THE COMPRESSIVE STRENGTH OF CONCRETE MADE USING CEMENT PRODUCED IN TANZANIA

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ABSTRACT

This paper presents the compressive strength of concrete made using cement produced in Tanzania. The data presented in this paper is based on extensive laboratory testing of the concrete cube compressive strength made at different water-cement ratio using cement from four factories manufacturing cement in Tanzania. The relationship between the water-cement ratio and cube compressive strength are presented. The developed tables can serve as a starting point for carrying out concrete mix design using cement produced in Tanzania and can be used by prospective bidders to estimate the amount of cement required to produce a certain grade of concrete during bidding.

1.0 INTRODUCTION

In accordance with BS EN 197, the cement produced in Tanzania can be classified as CEM I and CEM II. Most of the Tanzania factories are manufacturing two classes of cement, namely 32.5 and 42.5 under a major class of CEM II. Based on information available, one factory can produce cement class 52.5 but only when requested by the potential buyer. Therefore, cement class 52.5 was not used during this study since it is not readily available in the market and is not frequently used in Tanzania. CEM II blended with lime or pozzolana is available in the market; thus, was used during this study.

The compressive strength of concrete mainly depends on the water-cement ratio and is one of the most important concrete characteristics. The water-cement ratio can be used indirectly to assess other characteristics of concrete, like porosity, permeability and durability.

Therefore, understanding the compressive strength of concrete made with Tanzania cement as defined by the relationship between water-cement ratio and the cube compressive strength is very important for practising Engineer in the country. This is particularly important during the tendering stage as the contractor/bidder can estimate the proportional of concrete ingredients, particularly the cement content with reasonable accuracy. Since the cement is the most expensive ingredient in concrete, the price of concrete per cubic metre is primarily dictated by the quantity of cement within the concrete mix for a particular grade of concrete.

In this paper, the relationship between water-cement ratio and compressive strength for class 32.5 and 42.5 cement produced in Tanzania is developed. Based on this relationship, the amount of cement (kg/m^3) content required to produce concrete class 5-40 MPa is estimated.

2.0 TESTING METHODOLOGY

In the context of compressive strength of concrete, various interrelated factors that deserve attention are water-cement ratio, cement type and aggregates. The water-cement ratio bears direct relation with compressive strength, and it is the primary factor from which other properties like durability and permeability can be predicted. The cement type is also a very important factor as the strength development depends mainly on the cement type. The aggregate also plays a vital role in compressive strength since it can limit the compressive strength of concrete, i.e. in very high strength concrete. Therefore, the ability to quantify these interrelated factors and their influence on

compressive strength is of paramount importance.

The relationship between the water-cement ratio and the compressive strength of concrete was established by carrying out several concrete trial mixes using different brands of cement manufactured in Tanzania. These trial mixes were carried out using different aggregates of different geological origin. Crushed sand or pit-run sand was used as fine aggregate depending on the availability. The test results presented herein were collected from different construction sites in Tanzania namely construction of Songea - Namtumbo road, construction of Kilombero bridge, construction of Tabora – Sikonge road and construction of Usagara – Kisesa road. The concrete was made using two coarse aggregates of nominal size of 25 mm and 12 mm, which were blended together to form a continuous grading of 5/25 mm. The cement type used during this study was CEM II [*N or R*] class 32.5[*four cement brands used*] and 42.5 [*three cement brands used*].

Concrete mixes with a different water-cement ratio ranging from 0.3 - 1.0 were made at varied water content and varied cement content to achieve the desired water-cement ratio. The concrete was cast in a set of six 150 mm x 150 mm x 150 mm cubes and was crushed at 28 days for determination of the compressive strength. Based on the achieved compressive strength, the relationship between compressive strength and water-cement ratio for the two classes of cement CEM II 32.5 and 42.5 was established.

3.0 RELATIONSHIP BETWEEN WATER-CEMENT RATIO AND CUBE COMPRESSIVE STRENGTH

The concrete's compressive strength at 28 days at various water-cement ratios made with different cement brands produced in Tanzania is shown in Figure 1 and Figure 2. The 'best-fit curves' is fitted using an exponential regression model with a coefficient of determination [R^2] of 0.96 for class 32.5 cement and R^2 of 0.94 for class 42.5 cement.

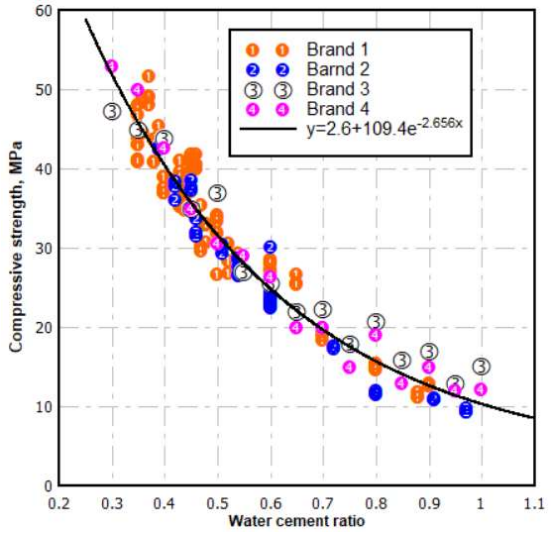

Figure 1: Relationship between water-cement ratio and compressive strength for cement class 32.5 (4 brands)

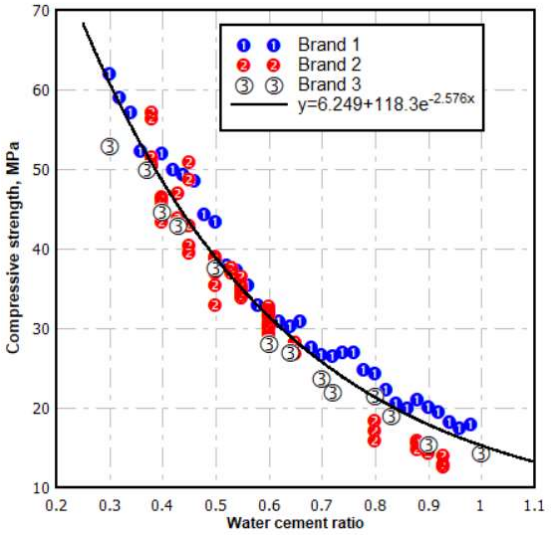

Figure 2: *Relationship between water-cement ratio and compressive strength for cement class 42.5 (3 brands)*

4.0 ESTIMATING THE CEMENT CONTENT REQUIRED TO PRODUCE VARIOUS GRADE OF CONCRETE

Estimating the amount of cement required to produce a certain grade of concrete can be challenging for both experienced and inexperienced estimators during bidding. The relationship between the water-cement ratio and the compressive strength of concrete can be used to estimate the cement content required to produce a certain grade of

concrete with reasonable accuracy. In accordance with mix design procedures as outlined in the Mix Design of Normal Concrete Mixes [3], if there is no previous concrete production data, the margin for any concrete grade is recommended to be 13 MPa [*assuming 5% defective k=1.64, a standard deviation of 8 Mpa, m=1.64*8=13 Mpa*]. However, based on the experience in concrete production, the concrete is typically produced with a standard deviation of about 5 Mpa, assuming 5% defective, the margin of 8 MPa [*5 x 1.64*] is ordinarily sufficient to produce concrete which complies with project specifications. Therefore, for the purpose of estimating the amount of cement required to produce a particular grade of concrete, a margin of 8 Mpa is used.

The concrete compressive strength depends largely on the water-cement ratio, implying that the amount of water used during concrete production governs the compressive strength. The water demand depends mainly on the shape of the aggregates, grading, surface area, and amount of clay in the sand. In most cases, the structural concrete can conveniently be placed and compacted when the slump is in the range of 60-150 mm. In accordance with Normal Concrete Mix Design Manual [3], the water demand is classified for crushed and uncrushed aggregates. Furthermore, the water demand is grouped to yield a slump of 0-10 mm, 10-30 mm, 30-60 mm and 60-180 mm. For this study's purposes, the slump of 60-180 mm has been selected since the structural concrete is placed and compacted within this slump range in most cases. Therefore, this range of slump is selected and used as the basis of estimating the water demand, subsequently cement content required to achieve various grades of concrete. The estimated water content required to yield a 60-180 mm slump is given in Table 1 [3].

Based on the established relationship between water-cement ratio and the compressive strength of the concrete as shown in Figure 1 and 2 and the estimated water demand to achieve target slump of 60-180 mm as shown in Table 1, the estimated amount cement required [kg/m^3] to produce the various grade of concrete is computed. The estimated cement content is shown in Table 3, 4 and 5.

Table 1: water demand required to achieve slump of 60-180 mm[3]

Aggregate size	Water content [l/m^3]	
10	Crushed	250
	Uncrushed	225
20	Crushed	225
	Uncrushed	195
40	Crushed	205
	Uncrushed	175

For computed cement requirements, a margin of 8 MPa for all grade of concrete has been assumed, i.e., for concrete grade 30, the targeted mean strength is 38 MPa. In order to utilise these tables, the user is required to specify whether sand to be used for concrete production is natural pit-run sand or crushed sand. If the type of the fine aggregates to be used for concrete production is unknown then, it is advised for the estimator to use crushed sand, which gives higher cement content to estimate the amount of cement required to produce a particular grade of concrete.

These tables showing the amount of cement for various concrete grades can help the prospective bidder estimate the amount cement required to produce a certain grade of concrete accurately enough for tendering purposes without delay and expense involving obtaining aggregate and making test mixes. During project implementation, the relationship between water-cement ratio and compressive strength provides a good starting point for concrete mix design for any grade of concrete using cement produced in Tanzania

Table 3: The amount of cement required to produce various grades of concrete for 10 mm aggregate size

Cement class 32.5 – uncrushed sand									
Cement (kg/m^3)	252	304	362	417	468	535	608	681	775
Concrete Grade	5	10	15	20	25	30	35	40	45
Water (l/m^3)	225								
Water Cement ratio	0.89	0.74	0.62	0.54	0.48	0.42	0.37	0.33	0.29
Cement class 42.5 – uncrushed sand									
Cement (kg/m^3)	205	250	300	346	395	440	500	562	643
Concrete Grade	5	10	15	20	25	30	35	40	45
Water (l/m^3)	225								
Water cement ratio	1.1	0.9	0.75	0.65	0.57	0.51	0.45	0.40	0.35
Cement Class 32.5 – crushed sand									
Cement (kg/m^3)	281	338	403	463	521	595	625	757	862
Concrete grade	5	10	15	20	25	30	35	40	45
Water	250								
Water-Cement Ratio	0.89	0.74	0.62	0.54	0.48	0.42	0.37	0.33	0.29
Cement class 42.5 – Crushed sand									
Cement (kg/m^3)	227	277	333	384	438	490	555	625	714
Concrete Grade	5	10	15	20	25	30	35	40	45
Water (l/m^3)	250								
Water-Cement ratio	1.1	0.9	0.75	0.65	0.57	0.51	0.45	0.40	0.35

Table 4: the amount of cement required to produce various grades of concrete for 20 mm aggregate size

Cement class 32.5 – uncrushed sand									
Cement (kg/m^3)	219	263	314	361	406	464	527	590	672
Concrete Grade	5	10	15	20	25	30	35	40	45
Water (l/m^3)	195								
Water Cement ratio	0.89	0.74	0.62	0.54	0.48	0.42	0.37	0.33	0.29
Cement class 42.5 – uncrushed sand									
Cement (kg/m^3)	177	216	260	300	342	382	433	487	557
Concrete Grade	5	10	15	20	25	30	35	40	45
Water (l/m^3)	195								
Water cement ratio	1.1	0.9	0.75	0.65	0.57	0.51	0.45	0.40	0.35
Cement Class 32.5 – crushed sand									
Cement (kg/m^3)	252	304	362	416	468	535	608	681	775
Concrete grade	5	10	15	20	25	30	35	40	45
Water	225								
Water-Cement Ratio	0.89	0.74	0.62	0.54	0.48	0.42	0.37	0.33	0.29
Cement class 42.5 – Crushed sand									
Cement (kg/m^3)	204	250	300	346	394	441	500	562	642
Concrete Grade	5	10	15	20	25	30	35	40	45
Water (l/m^3)	225								
Water-Cement ratio	1.1	0.9	0.75	0.65	0.57	0.51	0.45	0.40	0.35

Table 5: the amount of cement required to produce various grades of concrete for 40 mm aggregate size

Cement class 32.5 – uncrushed sand									
Cement (kg/m^3)	196	236	282	324	364	416	472	530	603
Concrete Grade	5	10	15	20	25	30	35	40	45
Water (l/m^3)	175								
Water Cement ratio	0.89	0.74	0.62	0.54	0.48	0.42	0.37	0.33	0.29
Cement class 42.5 – uncrushed sand									
Cement (kg/m^3)	159	194	233	269	307	343	388	437	500
Concrete Grade	5	10	15	20	25	30	35	40	45
Water (l/m^3)	195								
Water cement ratio	1.1	0.9	0.75	0.65	0.57	0.51	0.45	0.40	0.35
Cement Class 32.5 – crushed sand									
Cement (kg/m^3)	230	277	330	379	427	488	554	621	706
Concrete grade	5	10	15	20	25	30	35	40	45
Water	205								
Water-Cement Ratio	0.89	0.74	0.62	0.54	0.48	0.42	0.37	0.33	0.29
Cement class 42.5 – Crushed sand									
Cement (kg/m^3)	186	227	273	315	359	401	455	512	585
Concrete Grade	5	10	15	20	25	30	35	40	45
Water (l/m^3)	225								
Water-Cement ratio	1.1	0.9	0.75	0.65	0.57	0.51	0.45	0.40	0.35

5.0 PERFORMANCE OF CEMENT

As expected, the cement class 42.5 was found to be performing better than cement class 32.5.

The compressive strength test results indicate that if natural sand is available, it is more economical to produce concrete using pit run sand due to low water demand as compared to the crushed sand. The use of crushed sand with 32.5 CEM compared to the pit-run sand increases the cement content by 33 kg/m^3 for grade 5 concrete to 103 kg/m^3 for grade 50 concrete. When CEM 42.5 is used, the cement demand is estimated to increase within the range of 27 – 85 kg/m^3. The cement saving using cement class 42.5 over class 32.5 ranges from 37-103 kg/m^3 when uncrushed sand is used. When crushed sand is used, the saving in cement is ranging from 44-121 kg/m^3. The cement content increase is computed from Table 4 for 20 mm aggregate size, which is the most used aggregate size for structural concrete production.

6.0 PRODUCTION OF HIGH STRENGTH CONCRETE

Usually, the use of cement of more than 500 kg/m^3 is not recommended, firstly the cost can be prohibitive. Secondly, the high content of cement can lead to a generation of high heat of hydration, leading to cracking of the structure. Table 4 shows that cement class 32.5 can be used economically to produce concrete grade up 30 MPa and 25 Mpa using uncrushed sand and crushed sand, respectively. Cement class 42.5 can be used economically to produce concrete grade up to 40 MPa and 35 MPa using uncrushed and crushed sand, respectively.

Therefore, the production of concrete grade 45 and above requires the use of suitable superplasticiser and/or cement extender such as silica fume or fly ash.

7.0 DISCUSSION AND CONCLUSION

Based on the compressive strength test results, it is evident that the Portland cement produced by Tanzania factories can be used for the production of concrete grade up to C40. For the higher grade of concrete

exceeding C40, the use of a superplasticiser or cement extender shall be sought.

These developed water-cement ratio versus compressive strength and the associated Tables provide a useful starting point for designing competitive concrete mixes using cement available in Tanzania. It also provides reliable guidance for the estimator during the bidding stage to estimate the amount of cement required to produce a particular grade of concrete with reasonable accuracy.

REFERENCES:

1. BS 12: 1991, **Specification for Portland Cement,** British Standard Institute 1991.
2. BS 882: 1992, **Specification for Aggregates from Natural Sources for Concrete,** British Standard Institute 1992.
3. **Design of Normal Concrete Mixes, Building Research Establishment**, Second Edition, 1997, Reprinted 2002