, 33.70% and 68.14% at 200°C, 400°C and 800°C. The LAC has the highest resistance to elevated temperatures compared to RAC and CRCA. Generally, concrete is a heterogenous mix, subjecting concrete to elevated temperatures involves desiccation and disintegration of cement paste, deprivation of aggregates due to variations in the thermal expansion of various concrete ingredients. For all the aggregates, the disintegration of cement paste remains same for all mixes and so the variation in thermal expansion might have arisen due to the deprivation of aggregates. Thermal expansion is the volumetric change of material owing to temperature variation and it is prime as it results in stresses, cracks and spalling. The factors that influence thermal expansion include nature of aggregate, cementitious material, temperature, humidity etc. and among them, the nature of aggregate tend to have to major influence on thermal expansion. The thermal expansion reduces with increase in the porosity of aggregate and thus concrete with lower density show better resistance to thermal variation than conventional aggregate (Uygunoglu & Topcu 2012). Till 150°C, cement paste expands with temperature rise and beyond 150°C, cement paste expands owing to the desiccation of $Ca(OH)_2$ and C-S-H. Since the density of LA was less compared to NA, LA show better resistance to thermal expansion, whereas NA show maximum thermal expansion as the quartz in NA expand more upon temperature rise. Thus, according to experimentation, it was observed that higher degradation was observed in NAC owing to the higher silica content resulting in inner cracks and thus maximum strength loss was observed at elevated temperature.

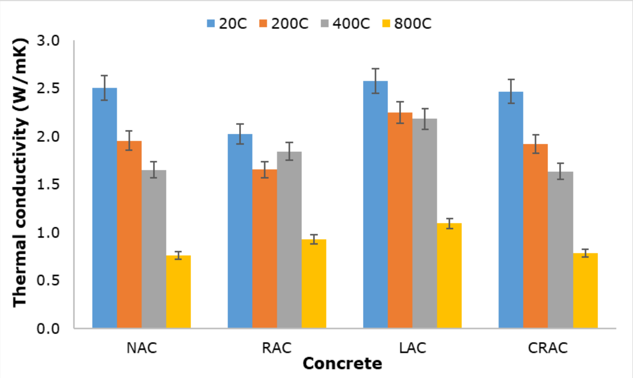


Figure 13. Thermal conductivity

4. Conclusions

In this research, influence of NA, RA, LA and CRA on concrete properties at elevated temperatures were discussed. Based on the test results, the subsequent conclusions are as follows:

a. The specific gravity and density of LA and RA was lower compared to NA and CRA and the water absorption of RA was found to be higher compared to other aggregates.

b. At room temperature, the strength of NAC was 38.68 MPa and the strength of RAC was lowered by 16.67%, while the strength of CRAC was lowered by only 1.32% and the strength of LAC was 2.38% higher than NAC. The properties of aggregates influence the hardened properties of the concrete.

c. The residual temperature of RAC was observed to be between 200 to 400°C, while no such residual temperature was observed in LAC but the percentage of strength reduction was minimal in LAC compared to others.

d. The strength for NAC was lowered by 19.10%, 30.09% and 63.93%, the strength of RAC was lowered by 15.84%, 7.76% and 48.46%, the strength of CRAC was lowered by 19.30%, 29.61% and 62.38 and the strength of LAC was lowered by 11.05%, 2.35% and 45.91% at 200°C, 400°C and 800°C.

e. The thermal conductivity of NAC was lowered by 21.97%, 34.12% and 69.68%, the thermal conductivity of RAC was lowered by, the thermal conductivity of CRAC was lowered by 18.28%, 9.03% and 53.95% and the thermal conductivity of LAC was lowered by 22.20%, 33.70% and 68.14% at 200°C, 400°C and 800°C.

f. Deprivation of aggregates was the prime reason for reduction in the concrete properties at elevated temperature. The higher quartz in conventional aggregate shows higher thermal expansion and thus resulting in disintegration of Ca $(OH)_2$ and C-S-H. The higher porosity and low density of aggregates show relatively lower thermal expansion as in case of RA and LA and also the equivalency in thermal expansion between mortar on RA and new mortar show better thermal resistance.

Conflicts of Interest

The authors have declared no conflict of interest

Data availability statement

The data that support the findings of this study are available within the study and can be collected from the corresponding author upon request.

References

Ahmed I., Rohith Renish R., Karthik K. and Karthik M. (2017). Experimental investigation of polymer matrix composite for heat distortion temperature test, *International Journal of Mechanical Engineering and Technology*, **8**, 520–528.

Arunkumar G.E., Nirmalkumar K., Loganathan P. and Sampathkumar V (2023). Concrete constructed with recycled water to experimental analysis of the physical behavior of polypropylene aggregate (PPA), *Global NEST Journal*, **25**, 126–135.

ASTM International. (2018). Standard Test Method for Compressive Strength of Concrete. ASTM C39 / C39M-18. West Conshohocken, PA.

ASTM International. (2018). Standard Test Method for elastic modulus of Concrete. ASTM C496. West Conshohocken, PA.

ASTM International. (2018). Standard Test Method for Flexural Strength of Concrete. ASTM C78. West Conshohocken, PA.

ASTM International. (2018). Standard Test Method for splitting tensile strength of Concrete. ASTM C1583. West Conshohocken, PA.

Bederina M., Makhloufi Z. and Bouziani T. (2011). Effect of limestone fillers the physic-mechanical properties of limestone concrete, *Physics Procedia*, **21**, 28–34.

Bentz D.P., Ardani A., Barrett T., Jones S.Z., Lootens D., Peltz M.A., Sato T., Stutzman P.E., Tanesi J. and Weiss W.J. (2015). Multi-scale investigation of the performance of limestone in concrete, *Construction and Building Materials*, **75**, 1–10.

Bonavetti V.L., Rahhal V.F. and Irassar E.F. (2001). Studies on the carboaluminate formation in limestone filler-blended cements, *Cement and Concrete Research*, **31**, 853–859.

Salahuddin H., Nawaz A., Maqsoom A., Mehmood T. and Zeeshan B. (2019). Effects of elevated temperature on performance of recycled coarse aggregate concrete, *Construction and Building Materials*, **202**, 415–425.

Carlos A., Masumi I., Hiroaki M., Maki M. and Takahisa O. (2010). The effects of limestone aggregate on concrete properties, *Construction and Building Materials*, **24**, 2363–2369.

Chen W., Peng L. and Yang H. (2021). Fracture behaviors of concrete incorporating different levels of recycled coarse aggregate after exposure to elevated temperatures, *Journal of Building Engineering*, **35**, 102040.

Fayaz H., Karthik K., Christiyan K.G., Arun Kumar M., Sivakumar A., Kaliappan S., Mohamed M., Subbiah R. and Yishak S. (2022). An Investigation on the Activation Energy and Thermal Degradation of Biocomposites of Jute/Bagasse/Coir/Nano-TiO_2/Epoxy-Reinforced Polyaramid Fibers, *Journal of Nanomaterials*, 3758212.

Hamada H.M., Shi J., Abed F., Al Jawahery M.S., Majdi A. and Yosif S.T. (2023). Recycling solid waste to produce eco-friendly ultra-high-performance concrete: A review of durability, microstructure and environment characteristics, *Science of the Total Environment*, **876**, 162804.

Jagan S. and Neelakantan T.R. (2023). Mechanical properties of the concrete with recycled coarse aggregate surface treated by microbes, *World Journal of Engineering*, **20**, 359–367.

Jagan S., Neelakantan T.R. and Saravanakumar P. (2021). Mechanical properties of recycled aggregate concrete treated by variation in mixing approaches, *Revista de la construccion*, **20**, 236–248.

Jagan S., Neelakantan T.R. and Saravanakumar P. (2022b). Enhancement on the properties of recycled coarse aggregate through bio-deposition – An experimental study, *Materials Today Proceedings*, **49**, 1141–1147.

Jagan S., Neelakantan T.R., Lakshmikantha Reddy. and Gokul Kannan R. (2020). Characterization study on recycled coarse aggregate for its utilization in concrete – A review, *Journal of Physics: Conference Series*, **1706**, 012120.

Karthik K., Udaya Prakash J., Binoj J.S. and Mansingh B.B. (2022). Effect of stacking sequence and silicon carbide nanoparticles on properties of carbon/glass/Kevlar fiber reinforced hybrid polymer composites, *Polymer composites*, **43**, 1–10.

Karthikeyan S., Neelakantan T.R. and Jagan S. (2023). Microbial technique to treat recycled aggregates from construction waste for its effective reutilization in concrete, *Global NEST Journal*, **25**, 1–8.

Kothari B.R. and Abhay S. (2016). Experimental Investigation of Recycle Concrete Aggregate, *International Journal for Innovative Research in Science & Technology*, **3**, 511–515.

Li B., Wang J. and Zhou M. (2009). Effect of limestone fines content in manufactured sand on durability of low- and high-strength concretes, *Construction and Building Materials*, **23**, 2846–2850.

Liu B., Qin J., Shi J., Jiang J., Wu Xi. and He Z. (2021). New perspectives on utilization of CO2 sequestration technologies in cement-based materials, *Construction and Building Materials*, **272**, 121660.

Malathy R., Sivamani J. and Karuppasamy N. (2023). Performance studies on recycled aggregate concrete with treated recycled aggregates, *Waste Disposal and Sustainable Energy*, **5**, 451–459.

Mavroulidou M. and Figueiredo J. (2010). Discarded tyre rubber as concrete aggregate: A possible outlet for used tyres, *Global NEST Journal*, **12**, 359–367.

Murali B., Karthik K., Marotrao S.S., Laxmaiah G., Yadav A.S., Prasanth I.S.N.V.R. and Abbas M. (2023). Mechanical and dynamic mechanical properties of hybrid kevlar/natural fiber composites, *Materials Research Express*, **10**, 105305.

Ramesh V., Karthik K., Arunkumar K., Unnam N.K., Ganesh R. and Rajkumar C. (2023a). Effect of sawdust filler with Kevlar/basalt fiber on the mechanical properties epoxy–based polymer composite materials, *Materials Today: Proceedings*, **72**, 2225–2230.

Ramesh V., Karthik K., Cep R. and Elangovan M. (2023b). Influence of Stacking Sequence on Mechanical Properties of Basalt/Ramie Biodegradable Hybrid Polymer Composites. *Polymers*, **15**, 985.

Saravanakumar P., Manoj D. and Jagan S (2021). Properties of concrete having treated recycled coarse aggregate and slag, *Revista de la construccion*, **20**, 249–258.

Sarhat S.R. and Edward G.S. (2013). Residual Mechanical Response of Recycled Aggregate Concrete after Exposure to Elevated Temperatures, *ASCE Journal of Materials in Civil Engineering*, **25**, 1721–1730.

Savva A., Manita P. and Sideris K.K. (2005). Influence of elevated temperatures on the mechanical properties of blended cement concretes prepared with limestone and siliceous aggregates, *Cement and Concrete Composites*, **27**, 239–248.

Singh J., Mukherjee A., Dhiman V.K. and Deepmala. (2021). Impact of crushed limestone dust on concrete's properties, Materials Today Proceedings, 43, 341–347.

Sivamani J., Neelakantan T.R., Saravanakumar P., Mugesh Kanna C., Harish H.V. and Akash M.R. (2021). Efficient Utilization of Recycled Concrete Aggregates for Structural Applications—An Experimental Study, *Lecture Notes in Civil Engineering*, **97**, 567–579.

Sivamani J. (2022b). Sustainable Utilization of Dumped Concrete Wastes as Fine Aggregates in Concrete – An Experimental Study, *International Journal of Engineering*, **35**, 1795–1802.

Sivamani J. and Kamaleshwar S. (2022). Review on Impact of Construction Waste Landfill on Environment and its Reutilization, *Ecological Engineering and Environmental Technology*, **23**, 233–242.

Sivamani J. and Neelakantan T.R. (2022a). Effect of fine recycled aggregate on the strength and durability properties of concrete modified through two-stage mixing approach, *Environmental Science and Pollution Research*, **29**, 85869–85882.

Sivamani J. and Thiyaneswaran P. (2023a). Thermal studies on recycled aggregate concrete modified with carbonated and bio-deposited recycled aggregates, *Engineering and Applied Science Research*, **50**, 468–477.

Sivamani J., Neelakantan T.R. and Saravanakumar P. (2021a). Enhancing the quality of recycled coarse aggregates by different treatment techniques—a review, *Environmental Science and Pollution Research*, **28**, 60346–60365.

Sivamani J., Thiyaneswaran M.P. and Navaneethan K.S. (2023b). Performance Studies on Glass Fiber Reinforced Recycled Aggregate Concrete, *International Journal of Engineering (Transactions B: Applications)*, **36**, 904–913.

Statista. Production volume of limestone in India from financial year 2012 to 2023, https://www.statista.com

Tanijaya J., Tappi S. and Jabair. (2021). The mechanical properties of limestone as an aggregate on high strength concrete, *IOP conference series: Materials Science and Engineering*, **1088**, Article no. 012098.

Tufail M., Shahzada K., Gencturk B. and Wei J. (2017). Effect of Elevated Temperature on Mechanical Properties of Limestone, Quartzite and Granite Concrete, *International Journal of Concrete Structures and Materials*, **11**, 17–28.

Uygunoglu T. and Topcu I.B. (2012). Effect of aggregate type on linear thermal expansion of self-consolidating concrete at elevated temperatures. *Science and Engineering of Composite Materials*, **19**, 259.

Varga C.S., Miskolczi N., Bartha L. and Palotas L. (2010). Modification of the mechanical properties of rubbers by introducing recycled rubber into the original mixture, *Global NEST Journal*, **12**, 352–358.

Wastewise, Construction and Demolition Waste in India, 2023, https://wastewise.be/

Yasar E., Erdogan Y. and Kilic A (2004). Effect of limestone aggregate type and water–cement ratio on concrete strength, *Materials Letters*, **58**, 772–777.