# DETERMINATION OF FIELD STRENGTH OF CONCRETE FROM MATURITY FUNCTIONS

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## ABSTRACT

*A maturity function valid for the Ethiopian cement and its equivalent is derived from test results of strength development of concrete in relotion to temperature and time. Making use of the maturity function so obtained, the time for the development of strength of concrete under prevailing field temperature is converted to an equivalent time under the standard laboratory temperature of 20°C. The strength (curing time) of the field concrete is then determined from the standard laboratory curve of the same concrete or cement using the respective equivalent time.*

## INTRODUCTION

The primary objective of the construction industry is the reduction of the cost and construction period of structures. The mounting of assembled formworks, the timely removal and subsequent reuse of forms, using ready-made reinforcements, mechanizing the concreting process and the application of larger filler surfaces could curtail the cost and construction period of concrete structures. The overall progress of the construction, however, is influenced to a very large extent by the hardening process of the fresh concrete which in turns is dependent upon the type of the cement, the composition of the concrete and the curing conditions. The speed of the construction of concrete structures is dependent upon the development of the minimum strength necessary for supporting the dead load and construction load at any particular time during the construction period. It is obvious therefore that the concrete hardening time for the development of the minimum strength necessary for supporting the dead load and construction load is crucial for reducing the cost and construction period of concrete structures.

Formwork costs may range anywhere from 15 to 25% of the cost of the concrete structure (White [1]). Hence one of the areas where significant savings could be realized is in the timely removal and subsequent reuse of forms. Forms should be removed as soon as practicable to provide the greatest number of uses. The criteria for formwork stripping is that the structure must have attained a certain degree of load bearing capacity such that it at least can support its own weight and the construction load with a certain degree of safety and without excessive deformation or crack formation.

Plans and schedules of concrete construction projects are prepared with the view of obtaining optimal construction period and cost. One of the most essential inputs for the preparation of an optimal schedule is the time required to attain the minimum strengths necessary for supporting own weights and construction loads by the various structural elements or parts of cocnrete structures. This may be the period necessary for formwork stripping, the casting of another floor on top of a previously cast one or any other undertaking of a similar category.

It would have been possible to obtain formwork stripping times and the other durations necessary for planning and scheduling from maturity function that are universally applicable if they so existed. However, such maturity functions are not available at present barring those maturity functions that have been derived piece meal for particular cements or compostions of concrete. On the other hand the above mentioned time elements are obtained from concrete site tests for each type of concrete mix design. This is time consuming and expensive. Hence one has to resort to the derivation of maturity functions that are applicable to particular cements and compostions of concrete. It is thus the objectve of this paper to derive a maturity function valid for the Ethiopian cement and its equivalent from test results of strength development of concrete in relation to temperature and time. Making use of the maturity function so derived the time for the development of concrete strength at a particular curing age under field temperature could be converted to an equivalent time under the standard laborartory temperature. Finally the strength of the field concrete could be read off from the standard laboratory curve of the same concrete or cement using the respective equivalent time.

## LITERATURE REVIEW

### Historical Development of Maturity Function

It has been known for a long time that the strength development of concrete is influenced by temperature. Meanwhile there has been the need to determine the effect of temperature on the strength development of concrete, especially in those conutries where the winter temperature is very low and concreting during the winter was impossible. In order to determine the strength development of concrete in relation to temperature and time numerous researches were carried out during the early part of the twentieth century. The results were indicative in a broad manner of the influence of temperature on the strength development of conccrete. There was no consideration of the type of the cement and the composition of the concrete. Consequently researchers could give only general information and recommendations.

After the second world war there was the need to rebuild the structures destroyed and build new and better ones. There was scarcity of manpower due to the casualities of the war. Moreover winter concreting and the industrial production of concrete building elements were not possible due to lack of accurate knowledge of the relation of strength development of concrete and temperatuere. Against this background numerous researches were carried out in the fifties in many countries, among whom are the Soviet Union and Canada. It was manily due to these researches that in the Rilem congress entitled "Winter Concreting" held in Copenhagen in 1956, formulas for calculating the strength development of concrete as influenced by temperature were given for the first time. It w then that heating the building sites for acceler ng the strength gain of concrete was started. The earliest propositions for formulating temperature-time relation came from Nurse (1949), Saul (1952), Hallstrom (1952) and Bergstrom (1953). Bergstrom lead the way with the newst proper research result as reported by (Rohling) [2].

$$f_T = \frac{T + 10}{30} \tag{1}$$

where $f_T$ = maturity function

$T$ = prevailing field temperature in °C

The equation is based on the assumption that cement hydration ceases and strength does not increase at temperature below -10°C.

From the above formula, the so called maturity of the concrete is expressed as follows:

$$M = (T + 10)t \tag{2}$$

For variable temperture $T$, Eq. 2. becomes

$$M = \int_0^t (T + 10)\, dt \tag{3}$$

where $M$ = maturity of the concrete

$t$ = time of hydration

A samll correction of Eqs. 1, 2 and 3 was introduced by Plowmann (1956), in which he rightly asserts that the beginning of noticeable hydration is neither from -10°C as proposed by Saul/Bergstrom nor from -15°C as advocated by nykanen but from -11.5°C. There were numerous contemporary researchers of Bergstrom who came up with various maturity functions. Few of these are presented in Table 1 (2). A great disparity is observed among the functions.

Table 1: Maturity functions for calculating the equivalent time at 20°C and maturity of concrete.

| | Source | Maturity Function | Maturity of Concrete |
|---|---|---|---|
| 1. | Nurse (1949) | $\frac{T_i}{20}$ | $T.t.$ |
| 2. | Henk (1951) | $\frac{T + 3}{30}$ | $(T + 3)t$ |
| 3. | Bergstrom/Saul | $\frac{T + 10}{30}$ | $(T+10)t$ |
| 4. | Nykanen (1954) | $\frac{0.3\ (T+15)}{35}$ | $0.3(T+15)t$ |
| 5. | Ras trup (1954) | $\frac{T-20}{795^{T+78}}$ | - |
| 6. | Plowman (1956) | $\frac{T + 11.5}{31.5}$ | $(T+11.5)t$ |

After few years of prctice with the then available maturity functions, researchers as well as practicing engineers have found out that none of them give satisfactory results in all cases. Consequently, during the subsequent years many functions were proposed by different researchers each claiming a better accuracy.

A feature which is common to all the maturity functions is that only variations in temperature are taken into consideration. In other words, variations in the cement and composition of concrete are not dealt with. Thus for all practical purposes the modelling of maturity functions has concentrated mainly upon the development of temperature-time functions that attempt to allow for the effect of temperature upon the rate of cement hydration.

The proposed maturity functions should have described without exceptions the rate of the hydration process. However it has been indicated by many researchers that none of the functions fully describe the rate of the hydration process. Alexander/Taplin [3] among others have pointed out that the prediction of the strength development of concrete in relation to temperature and time from simple temperature-time functions will at best be an approximation. They did however, show that many of the variations of compressive strength development of concrete were attributable to variation in cement hydration.

A maturity function which is based on the laws of change of the chemical process and as such takes into account the effect of the compound composition of the cement was developmed by Arrhenius, Freiesleben and Hansen [4].

$$f_T = K \exp - \frac{E}{R.T_K} \quad (4)$$

where $f_T$ = maturity function

$T_k$ = temperature in °K

$E$ - activation energy

$R$ - universal gas constant

Despite the fact that the above maturity function is based on the laws of change of the chemical process ad takes into account the compound composition of the cement, the calculated results do not correspond either to experimental results or field experiences. Under the circumstance it is thought that the discrepancy might have been caused by the failure to consider the effects of the specific surface of the cement which is known to influence the strength development of concrete significantly.

It has been clearly indicated in the previous discussions that the failure of the researchers to incorporate the effects of the chemical and physical properties of the cement and the composition of the concrete in their respective maturity functions has brought about the disparity and consequent error in their results. Infact it could be said that the various maturity functions are derived to express the test results obtained by the repsective researchers such that each yields the correct value only for the particular cement and composition of the concrete used in the test. The current thought is that maturity functions should be obtained experimentally by piece meal for each type of cement and composition of concrete. It was with this in mind that tests for the strength development of concrete in relation to temperature and time was conducted for the Ethiopian case.

**EXPERIMENTAL INVESTIGATION**

In Ethiopia there has been the awareness for quite some time now by the users of concrete that the strength gain of concrete is influenced by temperature. The seasons of the year that are classified into two, as dry and rainy pose no problem to the normal strength development of concrete. Moreover there was no prefabrication industry of concrete building elements that require the acceleration of the strength development of concrete. Hence the climatic and other conditions did not exert the pressure to conduct research in this vital area.

However it is to be born in mind that the prevailing temperature during the year ranges from 0°C to 50°C in all the regions taken together. On the other hand it is quite obvious that in order to build concrete structures or any structure to that matter economically, planning and scheduling must be undertaken. The cost estimates, durations, formwork stripping times of activities or operations as well as the time intervals between the beginning of succeeding activities or operations are essentail parameters in palanning and scheduling of concrete structures. These parameters are dependent on the strength development of concrete which in turn depends upon the type of cement, composition of concrete and temperatue. The experiences of other countries in this regard could not be adopted due to the fact that most of the results of their investigations are tied up with particular phases of hardening, cement type, composition of concrete and the use of heat or other concrete hardening process. Hence to obtain the time durations in question site tests of strength development of concrete in relation to temperature and time must be conducted under the prevailing conditions in the various regions of Ethiopia. However, in a contry like Ethiopia where the climatic variations are significant it is almost impossible and expensive to carry out the numerous site tests that would be required from time to time.

On the other hand the strength development of concrete in relation to temperature and time under the standard laboratory conditions is available for different composition of concrete, using Ethiopian cement. From results of laboratory tests conducted under simulated prevailing conditions, it is quite possible to derive a general experssion for transforming the curing age from the field to equivalent curing age under the laboratory conditions. Once the field curing age has been converted to an equivalent laboratoy curing age, the compressive strength of the field concrete could be read off from the standard curve of compressive strength versus time of the concrete. Consequently the laboratory investigation is aimed at deriving an expression for transorming the curing age in the field to an equvalent curing age under the laboratoy condition. The tests were carried out in Leipzing University of Technology in GDR. PZ2/35 alkalis resistante GDR cement that is identical to the Ethiopian cement was used (5).

## TEST CONDITION

In order to determine the strength development of concrete in relation to temperature and time in the temperature range of 0°C to 50°C that is prevalent in Ethiopia, tests were conducted. Standard 50 mm cube mortar samples were prepared using PZ2/35 cement and sand whose grading conforms to ASTM Standard C109(6). Moreover the preparation, storage and testing of the samples were carried out according to the same standard. The most important factors on which the strength development of concrete depends are the cement type, concrete mix design, water cement ratio, admixtures and curing condition. None the less the variations in strength development of concrete is attributable to cement hydration [3]. Moreover the derivation of the maturity function is based on the ratio of the time of hydration at 20°C to the time of hydration at field temperatures, $t_{20°C}/t_{T°C}$. Under the circumstances the use of mortar samples is justifiable.

A total of 125 standard 50 mm cube mortar samples are prepared, stored and tested in 5 batches of 25 samples each. Each batch is tested at a curing age of 9 hours, 24 hours, 72 hours, 168 hours and 672 hours respectively, under one of the selected temperatures of 0°C, 10°C, 20°C, 35°C and 50°C. Initally each batch of 25 mortar samples are stored in a moist room for 24 hours under one of the selected temperatures. Meanwhile, 5 samples at a time are tested at each of the designated testing ages of 9 hours and 24 hours respectively. The remaining 15 samples are then transferred into a storage chamber and kept under water subjected to the same selected temperature as that used in the moist room. The same selected temperature is maintained while 5 samples at a time are crushed at each of the designated test ages of 72 hours, 168 hours and 672 hours respectively. The compressive strengths of the 5 cubes of each batch tested at each of the designated test ages are averaged and the values plotted (Fig. 1). The curves show the strength development of cement mortar in relation to temperature and time.

## Discussion of the Test Result

Examination of the test result plotted in Fig. 1 indicates that the strength development of the samples stored at 0°C, 10°C, 20°C, and 35°C is in accordance with the known trend of strength development of cement mortar or concrete cubes in relations to temperature and time. The favourable effect of temperature on the strength development is clearly manifested. However the strength development of the samples stored at 50°C does not conform to the usual pattern. On close scrutiny it was found out that the particular storage chamber has leaks and as a result the samples were gradually exposed to lesser temperatures. On the other hand it has been found out that at the age of 9 hours there was not a significant difference amongst the strengths attained at the various storage temperature.

The ratios of the curing ages at 20°C to the curing ages at 0°C, 10°C, 35°C, and 50°C respectively were calculated at the ages of 9 hours, 24 hours, 72 hours 168 hours and 672 hours. These values were plotted in Fig. 2 and used for the derivation of the maturity function for calculating the equivalent time at 20°C of the prevailing temperature between 0°C and 50°C valid for the Ethiopian cement and its equivalent. On account of the fact that the experimental results of the samples stored at 50°C turned out to be erroneous the values of $t_{20°C}/t_{50°C}$ used for the derivation of the maturity functions was extrapolated from that of 35°C in light of tendencies known from past experience.

Drawing from the experiences of various researchers numerous expressions were tried to find a curve that passes through the points experimentally determined. The following expression has been found to tally best with the experimental values and the results of the site tests conducted here in Addis Ababa.

$$f_T = \frac{T + 11.5}{31.5}^{1.13} \quad (5)$$

$$t_{20} = f_T t_T \quad (6)$$

where

$t_{20}$ = maturity function

$T$ = temperature °C

$t_{20}$ = equivalent time at 20°C

$t_T$ = time of hydration at $T$°C

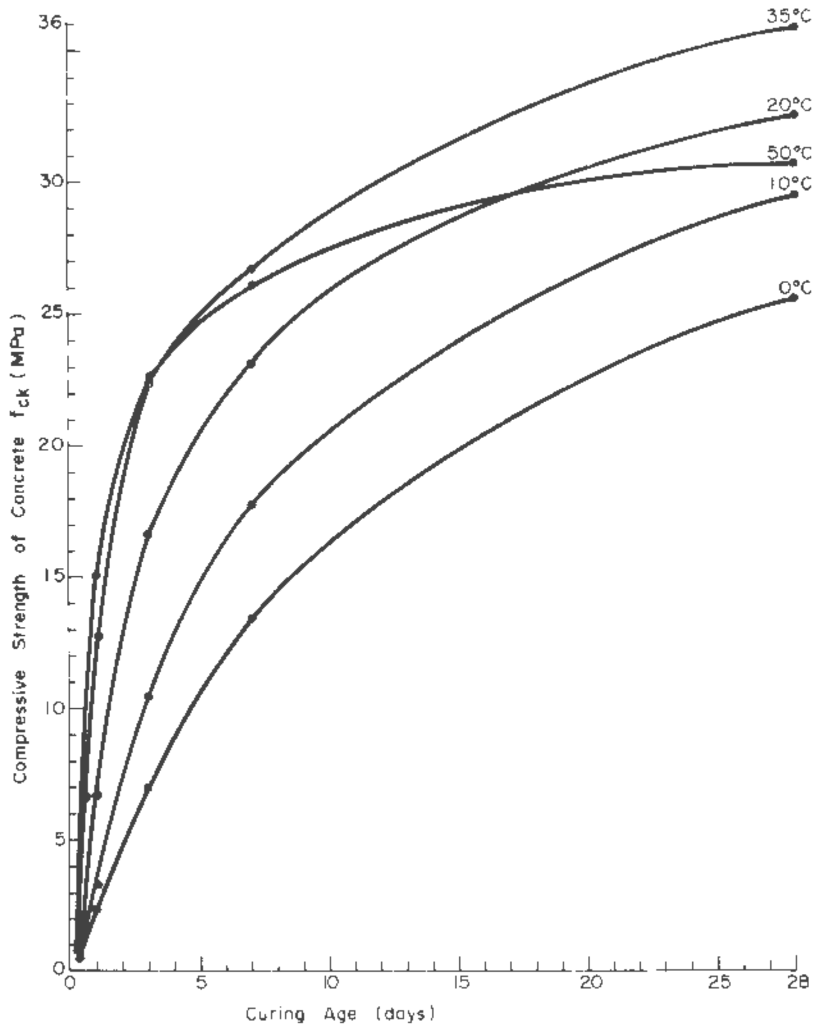


Fig. 1. Strength Development of Concrete in Relation to Temperature and Time.

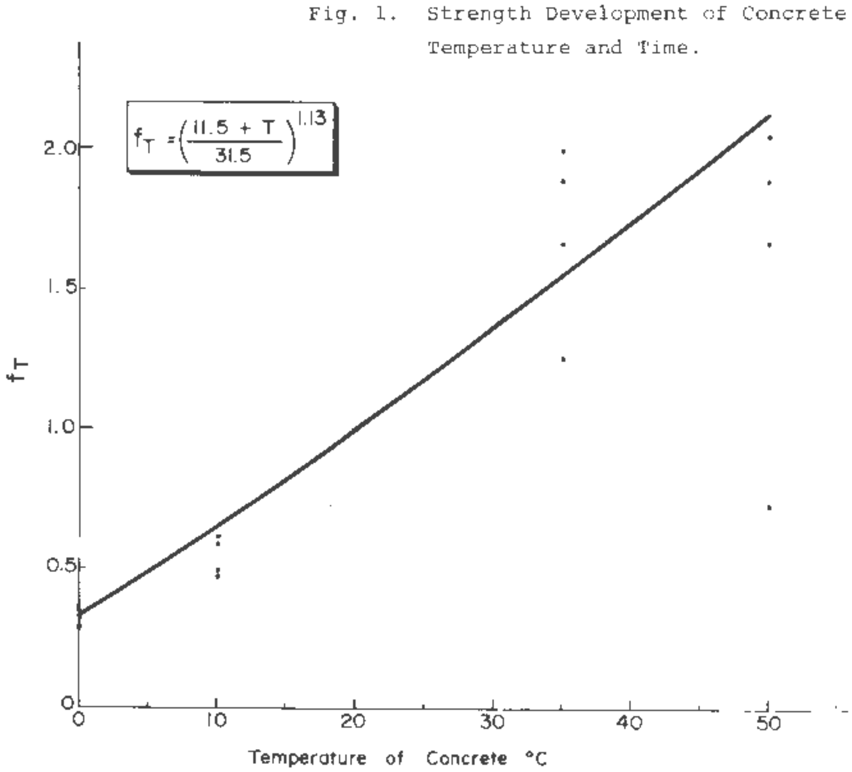


Fig. 2. Maturity Function for Calculating Equivalent Curing Age at 20$^{\circ}$C.

## CONCLUSION

A maturity function for calculating the equivalent time at 20°C for any field temperature of 0°C to 50°C has been derived for the Ethiopian cement. Converting the temperature at the construction site to an equivalent time at 20°C, the strength of the field concrete during the first 28 days period is obtained from the standard laboratory curve of the strength development of concrete in relation to temperature and time for the particular concrete mix-design. Conversely the time required for the concrete to develop a specified strength in the field is determined by means of the maturity function and the standard laboratory curve of the concrete. Consequently activity duration, formwork stripping times and the intervals between

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the beginnings of succeeding activities could easily be determined. These time durations are essential parameters in planning and scheduling using such construction management techniques as the Critical Path Mehod (CPM) and the metra Potential Mehtod (MPM) when determining the minimum cost and construction period of concrete construction projects.

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