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RESEARCH ARTICLE

ESTIMATION OF AGE COEFFICIENT TO PREDICT RESISTANCE AT J DAYS FROM MEASUREMENTS AT 7 DAYS, 28 DAYS, AND 90 DAYS

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ABSTRACT

The evaluation of the material strength of concrete over time is a significant concern in many civil engineering construction projects. Several reference documents, including BAEL 91, provide formulas to estimate the compressive strength of concrete at J days based on the strength measurements obtained at 7 days. However, noticeable differences exist between the estimated values and the actual values obtained during construction when applying these formulas. The objective of this study is to assess a reliable age coefficient for estimating the concrete strength at J days based on the strength measurements at 7 days, 28 days, and 90 days, depending on the locally used materials (Togo) for concrete production. The methodological approach adopted involves collecting rock samples (amphibole and biotite gneiss) from 33 sites in Southern Togo, sampling them, and conducting various identification tests on the obtained gravel samples. The chosen sand is from the Mono River, and a commonly used cement from the local market is used. The theoretical concrete mix design is performed using the Dreux Gorisse method. The results obtained from the hardened concrete allowed the examination of different ratios according to the concrete's age. It is found that the average RC28/RC7 and RC90/RC7 ratios obtained for B20 concrete are 1,35 and 1,56, respectively, and for B25 concrete, they are 1,43 and 1,67. Considering a risk level of P=10%, these ratios become 1,42 and 1,59 for B20 concrete and 1,37 and 1,75 for B25 concrete. These ratios differ from those provided by BAEL 91, which range from 80% to 93% for B20 and 86% to 99% for B25.

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INTRODUCTION

The strength of a material is a key parameter for assessing its durability and performance in various applications. For a structure or a part of a structure, using specific materials, it is necessary to achieve concrete with designated strengths at certain ages, such as 14 or 28 days (or longer), for formwork removal, prestressing, acceptance, and commissioning [6]. Therefore, when constructing concrete structures (dams, power plants, buildings, bridges), it is often necessary to estimate the strength at a given time based on measurements taken at shorter durations. However, conducting long-term strength testing can be costly and time-consuming. Establishing a reliable age coefficient to extrapolate experimental data to longer durations can be immensely useful. Several reference documents, including BAEL 91 and other authors, provide formulas to estimate the compressive strength of concrete at J days based on strength measurements at 7 days. However, significant discrepancies are often observed between the estimated values and the actual values obtained during construction when applying these formulas. The objective of this study is to evaluate a reliable age coefficient that can estimate the concrete strength at J days based on strength measurements at 7 days, 28 days, and 90 days, considering the locally used materials (Togo) for concrete production. In this study, we have established new ratios between the compressive strength at 7 days, 28 days, and 90 days and compared them to data collected in previous studies, as well as those provided by BAEL91.

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MATERIALS AND METHODS

The adopted methodological approach involves collecting rock samples (amphibole and biotite gneiss) from multiple sites in the southern region of Togo. These samples are then carefully sampled, and various identification tests (including granulometric analysis [1], real density [2], and bulk density [3]) are performed on the obtained gravel samples. The chosen sand is sourced from the Mono River, and a cement commonly used in the local market of Togo is selected. The choice of cement is guided by recommendations from prior research [6]. The cement utilized is a Portland cement (CPJ) with a compressive strength of approximately 42,5 MPa at 28 days. The theoretical formulation of the concrete mix is conducted following the Dreux Gorisse method. The results obtained from the cured concrete specimens allow for the examination of various ratios with respect to the age of the concrete. Figure 1 presents the map indicating the locations of the rock sample collection points.

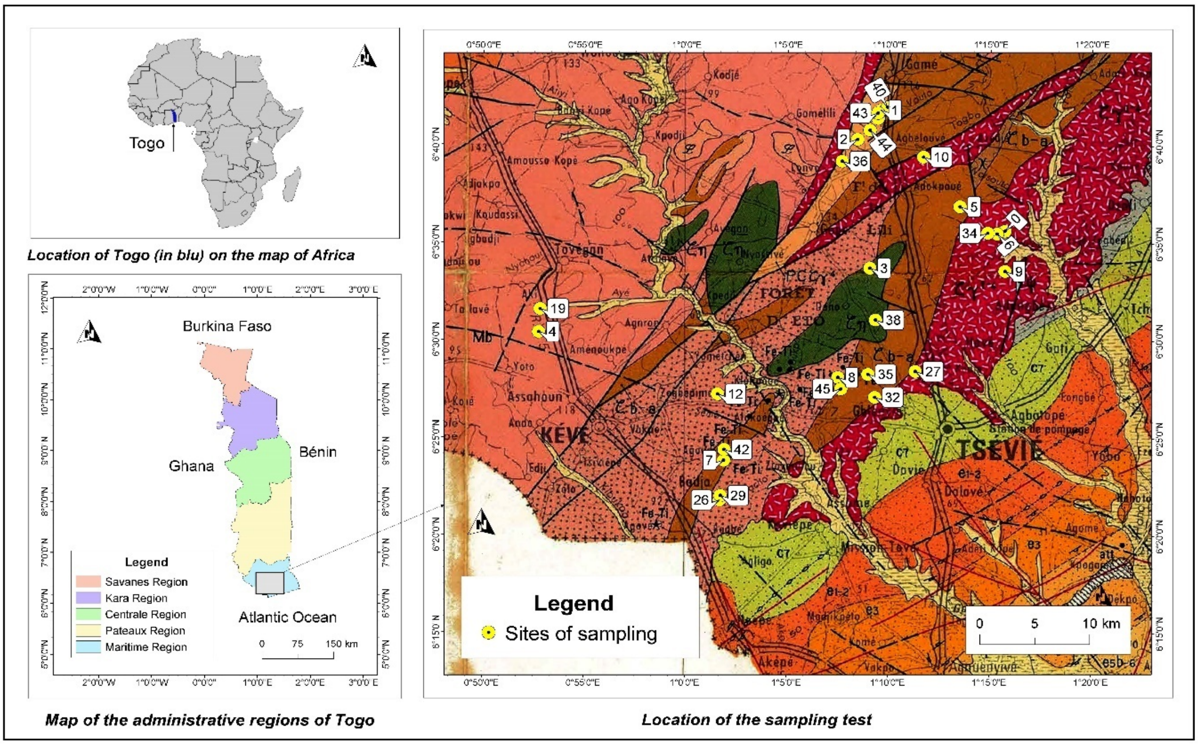

Figure 1. Geological Map Showing Rock Sample Collection Locations

Figure 1. Collection of rock blocks on-site

Figure 3. Crushing and sieving

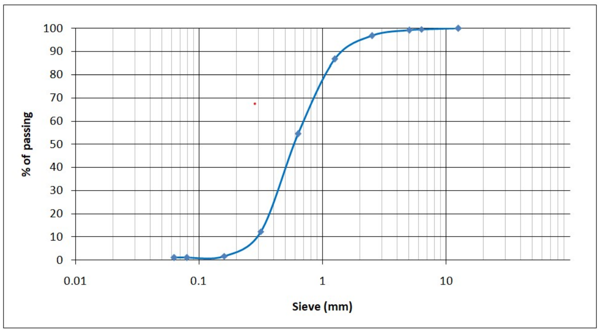

Figure 2. Granulometric curve of Mono River sand

Complete data set: The rocks collected from each site are brought to the laboratory and then crushed to obtain crushed gravel of size class 5/25, following the recommendations of the chosen concrete formulation method. The sand selected for this study is sourced from the Mono River. For the cement, we opted for the class 42.5 cement from the DANGOTE cement plant. Regarding the concrete mix formulation, the following assumptions were made: the slump and the granular coefficient G are 5 cm and 0,5, respectively. Two concrete classes were also chosen, referring to the most common concrete classes used in major construction projects within the country. These are the B20 and B25 concrete classes, corresponding to concrete with compressive strengths of 20 and 25 MPa at 28 days, respectively. The concrete will be placed without pumping.

RESULTS AND DISCUSSION

Test results for identifying the nature and condition parameters of Mono River Sand: The results of the tests identifying the nature and condition parameters of Mono River sand are presented in Table 1 and shown in Figure 4.

Tableau 1. Test results for identifying the nature and condition parameters of Mono River Sand

Material	< 5 mm (%)	D_{max} (1) (mm)	Apparent Density γ_d (g/cm^3)	Absolute Density γ_S (g/cm^3)	Fineness Modulus (Mf)	Cu	Cc	Sand Equivalence (ES) [5]
Sand	99,2	2,5	1,45	2,69	2,48	2,47	0,87	90
(1) Diameter for which 95% of the grains have a dimension smaller								

Table 2. Test Results for Identification of Crushed Gravel Nature Parameters

Geological Map Sequence Numbers	Absolute Density γ_S (g/cm^3)	Apparent Density γ_d (g/cm^3)	Absorption Coefficient (%)	Geological Map Sequence Numbers	Absolute Density γ_S (g/cm^3)	Apparent Density γ_d (g/cm^3)	Absorption Coefficient (%)
0	2,69	1,45	0,27	26	2,75	1,42	0,29
1	2,69	1,47	0,26	27	2,69	1,48	0,25
2	2,74	1,46	0,28	29	2,68	1,46	0,27
3	2,72	1,48	0,28	30	2,66	1,45	0,29
4	2,63	1,45	0,38	31	2,69	1,44	0,25
5	2,68	1,47	0,38	32	2,66	1,46	0,27
6	2,75	1,48	0,26	33	2,71	1,48	0,27
7	2,70	1,45	0,28	34	2,67	1,49	0,30
8	2,67	1,46	0,28	35	2,70	1,48	0,28
9	2,77	1,40	0,24	36	2,69	1,47	0,27
10	2,71	1,42	0,35	38	2,67	1,48	0,24
12	2,72	1,44	0,28	40	2,73	1,48	0,27
13	2,73	1,45	0,27	42	2,74	1,51	0,28
18	2,73	1,47	0,26	43	2,69	1,48	0,34
19	2,75	1,47	0,37	44	2,71	1,47	0,29
20	2,63	1,46	0,25	45	2,68	1,46	0,27
21	2,70	1,45	0,24				

Figure 3. Concrete specimens stored in the curing bath

Figure 4. Concrete specimens prepared for compression testing

Considering the values of the uniformity coefficient (Cu > 2) and the curvature coefficient (Cc between 1 and 3), we can conclude that the Mono River sand selected for this study is well-graded with a spread-out particle size distribution. The value of the fineness modulus is nearly equal to 2.5 (ranging from 2,2 to 2,8). Hence, it is a good sand [6].

Test Results for Identification of Crushed Gravel Nature Parameters: The results of tests identifying the nature and condition parameters of crushed gravel are presented in Table 2. The maximum diameter is 25 mm for all sites. The Los Angeles (LA) and Micro Deval tests conducted on the rock samples in the presence of water (MDE) yielded values ranging from 21 to 40 for LA with an average of 28 and from 10 to 20 for MDE with an average of 16. The granulometric curves of the obtained gravel samples show no discontinuities. The absorption coefficients of these aggregates range from 2,63 to 2,77.

Concrete Formulation Results: The results obtained from the concrete formulation are presented in tables 3 and 4.

Compression Test Results on Concrete Specimens: Following the theoretical formulation of the concrete mix, we proceeded with the preparation of concrete specimens, their curing, and subsequent compression testing at specified ages [4]. In total, nine (9) concrete specimens were prepared for each rock sampling site, corresponding to three (3) specimens for compression testing at the three selected ages: 7, 28, and 90 days, resulting in a total of 297 concrete specimens. The results obtained from the compression test are presented in Tables 5 and 6. Examining the results, it can be observed that the compressive strength generally increases with the age of the concrete, as expected. For instance, in the case of B20 concrete sample number 2, the compressive strength at 7 days was 17,66 MPa, which increased to 24,45 MPa at 28 days, resulting in an RC28/RC7 ratio of 1,38. Furthermore, at 90 days, the strength increased to 30,50 MPa, yielding an RC90/RC7 ratio of 1,73. However, there are exceptions to this trend, with some samples exhibiting higher strengths at younger ages. For instance, B20 concrete sample number 8 had a compressive strength of only 14,34 MPa at 7 days, but it increased to 22,22 MPa at 28 days, resulting in an RC28/RC7 ratio of 1,55.

Table 3. Concrete Formulation Results (B20 class concrete)

Geological Map Sequence Numbers	Cement			Sand			Gravel			Water
	Mass Composition (Kg)	Volume (l)	Volume Composition (l)	Mass Composition (Kg)	Volume (l)	Volume Composition (l)	Mass Composition (Kg)	Volume (l)	Volume Composition (l)	Volume (l)
0	340	110	340	631	235	435	1280	476	883	206
1	340	110	340	660	245	455	1280	476	871	206
2	340	110	340	619	230	427	1315	480	901	206
3	340	110	340	619	230	427	1316	483	889	206
4	340	110	340	638	237	440	1296	492	894	206
5	340	110	340	723	269	499	1176	439	800	206
6	340	110	340	672	250	463	1248	454	843	206
7	340	110	340	693	258	478	1232	457	850	206
8	340	110	340	657	244	453	1275	478	873	206
9	340	110	340	745	277	514	1200	434	857	206
10	340	110	340	677	252	467	1257	465	885	206
12	340	110	340	677	252	467	1257	462	873	206
13	340	110	340	696	259	480	1238	454	854	206
18	340	110	340	658	245	454	1278	468	869	206
19	340	110	340	598	222	412	1330	484	905	206
20	340	110	340	618	230	426	1312	498	899	206
21	340	110	340	640	238	441	1298	481	895	206
26	340	110	340	650	242	448	1289	469	908	206
27	340	110	340	672	250	464	1249	463	844	206
29	340	110	340	678	252	467	1258	469	862	206
30	340	110	340	698	260	482	1242	468	856	206
31	340	110	340	659	245	454	1279	476	888	206
32	340	110	340	617	229	425	1311	492	898	206
33	340	110	340	598	222	412	1330	491	899	206
34	340	110	340	656	244	453	1274	476	855	206
35	340	110	340	694	258	479	1234	458	834	206
36	340	110	340	707	263	488	1204	448	819	206
38	340	110	340	635	236	438	1290	483	871	206
40	340	110	340	668	248	461	1241	455	839	206
42	340	110	340	669	249	461	1265	461	838	206
43	340	110	340	761	283	525	1141	423	771	206
44	340	110	340	691	257	477	1229	453	836	206
45	340	110	340	726	270	501	1180	441	808	206

Table 4. Concrete Formulation Results (B25 class concrete)

Geological Map Sequence Numbers	Cement			Sand			Gravel			Water
	Mass Composition (Kg)	Volume (l)	Volume Composition (l)	Mass Composition (Kg)	Volume (l)	Volume Composition (l)	Mass Composition (Kg)	Volume (l)	Volume Composition (l)	Volume (l)
0	360	116	360	606	225	418	1288	479	888	187
1	360	116	360	573	213	395	1337	497	910	187
2	360	116	360	595	221	410	1323	483	906	187
3	360	116	360	612	227	422	1299	477	878	187
4	360	116	360	634	236	437	1288	489	888	187
5	360	116	360	660	245	455	1221	456	831	187
6	360	116	360	643	239	443	1248	454	843	187
7	360	116	360	623	232	430	1265	469	872	187
8	360	116	360	640	238	441	1241	465	850	187
9	360	116	360	682	254	470	1248	451	891	187
10	360	116	360	688	256	474	1222	452	861	187
12	360	116	360	594	221	410	1323	486	919	187
13	360	116	360	613	228	423	1304	478	899	187
18	360	116	360	651	242	449	1264	463	860	187
19	360	116	360	614	228	423	1304	475	887	187
20	360	116	360	634	236	437	1286	488	881	187
21	360	116	360	583	217	402	1239	459	854	187
26	360	116	360	587	218	405	1336	486	941	187
27	360	116	360	651	242	449	1264	469	854	187
29	360	116	360	690	257	476	1227	457	840	187
30	360	116	360	631	235	435	1282	483	884	187
31	360	116	360	634	236	437	1286	479	893	187
32	360	116	360	652	242	450	1265	475	867	187
33	360	116	360	673	250	464	1249	461	844	187
34	360	116	360	652	242	450	1266	473	850	187
35	360	116	360	634	236	437	1286	477	869	187
36	360	116	360	663	246	457	1231	458	837	187
38	360	116	360	612	227	422	1299	487	878	187
40	360	116	360	644	239	444	1268	465	857	187
42	360	116	360	644	239	444	1273	464	843	187
43	360	116	360	717	267	494	1169	434	790	187
44	360	116	360	631	234	435	1280	472	871	187
45	360	116	360	663	246	457	1226	458	840	187

Table 5. Results of the compression test on concrete (B20 class concrete)

Geological Map Sequence Numbers	Compression test en MPa			Ratios	
	RC (7jrs)	RC (28jrs)	RC (90jrs)	RC28/RC7	RC90/RC7
0	19,15	24,79	25,28	1,29	1,32
1	18,82	23,04	25,03	1,22	1,33
2	17,66	24,45	30,50	1,38	1,73
3	15,58	24,20	27,94	1,55	1,79
4	18,90	23,13	24,29	1,22	1,29
5	18,49	22,46	29,18	1,22	1,58
6	19,31	24,70	25,45	1,28	1,32
7	18,57	22,55	27,52	1,21	1,48
8	14,34	22,22	27,77	1,55	1,94
9	15,58	23,96	27,94	1,54	1,79
10	18,57	22,22	28,93	1,20	1,56
12	14,59	22,71	24,62	1,56	1,69
13	19,15	22,55	25,28	1,18	1,32
18	19,07	23,21	24,12	1,22	1,27
19	18,90	23,13	24,29	1,22	1,29
20	15,50	24,04	28,02	1,55	1,81
21	19,15	24,45	25,61	1,28	1,34
26	14,75	22,63	25,53	1,53	1,73
27	19,07	24,62	25,53	1,29	1,34
29	14,51	22,55	27,94	1,55	1,93
30	18,49	22,46	29,18	1,22	1,58
31	19,23	23,29	24,20	1,21	1,26
32	18,57	22,55	29,26	1,21	1,58
33	19,23	24,87	25,20	1,29	1,31
34	18,49	22,30	29,01	1,21	1,57
35	18,65	22,63	29,10	1,21	1,56
36	18,73	22,96	25,28	1,23	1,35
38	15,67	24,29	28,02	1,55	1,79
40	17,49	24,29	30,42	1,39	1,74
42	15,34	23,13	27,94	1,51	1,82
43	15,34	23,30	27,52	1,52	1,79
44	19,15	23,29	27,27	1,22	1,42
45	17,16	29,51	30,42	1,72	1,77

Table 6. Results of the compression test on concrete (B25 class concrete)

Geological Map Sequence Numbers	Compression test MPa			Ratios	
	RC (7jrs)	RC (28jrs)	RC (90jrs)	RC28/RC7	RC90/RC7
0	19,81	28,52	36,14	1,44	1,82
1	22,30	31,58	37,47	1,42	1,68
2	23,54	33,65	36,14	1,43	1,54
3	19,56	36,72	37,38	1,88	1,91
4	22,38	28,35	37,38	1,27	1,67
5	22,05	32,16	34,65	1,46	1,57
6	19,73	28,76	36,14	1,46	1,83
7	23,04	32,08	34,48	1,39	1,50
8	21,05	24,20	32,16	1,15	1,53
9	19,56	36,72	37,38	1,88	1,91
10	24,87	32,25	34,65	1,30	1,39
12	20,97	24,20	32,41	1,15	1,55
13	20,97	28,52	36,31	1,36	1,73
18	22,46	32,00	37,55	1,42	1,67
19	22,38	28,35	37,38	1,27	1,67
20	21,97	36,64	37,47	1,67	1,71
21	19,73	28,85	36,22	1,46	1,84
26	21,05	26,11	32,49	1,24	1,54
27	19,81	28,93	36,14	1,46	1,82
29	21,14	26,94	32,25	1,27	1,53
30	22,55	32,33	34,65	1,43	1,54
31	22,63	32,16	37,80	1,42	1,67
32	24,95	32,25	34,73	1,29	1,39
33	19,89	28,60	36,22	1,44	1,82
34	24,95	32,16	34,57	1,29	1,39
35	24,79	32,16	34,57	1,30	1,39
36	22,13	31,91	37,63	1,44	1,70
38	19,65	36,89	37,55	1,88	1,91
40	22,55	33,74	36,06	1,50	1,60
42	16,33	27,27	32,66	1,67	2,00
43	16,00	21,05	31,91	1,32	1,99
44	22,55	31,91	37,80	1,42	1,68
45	21,22	30,01	31,17	1,41	1,47

Looking at the average of each column, the average compressive strength at 7 days is 17,61 MPa, at 28 days is 23,53 MPa, and at 90 days is 27,08 MPa. The standard deviations, which indicate the variability of results around the average, are 1,76 MPa, 1,37 MPa, and 2,02 MPa for 7 days, 28 days, and 90 days compressive strengths, respectively, for B20 concrete. Furthermore, individual results reveal samples with exceptionally high or low strengths. These data can be used to identify potential issues in concrete production or to identify material characteristics that can be improved to enhance concrete compressive strength. The same analyses are conducted for B25 concrete as well. BAEL 91 recommends RC28/RC7 = 1,45 and RC90/RC7 = 1,95 for concrete made with CPA-CEMI or CPJ-CEMII/A cement. The corresponding values for the concrete produced for the 33 rock sampling sites are presented in Table 7. We observe that the minimum values of RC28/RC7 and RC90/RC7 are 1,18 and 1,26 respectively for B20 concrete; 1,15 and 1,39 for B25 concrete, with an average of 1,35 and 1,56 for B20 concrete; 1,43 and 1,67 for B25 concrete. The standard deviations vary between 0,16 and 0,22 for both concrete classes. It is clear that the standard deviations for the batch of 33 sampling sites are all less than 5. Therefore, in terms of dispersion control, we can conclude that the concretes produced in this study are very consistent and well-controlled [6]. For a large number n, the characteristic strength is defined as follows [6]:

$$f_{ck} = \overline{f_c} - k_1 S \qquad \text{………………(1)}$$

The value of k_1 depends on the order P% of the acceptable risk (% of values likely to be lower than f_{ck}in the entire production). By considering the values of$k_i$from table 8 and applying formula (1), we obtain the values presented in table 9.

CONCLUSION

In this study, we assessed the age coefficient to estimate the strength at j days based on measurements at 7, 28, and 90 days of concrete.

1. The obtained results showed that an age coefficient of X can be utilized to predict the strength at j days. Accordingly, the average RC28/RC7 and RC90/RC7 ratios for B20 concrete are 1,35 and 1,56, respectively, while those for B25 concrete are 1,43 and 1,67. It is evident that the obtained coefficients differ from those proposed by BAEL 91, which recommends an RC28/RC7 ratio of 1,45 and RC90/RC7 ratio of 1,65, corresponding to rates of 80% to 93% for B20 and 86% to 99% for B25.
2. These outcomes underscore the potential for using such a coefficient for accurate concrete strength estimation. However, it is crucial to note that these conclusions are specific to the studied materials, and further research is necessary to assess the applicability of these coefficients to various materials and concrete classes.
3. The observed trends of strength increasing with age align with expectations, with certain exceptions indicating high early-age strength.
4. The proposed age coefficient values differ from the recommendations of existing standards, emphasizing the requirement for context-specific coefficients.
5. These results provide valuable insights for construction practices, suggesting enhanced accuracy in estimating concrete strength. This study serves as a foundation for future research aimed at optimizing concrete formulations for improved performance and can therefore contribute to better strength predictions, enhancing the reliability and efficiency of construction projects.

List of Symbols: Not applicable.

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