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Application of the Maturity Method for Concrete Quality Control

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Abstract The maturity method has been successfully used to predict the strength of concrete prepared according to American standards (ASTM). This study investigated the applicability of the method to concrete prepared according to British standards (BS), and also assessed the effect of a plasticizer on the strength and maturity of concrete. Three mixes were prepared, one according to American standards (mix A) and two according to British standards (mixes B and C). Modified lignosulphonate (Sika Plastiment BV-40) was used to increase the workability of mix C. Although concrete mix proportioning according to British standards resulted in a denser mix (2400 kg/m^3) than American standards (2342 kg/m^3), a water-cement (w/c) ratio of 0.5 was used for all mixes. Cylindrical specimens (each measuring 150 mm in diameter by 300 mm deep) and beam specimens (each measuring 150 mm wide by 530 mm long by 150 mm deep) were made andcured at 23 ºC. The compressive and splitting tensile strengths of the cylinders and the flexural strength of the beams were approximately equal for the three mixes. Also, the internal temperature (and hence the calculated maturity) of concrete was the same for all mixes. The effect of using different standards was negligible, as was the addition of a plasticizer. These findings indicate that: (1) concrete mixes with identical w/c ratios provide the same strength regardless of composition; and (2) although ASTM C 1074 is based on the assumption that concrete is prepared according to American standards and without admixtures, the maturity method provides a satisfactory estimate of the strength of concrete prepared according to British standards, and concrete prepared usinga plasticizer.

Keywords Concrete, Maturity, Standards, Strength

1. Introduction

The use of accelerated schedules in the construction of concrete structures has been necessitated by a desire to achieve economic benefits [1]. Accurate prediction of in-situ concrete strength development can be used to shorten construction schedules and, as a result, reduce overall construction costs by determining the appropriate time to start critical construction activities such as removal of formwork and opening a pavement to traffic.

The maturity method is a useful, easily implemented, accurate means of predicting in-situ concrete strength [2]. It is based on the knowledge that concrete gains strength quickly when exposed to high temperatures, and slowly when exposed to low temperatures. This dependence of concrete strength on temperature presents a problem when the in-situ strength of concrete is determined using conventional methods.

Conventional methods of determining the in-situ strength of concrete involve sampling the concrete before it is placed in a structure, putting the samples under controlled conditions in a laboratory (typically at room temperature), and testing the samples at regular time intervals so as to determine the rate of concrete strength development. This rate of strength gain is used to predict the strength of the concrete placed in the structure. However, the temperature of the concrete within the structure is rarely the same as that of the samples [3].

If the concrete in the structure is exposed to a higher temperature than that at which the samples have been tested in the laboratory, it will gain strength at a higher rate than the samples and achieve the desired strength more quickly than predicted. As a result, the removal of formwork or the opening of a pavement to traffic may be delayed unnecessarily, resulting in the loss of valuable construction time [3].

In contrast, if the concrete within the structure is exposed to a lower temperature than the laboratory temperature, the concrete will gain strength at a lower rate than predicted. Therefore, there is a possibility that formwork could be removed, or a pavement could be opened to traffic, before adequate strength is attained, resulting in the collapse of the structure [3].

Knowing the actual strength of in-situ concrete is important in projects where the removal of formwork from structures or the opening of pavements to traffic is a critical factor in maintaining accelerated construction schedules [3]. Conventional methods of predicting in-situ concrete strength result in a conservative prediction during periods of hot weather when the temperature of the in-situ concrete may be higher than that at which samples of the concrete have been tested in a laboratory. These methods also result in an un-conservative prediction during cold weather periods when in-situ concrete temperature may be lower than the laboratory temperature.

Consequently, attempts have been made to use in-situ test methods to determine the actual rate of concrete strength development. These methods include the rebound hammer, probe penetration, pullout, ultrasonic pulse velocity, cast-in-place cylinders, and the maturity method. Although these methods have inherent limitations, the maturity method is gaining acceptance due to its simplicity in combining the effects of varying concrete temperatures and curing times on concrete strength development. This method provides a reliable approach for estimating the in-situ strength of concrete by monitoring the temperature of the concrete over time [4].

1.1 Maturity Concept

Concrete gains strength through the hydration reaction between cement and water. To maintain this increase in strength with age, concrete must be properly cured. This means that a satisfactory moisture content and temperature must be maintained in concrete for a period of time to allow the hydration of cement to occur. Temperature has a significant effect on concrete strength development [5]. An increase in curing temperature speeds up the hydration process, leading to an increase in strength development.

The maturity method uses the curing time and temperature of concrete to compute a single parameter which is indicative of the strength of the concrete. This parameter is called “maturity” [6]. The maturity of concrete is a function of the product of curing time and temperature of the concrete.

The maturity rule states that a unique relationship exists between the maturity and strength of a particular concrete mixture [6]. This means that if two samples of a given concrete mixture have the same maturity, they will have the same strength even though each may have been exposed to different curing times and temperatures.

A concrete mixture exposed to a low temperature takes more time to reach maturity M1 (Fig. 1), whereas a concrete mixture exposed to a high temperature takes less time to reach maturity M2. If M1=M2 (i.e., area of rectangle M1 = area of rectangle M2), these two mixtures will have equal strengths even though the individual curing times and temperatures are different [7].

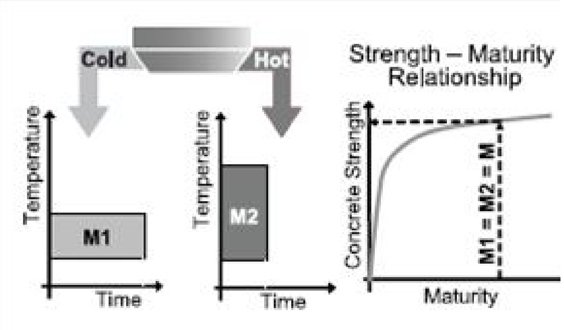

Fig. 1. Maturity concept

The effects of time and temperature on concrete strength gain are quantified through a maturity equation [6]. Saul (1951) proposed the following equation to compute the maturity of concrete:

$$M = \sum_{0}^{t} (T_a - T_0)\Delta t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

where:

M = maturity (temperature-time factor) at age t (°C-hour or °C-day)

T_a = average concrete temperature during time interval Δt (°C)

T_0 = datum temperature, taken as 0 °C.

Δt = time interval (hour or day)

Equation (1) is known as the Nurse-Saul equation [8]. The datum temperature is the temperature at which concrete strength gain ceases. Time periods during which temperatures are at or below this datum temperature do not contribute to strength gain.

The datum temperature depends on the type of cement used to prepare concrete, and the range of curing temperature that the concrete will be subjected to. For concrete prepared using general purpose Portland cement, and exposed to a curing temperature range from 0 to 40 °C, a datum temperature of 0 °C is applied [9].

1.2 Maturity Testing Procedure

The maturity testing procedure involves two steps [2]:

1. Laboratory calibration – A concrete mix which is representative of the concrete to be used for a construction project is prepared. Test specimens are prepared from the mix and a temperature sensor (Fig. 2) is inserted into at least two specimens for the purpose of recording concrete temperature for calculation of maturity values at specified ages (i.e., after 1, 3, 7, 14 and 28 days). Strength tests are performed on the remaining specimens at the specified ages, and a strength-maturity relationship curve (also known as a calibration curve) is developed.

Fig.2. Recording of internal concrete temperature

2. As soon as is practicable after concrete placement, a temperature sensor is embedded into the fresh in-situ concrete. The recorded temperature is used to calculate the maturity of the concrete. This maturity is used together with the previously developed calibration curve to estimate the in-situ concrete strength.

1.3 Quality Control of Concrete in Kenya

In Kenya as well as in many developing countries, where low wages favor manual methods, most concrete is mixed manually orwith small mixers on construction sites [10]. A standard mix used in Kenya, yielding concrete with a 28-day compressive strength of 25 N/mm^2, requires about 400 kilograms of cement [10]. Therefore, on a typical construction site, builders use between 160 and 400 bags of cement per day, each weighing fifty kilograms. The resulting concrete mixture is then hauled in wheelbarrows and poured into formwork. It is challenging to ensure quality whenthe process is so cumbersome and physically taxing [10].

Technicians from testing laboratories collect samples of the poured concrete and prepare specimens which are then stored under controlled conditions in laboratories. The specimens are subjected to compressive strength testing at pre-determined ages (7, 14, and 28 days), to ensure that the design strength is achieved in 28 days [10]. Engineers and inspectors determine if structures are safe based on the findings of their inspection visits to construction sites, and on the values of the compressive strength of concrete reported by materials testing laboratories. Real estate developers assume that the quality of the concrete used in construction is verified following the sampling and testing processes outlined in British codes, which are used to design structural concrete in Kenya. However, between 2006 and 2014, seventeen buildings collapsed in Kenya, causing eighty-four deaths and more than two hundred and ninety injuries. In 2009, Kenyan officials estimated that 65% of Kenya’s buildings fail to meet code standards[10]. This means that the quality control mechanisms for structural concrete currently used in Kenya are not as effective as they should be. Architects and engineers routinely certify buildings as safe for occupation based, in part, on inaccurate or false laboratory reports.

In 2014, a study conducted by Fernandez [10] examined the state of the construction industry’s compliance with standards for concrete used in Kenya. This was done in two ways: (1) a comparison of in-situ concrete strength test data, collected at twenty-four construction sites, with test results reported by established laboratories in Nairobi from a sample of new construction projects – In-situ concrete strength data was collected using rebound hammer tests; and (2) through a survey of fifty-one existing buildings in the metropolitan area of Nairobi. The sampled buildings included industrial, residential, commercial and religious structures. The construction sites were sufficiently diverse with regard to location, construction company size, building type, and design. They were considered a representative cross-section of the industry. The findings suggested that concrete is frequently weaker than claimed by laboratory test reports, and that current quality control practices are not effective in ensuring structural reliability of new or existing buildings.

The collapse of buildings in Kenya has triggered regulatory review. This has focused on zoning, building permits, and licensing, because it is commonly understood that defective designs and inadequate standards are to blame for the collapse of buildings. In 2011, the government of Kenya enacted two laws to improve the quality and safety of buildings: (1) the Engineers Act, which authorizes the Engineers Board of Kenya to access and inspect construction sites at will; and (2) the National Construction Authority Act, which created a National Construction Authority (NCA) with a mandate to regulate and improve the construction industry. The NCA Act expressly states that one of its objectives is to "promote quality assurance in the construction industry". However, despite these efforts, fundamental industry practices, including quality control protocols, have remained the same. This is partly because, until now, most of the work has focused on tighter regulation and certification of building contractors, while quality control methods remain as they have been for decades [10].

Unless better control systems are implemented, thousands of dangerously weak buildings will be built, and millions of people will likely be exposed to unnecessary risks for generations. Therefore, priority should be given to the improvement of construction quality control processes and regulation. Policymakers in government, nongovernmental organizations, and professional organizations must catalyze institutional change in the construction industry as a matter of urgency. Their efforts will be most effective if attention is given to the promotion and enforcement of prudent quality control protocols that encourage engineers and inspectors to assume less and verify more [10].

The maturity method can provide improvement in construction productivity, resulting in substantial time and cost savings, without compromising safety [2]. However, the applicability of the method as a means of estimating in-situ concrete strength is hindered by the fact that the standard practice for maturity testing (ASTM C 1074) is based on the assumption that concrete is prepared according to American standards, and without admixtures. It is estimated that chemical admixtures are present in 80% of the concrete placed today [11]. Plasticizers, which have been used for quite some time in the Kenyan construction industry [12], are chemical admixtures which are used to increase the workability of freshly mixed concrete without adjusting the water-cement ratio. In order to promote the adoption of the maturity method as a means of estimating in-situ concrete strength in Kenya, this research sought to determine the applicability of the method to: (1) concrete prepared according to British standards; and (2) concrete prepared according to British standards and with modified lgnosulphonate (Sika Plastiment BV-40) (Fig. 3) a locally available plasticizer added to increase workability.

Fig. 3. Modified lignosulphonate (Sika Plastiment BV-40)

2. Methodology

Three concrete mixtures, one prepared according to American standards and two prepared according to British standards, were used in this research. For all mixtures, class 42.5 general purpose Portland cement was used as a binder, and locally available natural river sand and ballast were used as fine and coarse aggregate respectively. Potable water was used to mix and cure the concrete. Each mix was designed to have an average 28-day compressive strength of 25 N/mm^2, a slump of 25-50 mm, and a maximum aggregate size of 20 mm. A plasticizer (Fig. 3) was added to one of the two mixes prepared according to British standards so as to increase workability without adjusting the water-cement ratio.The following data was first determined for mix design purposes: (1) sieve analyses of fine and coarse aggregates; (2) unit weights of fine and coarse aggregates; and (3) specific gravity and water absorption of fine and coarse aggregates.

2.1. Properties of Aggregates

Sieve analyses of fine and coarse aggregates were done in accordance with ASTM C 136 – 96a [13] for concrete prepared according to American standards, and BS 812 – Part 103.1:1985 [14] for concrete prepared according to British standards. The fineness modulus of aggregate , which is an indicator of the fineness of an aggregate,was calculated by adding the cumulative percentages retained on each of the following sieves, and dividing the sum by

100: 150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm, 4.75 mm, 9.5 mm, 19.0 mm, 37.5 mm, and larger.

The unit weight of aggregate , which is the mass of a unit volume of the aggregate, was determined in accordance with ASTM C 29 – 03 [15] for concrete prepared according to American standards, and BS 812 – 2: 1995 [16] for concrete prepared according to British standards.

The specific gravity and absorption of fine aggregate was determined in accordance with ASTM C 128 – 97 [17] for concrete prepared according to American standards, and BS 812 – 2: 1995 [16] for concrete prepared according to British standards. The specific gravity, which is the ratio of the mass of a unit volume of a material to the mass of the same volume of water, was calculated on the basis of saturated surface-dry fine aggregate. Water absorption was calculated as a percentage of dry mass.

The specific gravity and water absorption of coarse aggregate was determined in accordance with ASTM C 127 – 93 [18] for concrete prepared according to American standards, and BS 812 – 2: 1995 [16] for concrete prepared according to British standards.The specific gravity was calculated on the basis of saturated surface-dry coarse aggregate, and water absorption was calculated as a percentage of dry mass.

The grading of aggregates affects the relative aggregate proportions as well as cement and water requirements Aggregates that have a uniform distribution of particle sizes produce a workable concrete mixture [21].For both American standards (ASTM C 33 – 03 [19]) and British standards (BS 882: 1992 [20]), locally available natural river sand and ballast conformed to the grading requirements for suitability of use as aggregates (Fig. 4 and Fig. 5).

In addition, the fineness modulus of the fine aggregate used in this research was found to be 2.6 (Table 1). This value was used to determine the volume of coarse aggregate to be used per unit volume of concrete prepared according to American standards. Fine aggregates with a fineness modulus of 2.5 and under will produce concrete with low compressive strength [21]. Hence the selected natural river sand was suitable for use as fine aggregate.

Unit weight, specific gravity and water absorption of fine and coarse aggregates were found to be approximately the same regardless of the standards used (Table 1). The unit weight of aggregate was used to determine the weight of aggregate to be used per unit volume of concrete. The approximate unit weight of aggregates commonly used in concrete ranges from about 1120 to 1760 kg/m^3 [21].The unit weight of the aggregates used in this research was within this range (Table 1). The specific gravity of aggregate was used to calculate the volume that the aggregate would occupy in the concrete mixture. Most natural aggregates have specific gravities of between 2.4 and 2.9 [21].

The specific gravity of the aggregates used in this research was found to be 2.7 (Table 1). The water absorption of aggregate was used to calculate the change in the mass of the aggregate due to water absorbed in the pore spaces within the constituent particles. The amount of water used in the concrete mixture must be adjusted for the moisture conditions of the aggregates to meet the designated water requirement [21]. The aggregates used in this research met all the acceptance criteria of both American and British standards.

Table 1: Properties of aggregates

Type of aggregate	Fineness modulus	Unit weight (kg/m^3)	Specific gravity	Water absorption (%)
Fine aggregate	2.6	1500	2.7	3.4
Coarse aggregate	5.3	1600	2.7	3.2

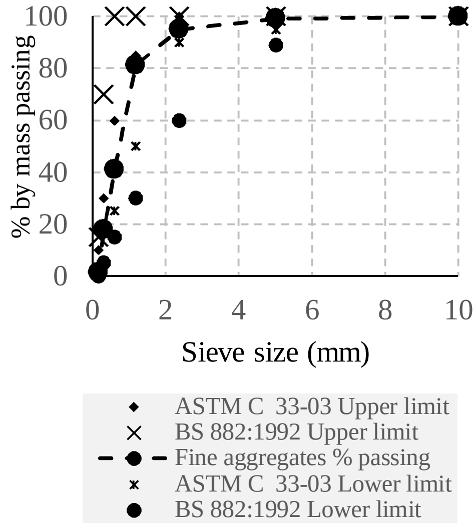

Fig. 4. Fine aggregate particle size distribution

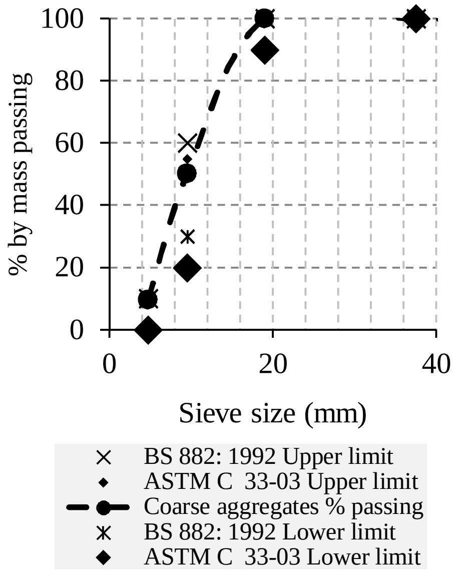

Fig. 5. Coarse aggregate particle size distribution

2.2. Concrete Mix Design

Concrete mix proportioning was done in accordance with the American Concrete Institute (ACI) mix design procedure (ACI 211.1 - 91) [22] for concrete prepared according to American standards, and the United Kingdom Building Research Establishment (BRE) mix design procedure [23] for concrete prepared according to British standards.Modified lignosulphonate (Sika Plastiment BV-40), a locally available plasticizer (Fig. 3), was added to one of the two mixes prepared according to British standards at a dosage of 0.2% by weight of cement as recommended by the manufacturer. The plasticizer was dispersed in the mixing water before addition.The slump of concrete was determined in accordance with ASTM C 143 – 05a [24] for concrete prepared according to American standards, and BS 1881 – 102:1983 [25] for concrete prepared according to British standards.

Mix proportions for 1 m^3 of class 25 concrete (concrete with a 28-day compressive strength of 25 N/mm^2) are shown in Table 2. Concrete mix proportioning resulted in approximately equal water-cement ratios for mix A (prepared according to American standards), mix B (prepared according to British standards, and without a plasticizer), and mix C (prepared according to British standards, and with a plasticizer).

Table 2: Mix proportions for 1 m^3 of class 25 concrete

Mix	Water (kg)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
A	184	307	816	1035
B	210	420	673	1097
C	210	420	673	1097

2.3. Determination of Concrete Strength and Maturity

Fifty-one (51) concrete test specimens were made and cured in accordance with ASTM C 192 – 02 [26] for concrete prepared according to American standards, and one-hundred and two (102) specimens were made and cured in accordance with BS EN 12390 – 2:2000 [27] for concrete prepared according to British standards (Fig. 6 and 7).

Fig. 6. Cylindrical concrete specimens

Fig. 7. Concrete beam specimens

The compressive strength of concrete, which is the measured maximum resistance of a concrete specimen to axial loading,was determined in accordance with ASTM C 39 – 14 [28] for concrete prepared according to American standards, and BS EN 12390 – 3: 2002 [29] for concrete prepared according to British standards (Fig. 8). Three cylindrical specimens were tested at each test age and the average compressive strength was computed.

Fig. 8. Compressive strength testing

The splitting tensile strength of concrete, which is a measure of the resistance of concrete to longitudinal stress, was determined in accordance with ASTM C 496 – 04 [30] for concrete prepared according to American standards, and BS EN 12390 – 6: 2009 [31] for concrete prepared according to British standards. Three cylindrical specimens were tested at each test age and the average splitting tensile strength was determined.

The flexural strength of concrete, which is a measure of the ability of concrete to resist deformation under load, was determined using a simple beam with third-point loading in accordance with ASTM C 78 – 02 [32] for concrete prepared according to American standards, and BS EN 12390 – 5: 2000 [33] for concrete prepared according to British standards (Fig. 9).Three beam specimens were tested at each test age and the average flexural strength was computed.

Fig. 9. Flexural strength testing

Maturity testing (Fig. 2) was done in accordance with ASTM C 1074 – 04 [34] for concrete prepared according to American standards, and concrete prepared according to British standards. For each concrete mixture, temperature sensors were embedded in the centres of three cylindrical specimens and three beam specimens as soon as practicable after the specimens were made. The temperature sensors were immediately connected to data loggers which recorded the temperature of the concrete specimens at intervals of 0.5 h.

3. Results and Discussion

3.1. Estimation of the Compressive Strength of Concrete Using the Maturity Method

The compressive strengths of mixes A, B, and C were approximately equal at all test ages.Comparable concretes generally provide the same strengths with identical water-cement ratios regardless of the concrete composition [35]. The 28-day compressive strength of mix A was about 99% of the design compressive strength (25 N/mm2) (Table 3). The 1-day, 3-day, 7-day, and 14-day compressive strengths of mix A were about 15%, 37%, 67%, and 88% of the 28-day design strength respectively (Table 3). For mix B (the control mix), the 28-day compressive strength was approximately 100% of the design compressive strength (25 N/mm^2) (Table 3). The 1-day, 3-day, 7-day, and 14-day compressive strengths of mix B were about 16%, 38%, 67%, and 90%

of the 28-day design strength respectively (Table 3). For mix C, the 28-day compressive strength was about 99% of the design compressive strength (25 N/mm^2) (Table 3). The 1-day, 3-day, 7-day, and 14-day compressive strengths of mix C were about 16%, 39%, 69%, and 89% of the 28-day design strength respectively (Table 3).

For mixes A and C, failure to achieve the exact 28-day compressive strength was attributed to variations in the quality of the constituent materials of the mix, as well as errors in batching processes. Mix B, which achieved the desired 28-day design compressive strength, was taken as the control mix.

Table 3: Compressive strength (N/mm^2) of class 25 concrete

Mix	Age of concrete (days)				
	1	3	7	14	28
A	3.8	9.1	16.5	21.7	24.7
B	4.0	9.5	16.8	22.3	24.9
C	3.9	9.7	17	22.1	24.8

For all instrumented specimens, at all test ages,the maturity of concrete was the same (Table 4). This is because the internal temperature of concrete was not affected by the composition of the mix.

Table 4: Maturity of concrete at intervals of 0.5 h

Age (h)	Temp. (ºC)	Average Temp. (ºC)	Maturity Increment (ºC-h)	Cumulative Maturity (ºC-h)
0	22.49			0
0.5	22.51	22.5	11.25	11.25
1	23.32	22.92	11.46	22.71
...	...	...	...	...
24	21.4	22.94	11.47	548.75
...	...	...	...	...
72	21.28	22.92	11.46	1643.36
...	...	...	...	...
168	24.76	23	11.5	3833.61
...	...	...	...	...
336	21.12	23.02	11.51	7670.96
...	...	...	...	...
672	21.72	22.52	11.26	15364.61

By plotting the observed compressive strength of mix B (the control mix) against the corresponding maturity values, a function which produced a best-fit curve was developed (Fig. 10).The compressive strength of each mix increased with increasing maturity. The relationship between compressive strength (y) and maturity (x) was expressed in the form of an equation (Equation (2)).

$$y = 6.6 \ln (x) - 37.839 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Equation (2) was used to compute compressive strength, against which the strengths of mix A (Fig. 11) and mix C (Fig. 12) were compared.

The maximum deviation of the observed compressive strength of mix A from the estimated compressive strength was only 1.6 N/mm^2 (about 17% of estimated value) (Fig. 11). For mix C, the maximum deviation was only 1.0 N/mm^2 (about 10% of estimated value) (Fig. 12). The highest deviations occurred at early ages, from day 1 to day 7. Afterwards, the deviations of observed values from estimated values were less than 4% (Fig. 11 and Fig. 12).

Therefore, it is concluded that the maturity method gives an accurate estimate of the compressive strength of concrete irrespective of the choice of concrete mix design standard or the addition of modified lignosulphonate (Sika Plastiment BV-40), a locally available plasticizer.

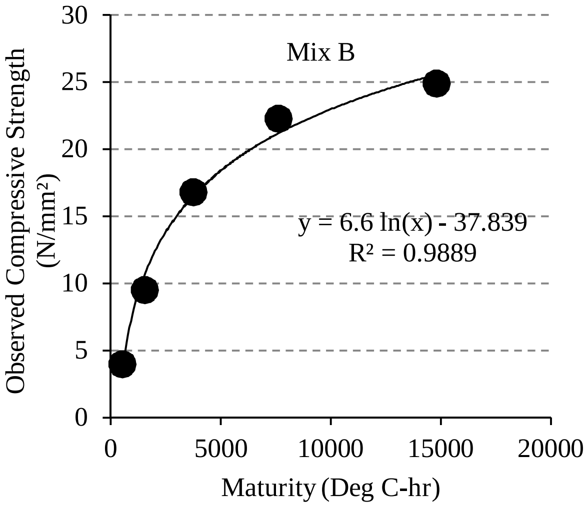

Fig. 10. Compressive strength-maturity curve for the experimental concrete mix B

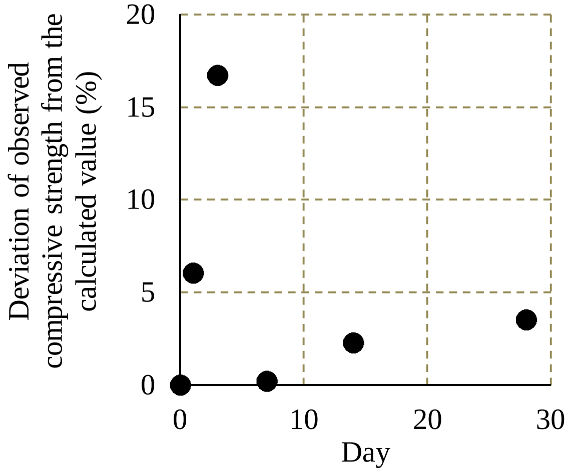

Fig. 11. Deviation of compressive strength of mix A from calculated compressive strength

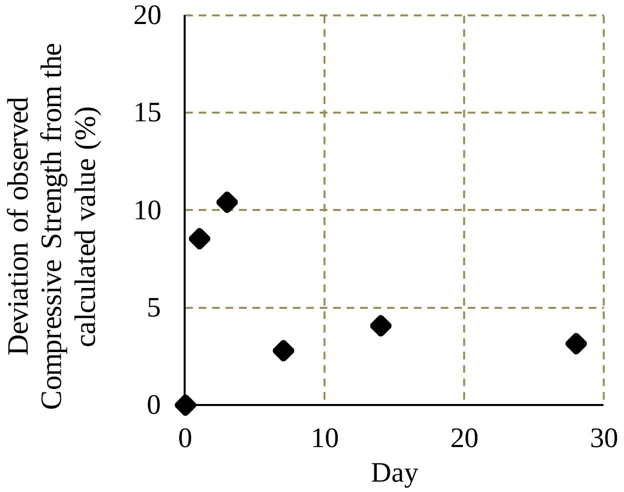

Fig. 12. Deviation of compressive strength of mix C from calculated compressive strength

3.2. Estimation of the Splitting Tensile Strength of Concrete Using the Maturity Method

The 1-day, 3-day, 7-day, 14-day, and 28-day splitting tensile strengths of mix A were about 11%, 11%, 10%, 14%, and 13% of the corresponding compressive strengths respectively (Tables 3 and 5). For mix B, the 1-day, 3-day, 7-day, 14-day, and 28-day splitting tensile strengths were about 13%, 12%, 11%, 14%, and 13% of the corresponding compressive strengths respectively (Tables 3 and 5). For mix C, the 1-day, 3-day, 7-day, and 14-day splitting tensile strengths were about 15%, 10%, 11%, 14%, and 13% of the corresponding compressive strengths respectively (Tables 3 and 5). The splitting tensile strengths of mixes A, B and C were not significantly different. This may be attributed to the fact that the three mixes had approximately the same water-cement ratios.The effect of using different standards was insignificant, as was the addition of a plasticizer. In addition, values of splitting tensile strength were within the prescribed range of 8% to 14% of corresponding values of compressive strength [36].

Table 5: Splitting tensile strength (N/mm^2) of class 25 concrete

Mix	Age of concrete (days)				
	1	3	7	14	28
A	0.4	1	1.6	3	3.1
B	0.5	1.1	1.8	3.2	3.3
C	0.6	1	1.8	3.1	3.2

The maturity of mixes A, B and C, which was computed using equation (1), was the same at all test ages (Table 4). Mix composition had no effect on the internal temperature of concrete. For all mixes, splitting tensile strength increased with increasing maturity. The splitting tensile strength of mix B was plotted against corresponding maturity values and a best-fit curve was drawn through the data (Fig. 13).

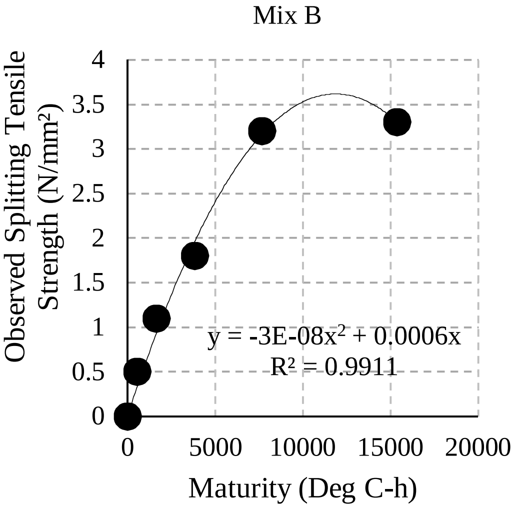

Fig. 13. Splitting tensile strength-maturity curve for the experimental concrete mix B

Splitting tensile strength (y) was related to maturity (x) according to equation (3).

$$y = -3E - 08x^2 + 0.0006x \quad \text{..........................} \ (3)$$

Equation (3) was used to calculate values of splitting tensile strength, against which the strengths of mix A (Fig. 14) and mix C (Fig. 15) were compared.

The maximum deviations of mixes A and C from the estimated values were only 0.9 N/mm^2 and 1.0 N/mm^2 respectively.

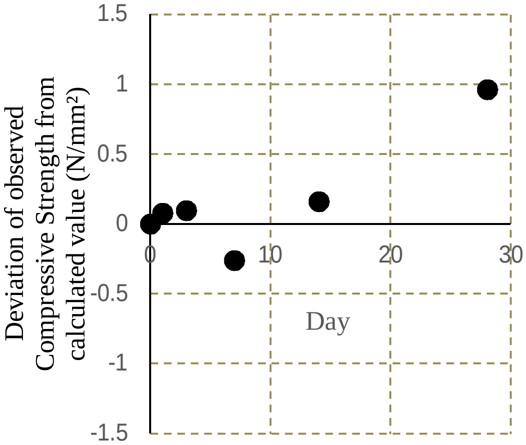

Fig. 14. Deviation of observed splitting tensile strength of mix A from calculated splitting tensile strength

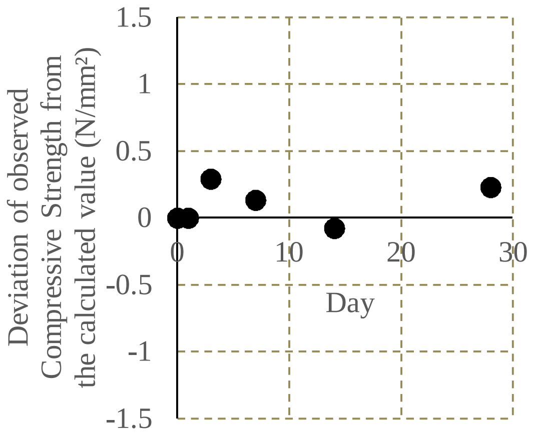

Fig. 15. Deviation of observed splitting tensile strength of mix C from calculated splitting tensile strength

It is concluded that the maturity method provides a satisfactory estimate of the splitting tensile strength of concrete regardless of the mix design standards used, or the addition of modified lignosulphonate (Sika Plastiment BV-40).

3.3. Estimation of the Flexural Strength of Concrete Using the Maturity Method

The 1-day, 3-day, 7-day, 14-day, and 28-day flexural strengths of mix A were about 16%, 11%, 13%, 14%, and 13% of the corresponding compressive strengths respectively (Tables 3 and 6). For mix B, the 1-day, 3-day, 7-day, 14-day, and 28-day flexural strengths were about 18%, 13%, 14%, 15%, and 14% of the corresponding compressive strengths respectively (Tables 3 and 6). For mix C, the 1-day, 3-day, 7-day, and 14-day flexural strengths were about 15%, 12%, 14%, 15%, and 14% of the corresponding compressive strengths respectively (Tables 3 and 6). Because mixes A, B and C had approximately the same water-cement ratios, the flexural strengths of the three mixes were not significantly different. The flexural strength of concrete was not affected by the use of different standards, or the addition of a plasticizer.

Table 6: Flexural strength (N/mm^2) of class 25 concrete

Mix	Age of concrete (days)				
	1	3	7	14	28
A	0.6	1	2.1	3.1	3.2
B	0.7	1.2	2.4	3.3	3.5
C	0.6	1.2	2.3	3.4	3.5

Mixes A, B and C had the same maturity at all test ages (Table 4). The effect of concrete mix composition on the internal temperature of the concrete was not significant.The flexural strength and maturity of mix B were used to obtain the curve shown in Fig. 16. Flexural strength (y) was related to maturity (x) according to equation (4).

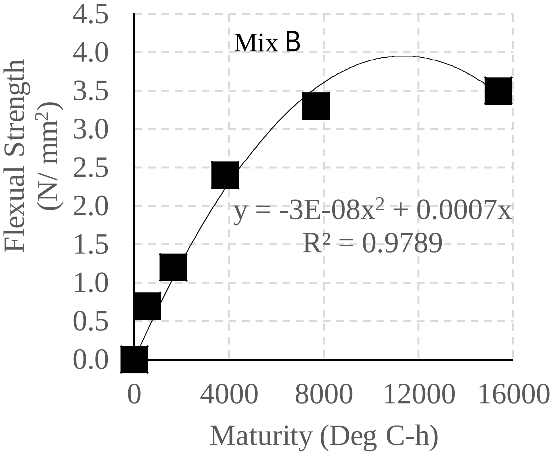

Fig. 16. Flexural strength-maturity curve for the experimental concrete mix B

Equation (4) was used to calculate values of flexural strength, against which the flexural strengths of mix A (Fig. 16) and mix C (Fig. 9) were compared.

$$y = -3E - 08x^2 + 0.0007x \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The maximum deviation of mix A was only 0.6 N/mm^2 (Fig. 17), while the maximum deviation of mix C was only 0.25 N/mm^2 (Fig. 18).

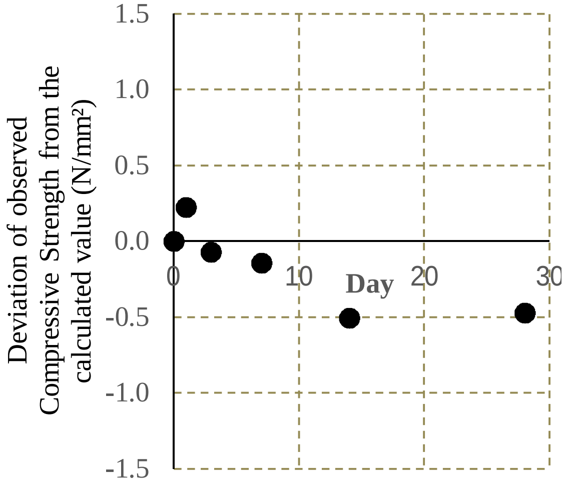

Fig. 17. Deviation of observed flexural strength of mix A from calculated flexural strength

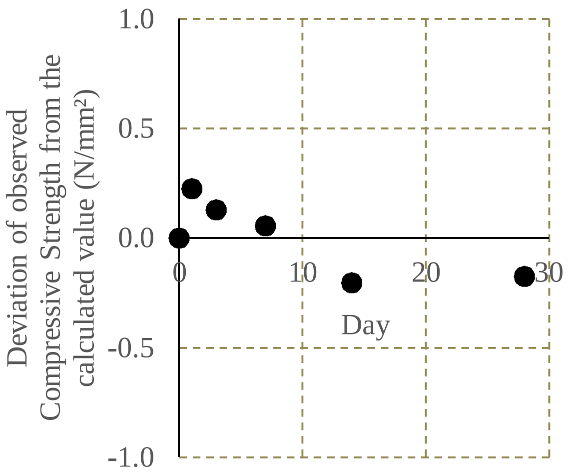

Fig. 18. Deviation of observed flexural strength of mix C from calculated flexural strength

Clearly, the maturity method may be used to estimate the flexural strength of concrete and the results are independent of the mix design standards used, or the addition of modified lignosulphonate (Sika Plastiment BV-40).

4. Conclusions and Recommendations

The aim of this research was to compare the applicability of the maturity method to concrete prepared according to British standards against concrete prepared according to American standards. At all test ages, the compressive strength, splitting tensile strength, flexural strengthand maturityof concrete prepared according to British standards were not significantly different from those of concrete prepared according to American standards. This was so regardless of whether a plasticizer was added or not. It was therefore concluded that the maturity method is applicable in Kenya where structural concrete is designed according to British standards.The method may also be applied to concrete containing modified lignosulphonate (Sika Plastiment BV-40), a locally available plasticizer. It is recommend that a policy be formulated that requires construction professionals in Kenya to use the maturity method as a tool for concrete quality control.

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