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Strength-maturity correlation models for recycled aggregate concrete using Plowman's coefficient

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Abstract

Predicting the early age strength of concrete is critical in construction and structural part fabrication. Concrete's strength development is critical in the safe and cost-effective scheduling of important operations like form removal and reshoring, post-tensioning, in-process transportation, and speedy delivery of goods. The concrete maturity approach is a quality control/assurance tool that can help contractors and transportation administrators create cost-effective, long-lasting concrete structures. This study investigates the use of normal aggregate concrete (NAC) and recycled aggregate concrete (RAC) strength made with a cement content of 300 kg/m³, 350 kg/m³, 400 kg/m³, 450 kg/m³ with varying water-to-cement ratio (w/c) and super plasticizer (SP) in estimating the maturity index by attaining strength-maturity relationship models by Plowman method. The obtained results indicated a good correlation between 0.994 to 0.999 for normal aggregate concrete and 0.993 to 0.999 for recycled aggregate concrete. The approach has been demonstrated to be a simple tool for estimating strength development, speeding up construction activities, and documenting contractor errors.

Keywords Maturity index · Recycled aggregate concrete · Strength-maturity relation,·Prediction models

Abbreviations

RAC	Recycled aggregate concrete
W/C	Water-to-cement ratio
CC	Cement content
SP	Super plasticizer
NAC	Natural aggregate concrete
CSC	Compressive strength of concrete
ASTM	American Society for Testing and Materials
TTF	Time temperature factor
IS	Indian Standard

Introduction

In recent decades, many specialists have researched the endurance of reinforced concrete structures particularly in corrosive environments, and most have determined that strength alone cannot provide all of concrete's needed attributes, particularly its durability. In addition to the strength and load-bearing needs during operation, the dependability and durability of concrete should be considered while developing it for various purposes. The usage of lightweight natural and artificial materials is considered an efficient approach for reducing the structure's dimensions and minimizing the seismic stress acting on the concrete, resulting in faster construction and lower costs (Khoshvatan and Pouraminian 2021). The demolition of existing houses and buildings has increased the volume of non-biodegradable waste in landfills (Shamili and Karthikeyan 2021). While most of the roads, water systems, bridges, and sewers built over 60 years ago are rapidly degrading, the world's population continues to rise at an exponential rate, increasing the demand for drinkable water and transportation. "As Americans tear up roads and demolish buildings, they generate significant amounts of demolition waste, resulting in about 200 million tonnes (metric tonnes) of recycled aggregates per year." (Wilburn and Goonan 1998). Recycling has the potential to (i) extend the availability of natural resources by augmenting resource supplies, (ii) reduce environmental disturbance surrounding construction sites, and (iii) promote the long-term development of our natural resources (Wilburn and Goonan 1998). The extensive use of recycled aggregates could be a smart and well-thought-out way to address those challenges as

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Table 1 Compressive strength of RAC and NAC mixes from various literature

No	Name of researcher	Material Proportion (%)	W/C	Compressive strength (MPa)
1	Rahal (2007)	100R + 0N	0.65	20.3
		100R + 0N	0.5	29.2
		100R + 0N	0.48	32.2
		100R + 0N	0.43	39.4
		100R + 0N	0.4	46.5
		0R + 100N	0.65	22.7
		0R + 100N	0.5	32.3
		0R + 100N	0.48	36
		0R + 100N	0.43	46
		0R + 100N	0.4	53.5
2	Tu et al. (2006)	100R + 0N	0.32	32
		100R + 0N	0.36	27
		100R + 0N	0.4	28
3	Kou et al. (2007)	100R + 0N	0.55	38.1
		0R + 100N	0.45	42

indicated (Marinković et al. 2010). This study identifies the difficulties and explores prospects related to the usage of recycled aggregate concrete and high-volume fly ash in Portland cement concrete. In addition, to the impacts of placement, compaction, or curing, 28-day cube test results have been used in construction for years to estimate the compressive strength of concrete (CSC). For evaluating the CSC in structures, nondestructive in-place test methods have been devised. These tests are necessary for an accurate representation of concrete element in-place strength. The maturity approach is one way to assess in-place concrete strength growth. This technique is based on the temperature data of concrete during the curing period. The maturity method is used to calculate the cumulative influence of time and temperature on concrete strength progression, as stated in ASTM C1074 (2019). The two maturity measures mentioned in ASTM C1074 (2019) are the TTF for the Nurse-Saul maturity function and the "Equivalent Age" for the Arrhenius maturity function. In the Nurse-Saul maturity model, the rate of strength gain is considered to be a linear function of temperature. When curing temperatures changed substantially during the curing period, it was discovered to be unsuccessful, leading to the invention of the Arrhenius maturity function (Soutsos et al. 2018). In the literature on cement concrete's maturity, there are various research on the prediction of early-age strength using a modified maturity model by Carino et al. (1983), Benaicha et al. (2016), Waller et al. (2004), Liao et al. (2008), as well as multiple studies employing a modified maturity model to predict late-age strength by Topçu and Toprak (2007), Kjellsen and Detwiler (1993). Jin et al. (2017) used the maturity method in predicting the compressive strength of vinyl ester polymer concrete at an early age by introducing an appropriate scaled down factor (n) of 0.3 and found that the maturity method is useful for quality control of vinyl ester polymer concrete and
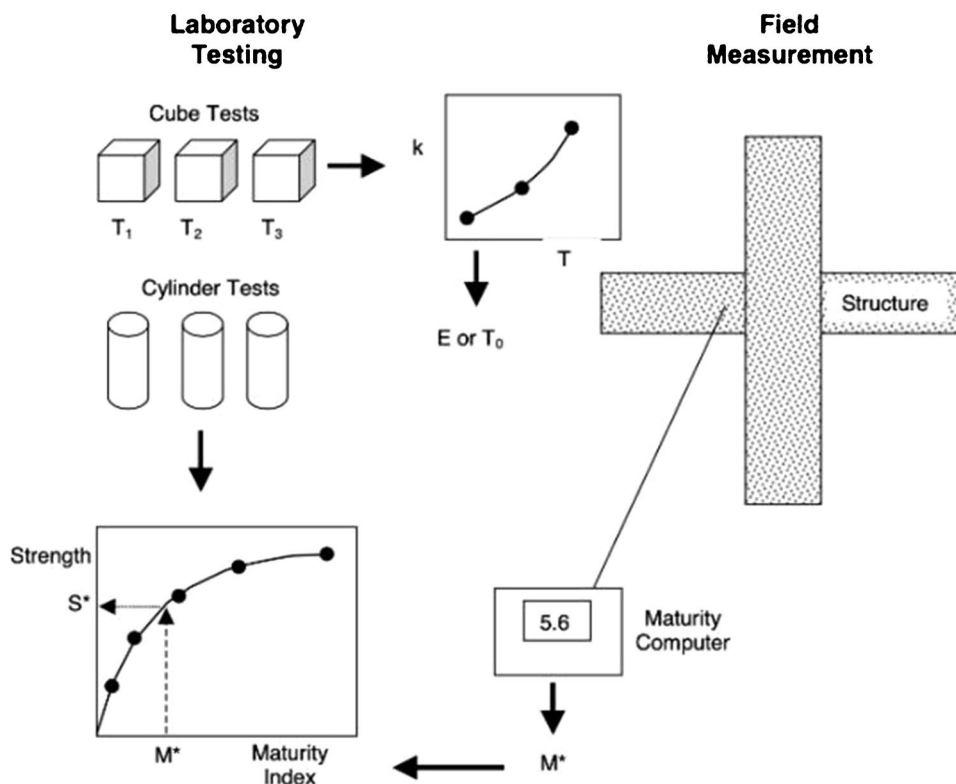
Fig. 1 Experimental procedure

Table 2 Mix proportions

Mix. no	Material Proportion (%)	Cement content (kg/m^3)	W/C	SP (%)	Fine aggregate (kg/m^3)	Natural coarse aggregate (kg/m^3)	Recycled coarse aggregate (kg/m^3)	Slump (mm)	Water content (kg/m^3)
Mix 1	100R + 0N	300	0.35	1.5	627.79	0	1195.89	0	214.926
Mix 2	0R + 100N	300	0.35	1.5	627.79	1313.84	0	25	195.87
Mix 3	100R + 0N	300	0.45	0	619.44	0	1290.32	50	186.49
Mix 4	0R + 100N	300	0.45	0	619.44	1416.88	0	70	165.93
Mix 5	100R + 0N	300	0.55	0	631.37	0	1202	50	195.63
Mix 6	0R + 100N	300	0.55	0	631.37	1320.99	0	80	196
Mix 7	100R + 0N	350	0.4	1.5	552.86	0	1207.78	100	220.07
Mix 8	0R + 100N	350	0.4	1.5	552.86	1323.986	0	130	202.824
Mix 9	100R + 0N	350	0.5	0	591.59	0	1177.951	60	223.079
Mix 10	0R + 100N	350	0.5	0	591.59	204.32	0	80	1294.13
Mix 11	100R + 0N	350	0.35	1.5	575.904	0	1207.78	40	220.07
Mix 12	0R + 100N	350	0.35	1.5	575.904	1323.98	0	65	202.824
Mix 13	100R + 0N	400	0.48	0	557.729	0	1130.564	90	237.734
Mix 14	0R + 100N	400	0.48	0	557.729	1242.08	0	160	219.718
Mix 15	100R + 0N	400	0.4	0	556.157	0	1290.32	75	207.295
Mix 16	0R + 100N	400	0.4	0	556.157	1331.838	0	110	187.985
Mix 17	100R + 0N	400	0.3	1.5	546.884	0	1308.92	65	151.235
Mix 18	0R + 100N	400	0.3	1.5	546.884	1138.01	0	80	147.981
Mix 19	100R + 0N	450	0.45	0	525.96	0	1095.1	150	246.2
Mix 20	0R + 100N	450	0.45	0	525.96	1204.5	0	190	228.77
Mix 21	100R + 0N	450	0.35	0.3	527.47	0	1203.4	90	203.36
Mix 22	0R + 100N	450	0.35	0.3	527.47	1323.6	0	100	184.26
Mix 23	100R + 0N	450	0.3	1.5	523.53	0	1252.4	90	181.72
Mix 24	0R + 100N	450	0.3	1.5	523.53	1377.5	0	100	161.79

nondestructive prediction of early age strength. Research has been done on predicting the setting time of concrete using maturity approaches Han and Han (2010), Pinto and Hover (1999). Studies to evaluate mass concrete's compressive strength using maturity approaches (Yikici and Chen 2015) and the fracture properties of dam concrete cast on-site (Guan et al. 2016) have been done. In addition, research based on ASTM C1074 (2019), the study Wade et al. (2006) conducted to evaluate the maturity approach for estimating concrete strength. RAC has attracted many researchers to study its performance. Previous researchers have conducted study on the application of recycled coarse aggregates (RCA) and found that recycled aggregate concrete (RAC) has lower compressive strength compared to natural aggregate concrete (NAC) (Ismail et al. 2007). In general, some of the treatment methods are thermal, chemical process, and mechanical scrubbing which may significantly weaken the residual mortar (Revathi et al. 2015). Hence, this work considers RCA with adhered mortar. Table 1 shows the compressive strength results of RAC and NAC mixes from previous studies.

Research significance

Some of the machine learning techniques and maturity techniques were used so far to predict concrete compressive strength. However, no attempts or models were made to estimate the maturity index for recycled concrete compressive strength. Given the immense field of knowledge on assessing the maturity of cement concrete, it is hard to identify studies that are appropriate to RAC. The goal of this study is to determine the maturity index by attaining strength-maturity relationship models for different cement content with varying w/c.

Maturity models

Concrete maturity study includes both estimating a maturity index and predicting strength based on a maturity index. Here is a summary of what has been revealed so far.
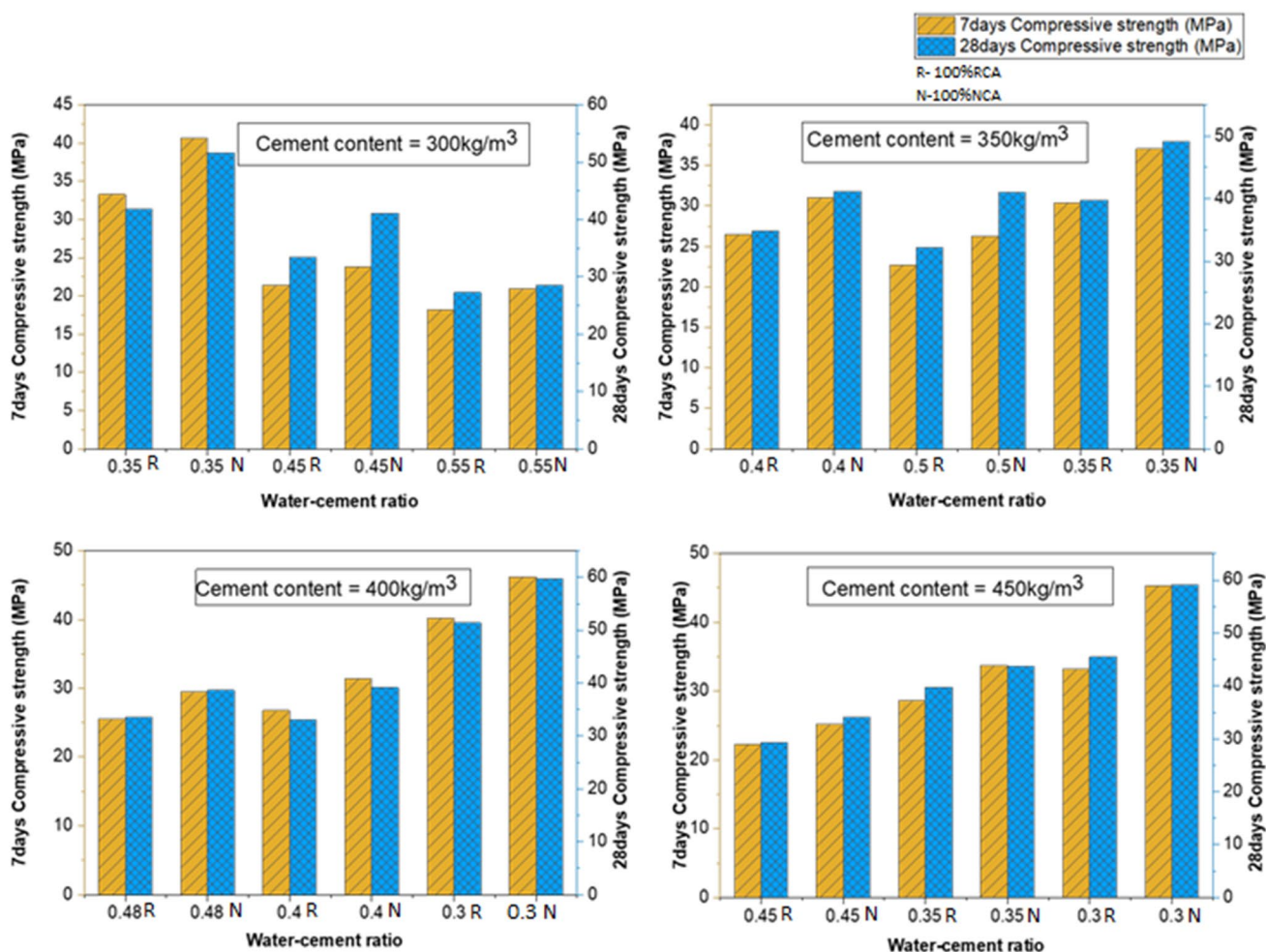
Fig. 2 Average compressive strength results with different cement content for RAC and NAC mixes respectively

Maturity estimation model

Carino and Lew (2001) stated that the maturity function is linked to the temperature sensitivity of early strength growth, and no single maturity function fits all concrete combinations. By measuring the fluctuations of the rate constant with the curing temperature, the suitable maturity function for a given concrete is determined. Soutsos et al. (2018) developed maturity techniques in the 1950s to determine the effects of steam curing temperature on concrete strength increase. These approaches were created to take into account the combined effects of time and temperature on the strength development of concrete. These principles were used to create the Nurse-Saul maturity function and it is shown in below Eq. (1).

$$M = \sum (T - T_0) \times \Delta t \tag{1}$$

M maturity index

T average temperature

T_0 datum temperature

Δt time interval

The equivalent age maturity function, first proposed by Rastrup (1954) and represented in Eq. (2), is regarded as nearly equal in terms of comfort in Eq. (1). Hansen and Pedersen (1977) derived an equal age maturity function as shown in Eq. (3).

$$t_e = \frac{\sum (T - T_0)}{(T_r - T_0)} \tag{2}$$

$$t_e = \sum e^{(-E/E)[1/T - 1/T_r]} \times \Delta t \tag{3}$$

Table 3 Plowman's coefficient for maturity equations

Strength after 28 days at 18 °C (maturity of 19.800°Ch): MPa	Coefficient	
	A	B
Less than 17.5	10	68
17.5–35.0	21	61
35.0–52.5	32	54
52.5–70.0	42	46.5

t_e　equivalent age

E　activation energy

R　universal gas constant

T_r　reference temperature

Equation (4), proposed by Carino et al. (1983), can be used to estimate an equivalent age at the reference temperature. Although this is a simplified version of the above Eq. (3), the ages computed are identical.

$$t_e = \sum e^{B(T-T_r)} \times \Delta t \tag{4}$$

B　temperature sensitivity factor

T　average temperature

T_r　reference temperature

Strength prediction model

The strength prediction model is just as crucial as the maturity index because even if the maturity index is calculated correctly, nothing else matters if the strength prediction is incorrect. Using the data, a better smooth curve for an appropriate strength-maturity relationship is constructed, or regression analysis, as recommended by Carino et al. (1983). The logarithmic equation by Carino et al. (1983) is one of the most widely used strength-maturity connections. Plowman (1956) correctly identified the strength-to-maturity link in 1956. Plowman (1956) tried to prove a correlation between concrete strength and maturity. The concrete cube specimens were exposed to temperatures ranging from 11.5 to +18 °C after being exposed to conventional curing for 24 h. The Nurse-Saul method was created on the idea that it will follow a linear model while representing strength with a logarithmic maturity function. This equation is well-known because it is simple, but it, too, has a flaw Carino et al. (1983).

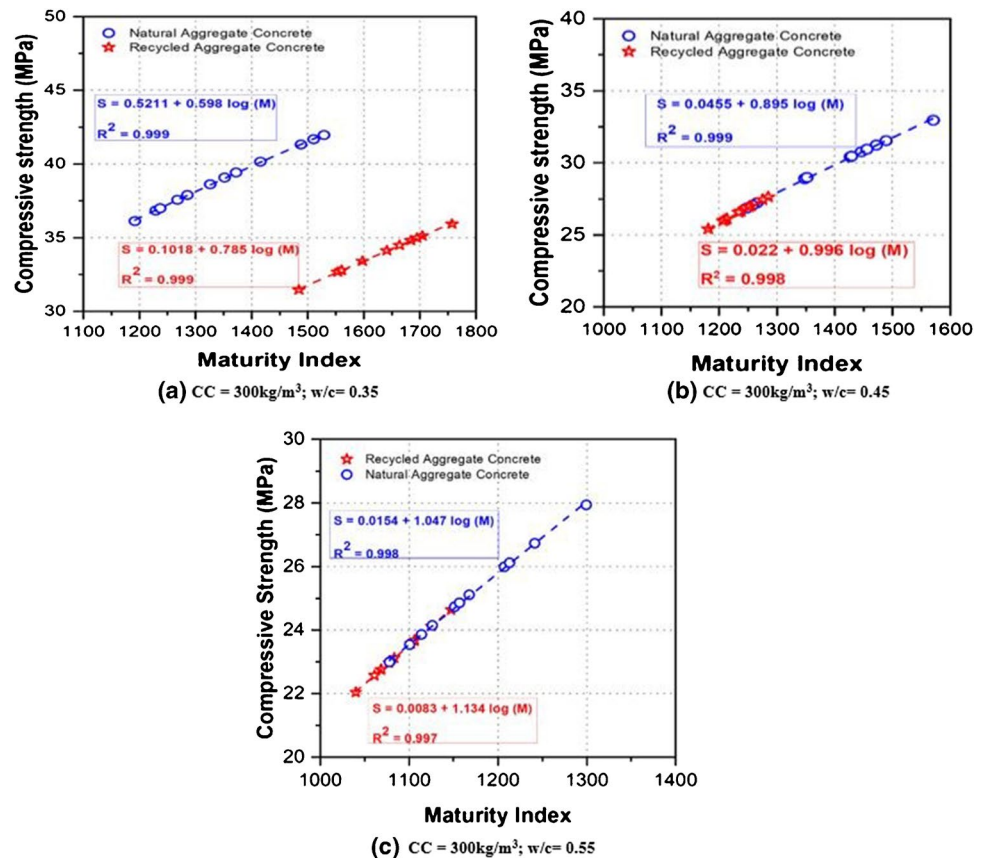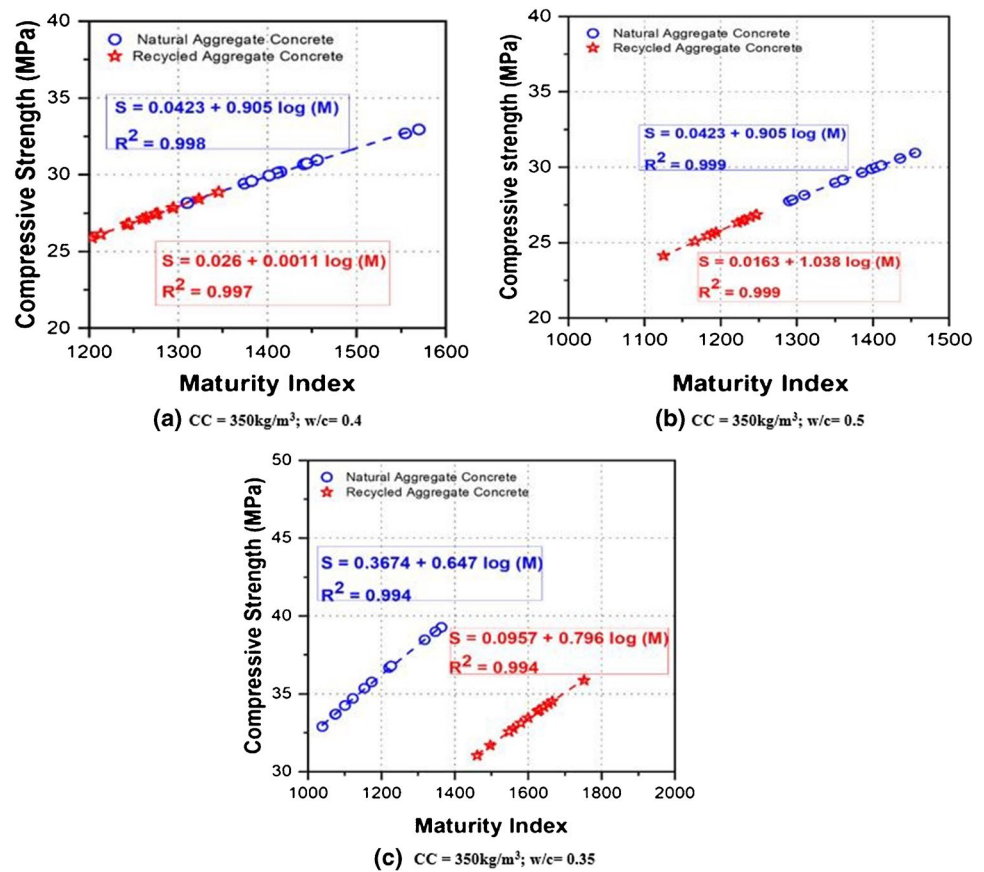**Fig. 3** Strength-maturity relationship for 300 kg/m³ with various w/c

Fig. 4 Strength-maturity relationship for 350 kg/m³ with various w/c

(a) CC = 350kg/m³; w/c= 0.4

(b) CC = 350kg/m³; w/c= 0.5

(c) CC = 350kg/m³; w/c= 0.35

$$S = a + b \log(M) \tag{5}$$

Equation 5 shows the semi-logarithmic function proposed by Plowman in (1956).

where,

S strength of maturity index

a, b regression coefficients

By analyzing the relationship between the results of a compressive strength test and maturity, Lew and Reichard (1978) suggested a novel nonlinear regression equation in 1978, which is shown in Eq. (6).

$$S = \frac{K}{1 + Ka[\log(M - 30)]^b} \tag{6}$$

where

"K," "a," "b" denotes the arithmetic constants.

30 denotes the maturity, below which the strength is 0.

The logistic curve is a mathematical model for expressing population expansion. Around the inflection point, it is a S-shaped curve with bilateral symmetry, and it is indicated in Eq. (7).

$$S = \frac{a}{1 + be^{-cM}} \tag{7}$$

where

"a", "b", "c" denotes parameters.

The estimates above are based on the premise that maturity and age do not affect the limiting strength. Several scholars, however, have stated that the equations' usefulness is limited. They also overlook the influence of age on limiting strength. The following equations were changed to overcome these limitations. In 1971, F. K. Chin (1971) hypothesized that the strength-maturity connection may be represented as a hyperbola using the below Eq. (8).

$$S = \frac{M}{{}^1/_A + {}^M/_{S_u}} \tag{8}$$

where "S_u" denotes the limiting strength as maturity approaches infinity, and "A" denotes the strength-maturity curve's initial slope.

Many models for predicting strength have been proposed, as illustrated above. The models were proposed before the widespread adoption of computer programming technology. Many commonly available computer programs linked to forecasts are now available, and the best models may be found fast. Because

Fig. 5 Strength-maturity relationship for 400 kg/m^3 with various w/c

(a) CC = 400kg/m^3; w/c= 0.48

(b) CC = 400kg/m^3; w/c= 0.4

(c) CC = 400kg/m^3; w/c= 0.3
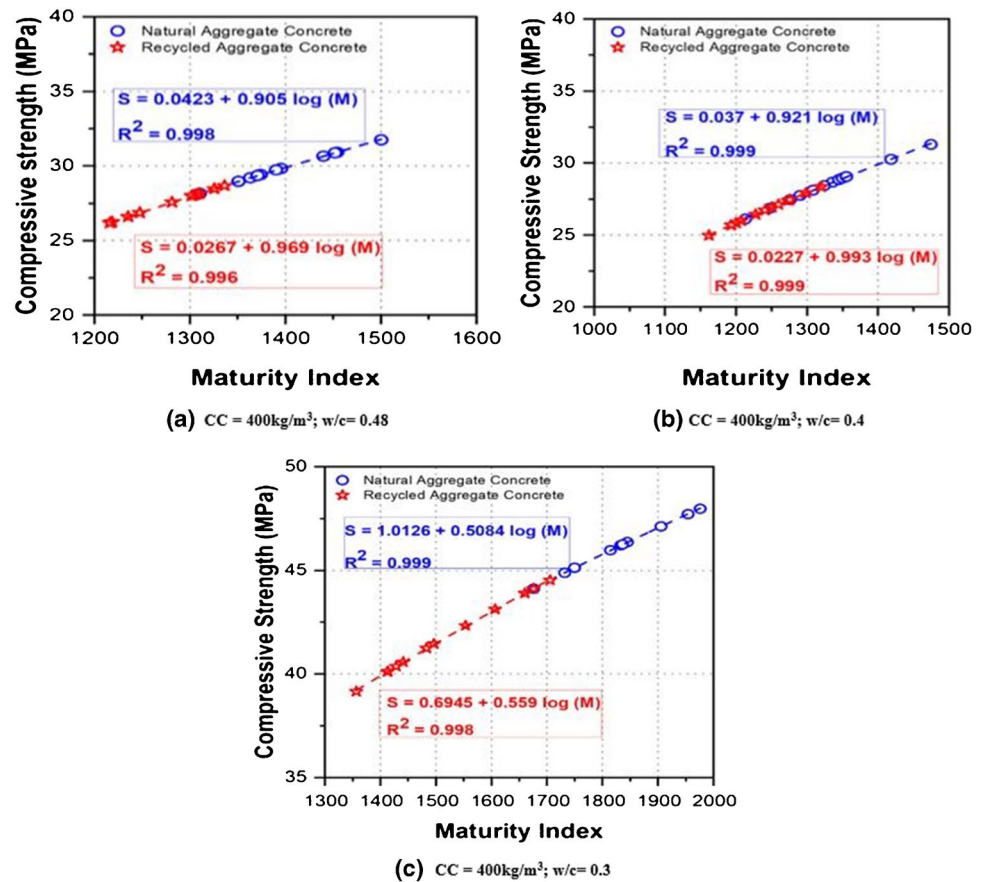
of its simplicity, the semi-logarithmic equation given by Plowman (1956) is employed in this work to generate strength-maturity relationship models; it plots as a straight line when a log scale is chosen for the maturity index axis. Figure 1 shows the experimental procedure of the maturity index test.

Experiments and discussions

The nature of RCA is its adhered mortar, which is highly porous. In this research, the water absorption of RCA and NCA was found to be 2.09% and 0.36% respectively. The specific gravity of RCA and NCA was found to be 2.35 and 2.76 respectively. The fineness modulus of RCA and NCA was found to be 7.72 and 7.23 respectively. The impact value for RCA and NCA was found to be 34% and 30% respectively. The crushing value for RCA and NCA was found to be 21% and 18% respectively. Slump tests were performed to determine the workability of NAC and RAC mixes.

For 300 kg/m^3 of cement content with W/C of 0.45 and 0.55, the slump was 50 mm, whereas for 0.35W/C, the slump was 0 because of its low W/C and minimum cement content. Moreover, the mix with 0.35 W/C was found to be very dry. The nature of RCA is its adhered mortar,

which is highly porous. When experimenting with high w/c, the attached mortar absorbs the water and makes the concrete mix harsh or reduced workability. For 350 kg/m^3 of cement content with W/C of 0.4 and 0.5, the slump was 100 mm and 60 mm respectively. For 0.35W/C, the slump was 40 mm, which was dry. For 400 kg/m^3 of cement content with W/C of 0.4 and 0.3, the slump was 75 mm and 65 mm respectively. For 0.48W/C, the slump range was 90 mm, which falls within the medium slump value.

For 450 kg/m^3 of cement content with W/C of 0.35 and 0.3, the slump was 90 mm, whereas for 0.4 W/C, the slump range was 150 mm, which was the high slump value.

Also, it is reported that the use of fine recycled aggregates generally leads to a higher porosity of the resulting concrete, which increases carbonation depth, water absorption, and chloride-ion penetration. Barvo et al. (2010) stated that the pozzolanic activity may promote durability with the inclusion of steel, polypropylene fibers, or mineral additives like silica fume, and fly ash in concrete mixes that might enhance the durability.

By varying the w/c and cement content, 24 mixes were obtained. Concrete was made by using potable water. All the concrete mixes were prepared and cured under proper conditions. The testing of specimens was done at a curing period of 7 and 28 days. For the succeeding step, in the case of the maturity index, Plowman equations have been used.

Fig. 6 Strength-maturity relationship for 450 kg/m³ with various w/c

(a) CC = 450kg/m³; w/c= 0.45

(b) CC = 450kg/m³; w/c= 0.35

(c) CC = 450kg/m³; w/c= 0.3
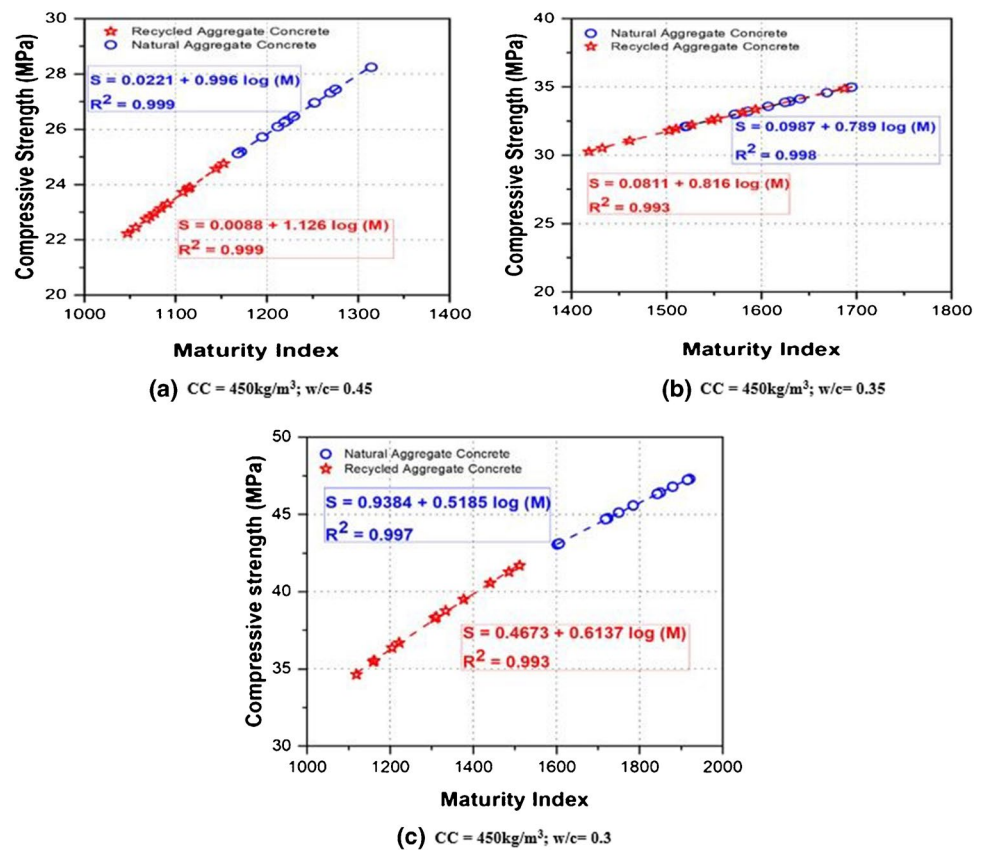
Testing procedure

The CSC test was performed on a 150 mm cube that was sufficiently cured with potable water according to IS 456–2000. With curing ages of 7 and 28 days, the CSC was calculated. The cubes are tested using a compression testing machine with a capacity of 3000 kN. The force was gradually increased at a rate of 140 kg/cm²/min, identifying the least load that the cubes could support. The compressive strength of the specimen was evaluated by the greatest load applied to its cross-sectional area. The value at which the differences between the three cubes shall not exceed is 15% Deshpande et al. (2014). Table 2 shows the different mix proportions and used for 7, 28 days of curing ages. 100R + 0N represents 100% of RCA and 0R + 100N represents 100% of NCA. Figure 2 shows the average compressive strength results with different cement content for RAC and NAC mixes respectively.

Maximum strength for 7 days and 28 days for RAC was found to be 40.16 MPa and 51.41 MPa respectively for the mix 17 with a cement content of 400 kg/m³, w/c of 0.3, and SP of 1.5% dosage. Maximum strength for 7 days and 28 days for NAC was found to be 46.18 MPa and 59.64 MPa respectively for the mix 18 with a cement content of 400 kg/m³, w/c of 0.3, and SP of 1.5% dosage. Minimum strength

for 7 days and 28 days for RAC was found to be 18.15 MPa and 27.25 MPa respectively for the mix 5 with a cement content of 300 kg/m³, w/c of 0.55, and SP of 0% dosage. Minimum strength for 7 days and 28 days for NAC was found to be 20.97 MPa and 28.49 MPa respectively for the mix 6 with a cement content of 300 kg/m³, w/c of 0.55, and SP of 0% dosage. The decrease in strength of RAC is because of the adherence in the recycled aggregate, which affects the porous ITZ, hence becoming the weakest point in RAC and due to the higher crushing value, porous microstructure, and pre-existing micro-cracks present in RCA.

Maturity method procedure

One of the most accurate ways to determine the strength of early-age in situ concrete is through the maturity method, especially for rapid building projects. To measure the maturity of concrete empirically, numerous approaches have been suggested by Malhotra and Carino (2004). However, Carino and Lew (1984) created a number of techniques that are rooted in the concept of activation energy and the Arrhenius law on reaction rate. The determination of prestressed heat-accelerated concrete elements' strength is just one of the many uses for this technique in the precast concrete sector.

Table 4 Proposed models for RAC and NAC mixes

Mix.no	Material proportion (%)	Cement content (kg/m³)	W/C	SP (%)	Proposed model [$S = a + b \log(M)$]	Maturity Iindex	R^2
Mix 1	100R + 0N	300	0.35	1.5	$S = 0.1018 + 0.785 \log(M)$	1523.92	0.999
Mix 2	0R + 100N	300	0.35	1.5	$S = 0.5211 + 0.598 \log(M)$	2311.47	0.999
Mix 3	100R + 0N	300	0.45	0	$S = 0.022 + 0.996 \log(M)$	1596.30	0.998
Mix 4	0R + 100N	300	0.45	0	$S = 0.0455 + 0.895 \log(M)$	1471.56	0.999
Mix 5	100R + 0N	300	0.55	0	$S = 0.0083 + 1.134 \log(M)$	1266.78	0.997
Mix 6	0R + 100N	300	0.55	0	$S = 0.0154 + 1.047 \log(M)$	1308.78	0.998
Mix 7	100R + 0N	350	0.4	1.5	$S = 0.026 + 0.0011 \log(M)$	1688.02	0.998
Mix 8	0R + 100N	350	0.4	1.5	$S = 0.0423 + 0.905 \log(M)$	1479.74	0.998
Mix 9	100R + 0N	350	0.5	0	$S = 0.0163 + 1.038 \log(M)$	1523.31	0.999
Mix 10	0R + 100N	350	0.5	0	$S = 0.0423 + 0.905 \log(M)$	1465.05	0.999
Mix 11	100R + 0N	350	0.35	1.5	$S = 0.0957 + 0.796 \log(M)$	1394.58	0.994
Mix 12	0R + 100N	350	0.35	1.5	$S = 0.3674 + 0.647 \log(M)$	2072.44	0.994
Mix 13	100R + 0N	400	0.48	0	$S = 0.0267 + 0.969 \log(M)$	1609.61	0.996
Mix 14	0R + 100N	400	0.48	0	$S = 0.0423 + 0.905 \log(M)$	1327.85	0.998
Mix 15	100R + 0N	400	0.4	0	$S = 0.0227 + 0.993 \log(M)$	1579.52	0.999
Mix 16	0R + 100N	400	0.4	0	$S = 0.037 + 0.921 \log(M)$	1354.15	0.999
Mix 17	100R + 0N	400	0.3	1.5	$S = 0.6945 + 0.559 \log(M)$	2287.94	0.998
Mix 18	0R + 100N	400	0.3	1.5	$S = 1.0126 + 0.5084 \log(M)$	2395.27	0.999
Mix 19	100R + 0N	450	0.45	0	$S = 0.0088 + 1.126 \log(M)$	1366.90	0.999
Mix 20	0R + 100N	450	0.45	0	$S = 0.0221 + 0.996 \log(M)$	1642.76	0.999
Mix 21	100R + 0N	450	0.35	0.3	$S = 0.0811 + 0.816 \log(M)$	1395.18	0.993
Mix 22	0R + 100N	450	0.35	0.3	$S = 0.0987 + 0.789 \log(M)$	1646.90	0.998
Mix 23	100R + 0N	450	0.3	1.5	$S = 0.4673 + 0.6137 \log(M)$	1775.25	0.993
Mix 24	0R + 100N	450	0.3	1.5	$S = 0.9384 + 0.5185 \log(M)$	2335.54	0.997

- Determine the strength-maturity connection graph using concrete specimens made from the project's intended concrete mix. Temperature probes inserted in one or two specimens are used to check the temperature of the samples. Compressive strength is determined by standard brake testing at various ages. This information is saved, and the maturity function is established (Nurse-Saul or Arrhenius function).
- Consider the in-place concrete construction, and record the temperature history by placing sensors in strategic areas (based on exposure conditions and structural requirements).
- Calculate the maturity index using the temperature and age parameters.
- Estimate the in-place strength of the field concrete by comparing this maturity index to the previously produced strength-maturity relationship.

As demonstrated in Fig. 1, the maturity function approach makes it easier to design a mixture-specific calibration curve that connects maturity and concrete compressive strength. Temperature is measured against time using thermocouples implanted into fresh concrete. The calculated period of history can be used to generate a maturity index, which provides an exact estimate of the early-age quantitative influence as a function of time (Saul 1951). The ASTM C1074 (2019) experimental study procedures and criteria were used. The maturity function was determined by putting the sensor into the concrete cube. The concrete cube included a wireless sensor, which was protected by a cement mortar shell (Nandhini and Karthikeyan 2021). To acquire the analog signals and convert them to digital signals, a data acquisition system was designed and built. This method was developed to determine the early-age temperature in concrete cube specimens (Barroca et al. 2013).

Strength maturity relationship

To determine the relationship between concrete cube strength and the maturity of recycled aggregate concrete, this study developed the model using the logarithmic equation proposed by Plowman. Table 3 shows the plowman

coefficient used for maturity equations. The values of coefficients *A* and *B* depend on the strength level of the concrete. With the help of known strength results and Plowman coefficients, the maturity index has been determined.

The paper initiated an investigation of the use of normal aggregate concrete (NAC) and recycled aggregate concrete (RAC) strength made with cement content of 300 kg/m³, 350 kg/m³, 400 kg/m³, 450 kg/m³ with varying w/c and SP dosage to attain strength-maturity relationship models. The following are the figures showing strength-maturity relationship models attained for different cement content. Figure 3a, b, and c shows the strength-maturity relationship for 300 kg/m³ of cement content with different w/c such as 0.35, 0.45, and 0.55 respectively.

Figure 4a, b, and c shows the strength-maturity relationship for 350 kg/m³ of cement content with w/c of 0.4, 0.5, and 0.35 respectively.

Figure 5a, b, and c shows the strength-maturity relationship for 400 kg/m³ of cement content with w/c of 0.48, 0.4, and 0.3 respectively.

Figure 6a, b, and c shows strength-maturity relationship for 450 kg/m³ of cement content with w/c of 0.45, 0.35, and 0.3 respectively.

Based on the strength-maturity correlation models that were attained, it was observed that all the mixes had good accuracy of regression coefficient predicting the maturity index of RAC and NAC mixes. Table 4 shows the proposed models for RAC and NAC mixes.

In the proposed model, "*a*" and "*b*" are the regression coefficients obtained from the Plowman coefficient for maturity equations. The maximum maturity index was found for mix 17 and mix 18 with a cement content of 400 kg/m³, w/c of 0.3, and SP of 1.5% dosage, which was found to be 2287.94 and 2395.27 for RAC and NAC respectively. The minimum maturity index was found for mix 5 and mix 6 with a cement content of 300 kg/m³, w/c of 0.55 which was found to be 1266.78 and 1308.78 for RAC and NAC mixes respectively.

Limitations

The approach did not consider the influence of temperature on the mechanical characteristics of concrete at later ages after it was cast. The fundamental limitation on the maturity framework was that in most cases for Portland cement mixed medium-strength concrete, the curing temperature of the early-age exit increased with the curing temperature of the later-age output to provide much strength at later ages.

At an early stage, the plan should be backed up by various concrete strength assessments. An inspection to evaluate strength is required before a particularly powerful procedure that involves the removal of formwork.

Conclusions

The strength-maturity connection models for RAC and NAC mixtures were developed and compared in this work using the Plowman equation. The following are the key conclusions drawn from this inquiry on all counts and with proven results:

The fineness modulus, specific gravity, and water absorption of RCA was found to be 6.3% greater, 15% lower, and 80% greater than NCA.

The percentage of water absorption increased due to the porous structure and micro-cracks present in RCA, which showed an adverse impact on the properties of RAC mixes.

The impact and crushing resistance of RCA were found to be 12% and 14% lower than NCA.

The workability of the NAC mix was found to be 20% greater than the RAC mix.

The compressive strength of recycled coarse aggregate with a cement content of 400 kg/m³, w/c of 0.3, and SP dosage of 1.5% was found to be 51.41 MPa, which is 14% lower than the NAC mix.

The maximum maturity index for NAC was found to be 2395.27, which is 4.5% greater than the RAC mixes. The minimum maturity index for NAC was found to be 1308.78, which is 3.2% greater than the RAC mixes.

The logarithmic strength-maturity correlation proves the best fit for strength vs. maturity index data where the R^2 values of RAC mixes were found between 0.993 and 0.999. While the R^2 value for NAC mixes were found between 0.994 and 0.999. This shows the concrete has been fully matured.

The maturity technique, rather than absolute strength, is more dependable in predicting relative strength development.

As a result, the strength maturity correlation models arrived are utilized to forecast the maturity index for normal and recycled aggregate concrete.

Because of the convenience and capacity of getting an estimated maturity index, the maturity technique has been employed to forecast the increase of concrete strength growth with amazing efficiency in numerous construction initiatives. It might also be used to evaluate in-situ concrete strength, resulting in greater construction efficiency as well as significant energy and labor cost savings.

Declarations

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