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Full Length Research Paper

Effect of cement content and water/cement ratio on fresh concrete properties without admixtures

Khaled Marar[1]* and Özgür Eren[2]

[1]Department of Civil Engineering, European University of Lefke, Gemikonağı-Lefke, North Cyprus, Mersin 10, Turkey.
[2]Department of Civil Engineering, Eastern Mediterranean University, Gazimağusa, North Cyprus, Mersin 10, Turkey.

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This paper investigates the effects of cement content and water/cement ratio on workable fresh concrete properties with slump changing between 90 to 110 mm, and determines the relations among fresh concrete properties such as slump, compacting factor, VeBe, unit weight and setting times of mortar with temperature history. The experiments were conducted under laboratory conditions on eight different concrete mixtures prepared from ordinary Portland cement (cement contents of 300, 350, 400, 450, 500, 550, 600 and 650 kg/m^3) and crushed limestone coarse and fine aggregates. Relations such as (a) VeBe time/unit weight/slump/K-slump/compacting factor/w/c ratio for cement content, (b) K-slump/compacting factor/unit weight/VeBe time for slump, (c) aggregate/cement ratio/unit weight/VeBe time for compacting factor, and (d) penetration resistance for elapsed time were determined. It was observed that increasing the cement content causes increase in the slump, K-slump, compacting factor and fresh concrete unit weight, and reduces VeBe time. Proposed fresh concrete relationships are quite appropriate for concretes without using any mineral or chemical admixtures.

Key words: Fresh concrete, slump, compacting factor, VeBe time, unit weight, setting time.

INTRODUCTION

The properties of fresh concrete are extremely important. Consistency and workability of fresh concrete are significant criteria for the concrete mix design proportioning and important properties affecting the placing of fresh concrete on site and the later performance of the hardened state of concrete.

Workability represents diverse characteristics of freshly mixed concrete that are difficult to measure quantitatively. Workability involves certain characteristics of fresh concrete such as cohesiveness and consistency. Cohesiveness (stability) is a measure of the compactability and finishability of fresh concrete. Compacting factor test is used to evaluate the compactability characteristics of a concrete mixture (Mehta and Monteiro, 1993). Consistency, which is the relative mobility or ability of freshly mixed concrete to flow (ACI Committee 309, 1987), is a measure of the wetness of the fresh concrete mix. It is evaluated in terms of slump, and it is the most widely used test for concrete at construction site (Ferraris and de Larrard, 1998; Neville, 2005; Topçu and Uygunoğlu, 2010; Wallevik, 2006). The required workability depends on the type of construction, placement method, consolidation method, shape of formwork and structural design (Khayat, 1999).

Setting of concrete represents the transition phase between a fluid and a rigid state. This period starts when concrete loses its plasticity, becoming unworkable, and it is complete when it possesses enough strength to support loads with acceptable and stable deformation (Pinto, 1999). At the end of the setting period, concrete continuously gains strength with time in the subsequent hardening period (Pinto, 1999; Reinhardt and Grosse, 2004). Rheological properties of fresh concrete vary steadily within the initial and final setting times with consequent decrease in workability, as well as increase of energy consumption at the subsequent consolidation (Kruml, 1990).

*Corresponding author. E-mail: kmarar@eul.edu.tr. Tel: + 90 392 660 2313. Fax: + 90 392 727 7528.

Table 1. Proportioning of concrete mixtures.

Mix number	Cement (kg/m^3)	Water (kg/m^3)	w/c ratio	Aggregates (kg/m^3)			
				Type 1	Type 2	Type 3	Type 4
1	300	237	0.79	217	398	379	813
2	350	235	0.67	211	387	369	789
3	400	240	0.60	203	372	355	759
5	450	248	0.55	195	357	351	729
5	500	250	0.50	189	355	329	705
6	550	264	0.48	179	328	312	667
7	600	270	0.45	171	313	299	639
8	650	280	0.43	163	298	285	609

Test methods usually used to evaluate the alteration of the properties of cement based materials with time after initial contact of cement with water include slump test, flow test, compacting factor test, VeBe test, Vicat needle test, Proctor penetration resistance test and strength test. These methods have different ranges of material properties and are hence applicable to different ranges of time of setting and hardening processes of cement (Kamada et al., 2005). Therefore, the setting of concrete is dependent on the penetration resistance at a given time and the connectivity level between voids and particles such as its consistency just before its placement and vibration (Garcia et al., 2008).

The effect of cement content on fresh concrete properties and setting times is still under research. These properties eventually affect the hardened properties of concrete. On the other hand, unit weight (wet density) of fresh concrete is another strength determining factor. Setting times are needed in order to know the formwork stripping times as well as correct finishing time of concrete. Therefore, this study focused on the effect of cement content (300, 350, 400, 450, 500, 550, 600 and 650 kg/m^3) and w/c ratio (0.79, 0.67, 0.60, 0.55, 0.50, 0.48, 0.45 and 0.42) on fresh concrete properties together with setting times and temperature changes of concretes having slump values between 90 to 110 mm without using any chemical or mineral admixture. The slump test is only suitable for reasonably workable, cohesive mixes. Variations in slump measurements for a slump value of less than 90 mm and higher than 110 mm may indicate a very wet concrete and may not be useful for comparison between different mixtures in this study. This is the reason for choosing a slump between 90 and 110 mm.

EXPERIMENTAL PROGRAM

Materials

In this study, eight different mixes were made (Table 1). Portland cement of class 52.5 compatible with TS EN 197-1 (2004) was used at different dosages (300 to 650 kg/m^3) to achieve workable concretes. Since Cyprus is an Island, high class cement is generally preferred due to durability requirements. Its physical and chemical properties are shown in Table 2. Four types of crushed limestone aggregates with maximum sizes of 20, 14, 10 and 5 mm were used (Table 3). According to BS 882 (1992), aggregates were combined and proportioned (Figure 1). No mineral or chemical admixtures were added to the mixes. Drinkable water was used for the preparation of concrete mixtures. The specific gravities of aggregate type 1, 2, 3 and 4 are 2.68, 2.67, 2.68 and 2.68, respectively.

Mixture proportions and mixing procedure

All mixtures were made in a laboratory pan mixer with a capacity of 0.018 m^3. The mixed ingredients were placed in the mixer in the following order; coarse aggregates, fine aggregates, cement and water. Dry ingredients (aggregates and cement) were mixed for 60 s. Then, water was added gradually in 15 s and the mixing continued during 3 min. The total mixing time was 5 min. Vibrating table was used for compaction of fresh mixes. The compaction time for all concrete mixes was 1 min.

Experiments on fresh concrete

VeBe test

The consistency of freshly mixed concrete was assessed according to BS EN 12350-3 (2000) using VeBe consistometer (Figure 2).

Unit weight test

According to ASTM C 29-03 (2003), unit weight of fresh concrete (kg/m^3) was done.

Slump test

According to BS EN 12350-2 (2000), slump test (Figure 3) was done.

K-slump tester

According to ASTM C 1362-04 (2004), K-slump test (Figure 4) was done. K-slump tester measures the K-slump consistency reading in

Table 2. Physical and chemical properties of cement PÇ 52.5.

Chemical composition	(%)	Physical properties	
SiO_2	20.88	Fineness-Blaine (cm^2/gr)	3178
Al_2O_3	5.85		
Fe_2O_3	3.56	**Setting time (min):**	
CaO	65.38	Initial	150
MgO	0.66	Final	190
SO_3	2.85		
L.O.I.	0.89	**Compressive strength (MPa):**	
C_2S	23.07	2 days	26.1
C_3S	57.85	7 days	38.6
C_3A	9.55	28 days	52.8
C_4AF	10.83		
		Flexural strength (MPa):	
		2 days	5.28
		7 days	7.59
		28 days	8.66

Table 3. Physical and mechanical properties of crushed limestone aggregates.

Property	Type of crushed limestone aggregates (maximum aggregate size in mm)				
	Type 1 (20 mm)	Type 2 (15 mm)	Type 3 (10 mm)	Type 4 (<5 mm)	British standards limit
Relative density (SSD)	2.68	2.67	2.68	2.68	-
Relative density (Dry)	2.67	2.65	2.65	2.62	-
Absorption (% of dry mass)	0.65	1.00	1.01	1.20	-
Apparent specific gravity	2.70	2.71	2.73	2.80	-
Impact value (fines %)	19.87	-	-	-	Max. 25
Crushing value (fines %)	25.38	-	-	-	Max. 30
Dust content < 75 μm (%)	-	-	-	13	-

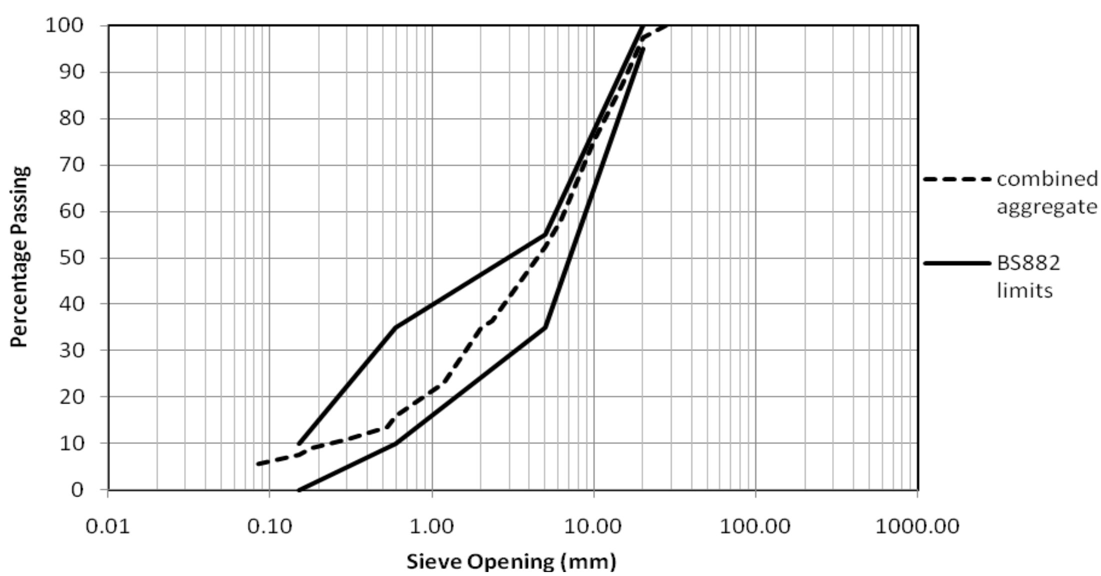

Figure 1. Particle size distribution of limestone based crushed rock combined aggregate.

Figure 2. VeBe consistometer test.

Figure 3. Slump cone test.

Figure 4. K-slump test.

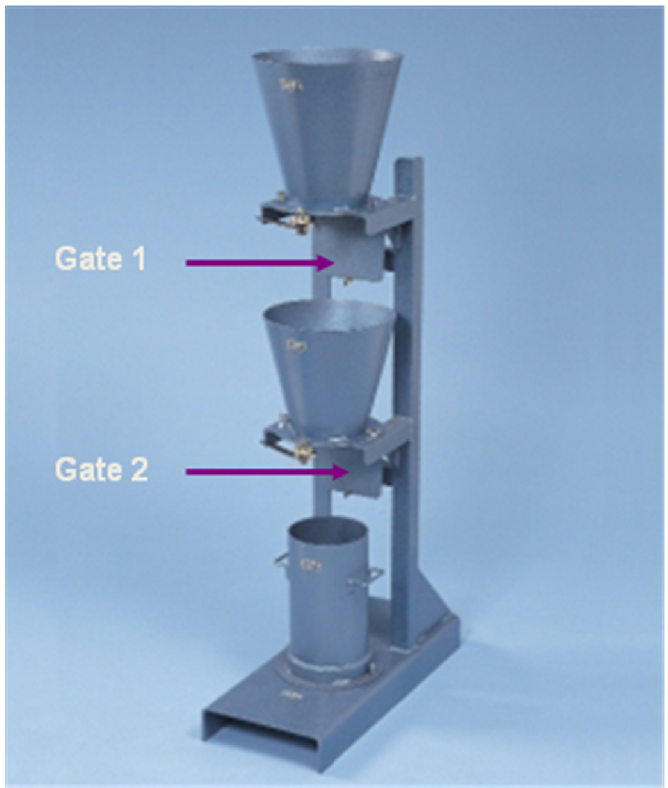

Figure 5. Compacting factor test.

centimeters; also it is used to determine a workability index which is an indicator of workability and compaction. The K-slump readings were averaged from three readings.

Compacting factor test

According to BS 1881: Part 103 (1993), compacting factor test (Figure 5) was done.

Setting time of concrete mixtures

Time of setting of concrete mixtures was assessed according to ASTM C 403-05 (2005), using penetration resistance. In this method, the initial and final setting times are defined as the elapsed time (after initial contact of cement and water) required for the mortar to reach a penetration resistance of 3.5 and 27.6 MPa, respectively.

RESULTS AND DISCUSSION

VeBe time

Results of VeBe time tests are given in Table 4 for all mixes. Figure 6 shows the effect of cement content on VeBe times for the concrete mixes studied.

In general, as cement content increases, VeBe time decreases. Therefore, increasing amount of cement in

Table 4. Properties of fresh concrete and compressive strength at 28-day of all mixtures.

Mixture number	Compacting factor	Unit weight (kg/m^3)	K-Slump (cm)	Slump (mm)	VeBe Time (s)	Compressive strength (MPa)
1	0.962	2304	0.25	90	3.30	23.4
2	0.966	2306	0.75	90	3.00	33.1
3	0.966	2310	2.00	95	2.80	39.8
4	0.969	2314	3.00	95	2.60	43.7
5	0.973	2319	5.25	100	2.30	49.4
6	0.976	2320	6.00	100	2.10	52.1
7	0.984	2325	8.25	105	1.92	54.4
8	0.987	2328	9.00	105	1.75	57.1

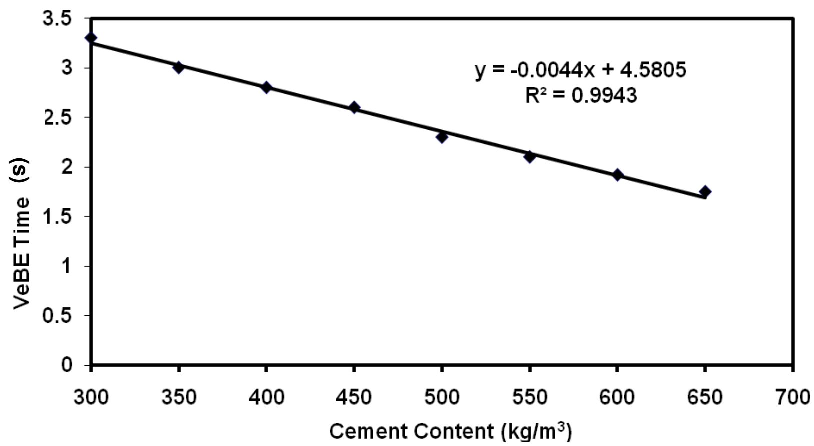

Figure 6. Effect of cement content on VeBe time of fresh concrete mixtures.

the mix and decreasing aggregate content will increase workability and consistency of fresh concrete. The highest VeBe time is obtained in Mix 1 with cement content of 300 kg/m^3 which is 3.3 s. A linear relation is obtained between VeBe time and cement content with a regression coefficient of 0.9943, as shown in Figure 6.

Fresh concrete unit weight

A linear relation is obtained between unit weight (wet density) and cement content with a regression coefficient of 0.9908 as shown in Figure 7. As cement content increases, unit weight increases slightly, because, increasing the amount of cement in the mixture increases the amount of fine materials (cement) and reduces aggregates content, and in turn increases the weight density of concrete.

Slump

A linear relation has been obtained between slump and cement content with a regression coefficient of 0.9524 as shown in Figure 8.

The slump range was restricted between 90 mm to 110 mm to achieve workable concrete. In general, as cement content increases slump also increases.

It can be said that at a given slump, the water requirement increases as the cement content increases and total aggregate content decreases.

Therefore, increasing amount of cement in the mixes and decreasing aggregate content leads to an excess of water in the medium and hence, to an increase of their workability.

K-Slump

A linear relation is obtained between K-slump and cement content with a regression coefficient of 0.9811 as shown in Figure 9. In general, as cement content increases, K-slump values increases. Therefore, workability increases with increasing the amount of cement and decreasing the aggregate content, as a result, the

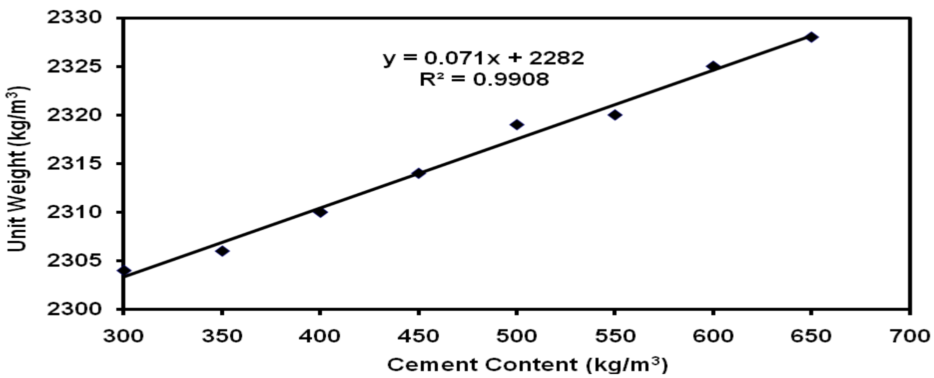

Figure 7. Effect of cement content on unit weight of fresh concrete mixtures.

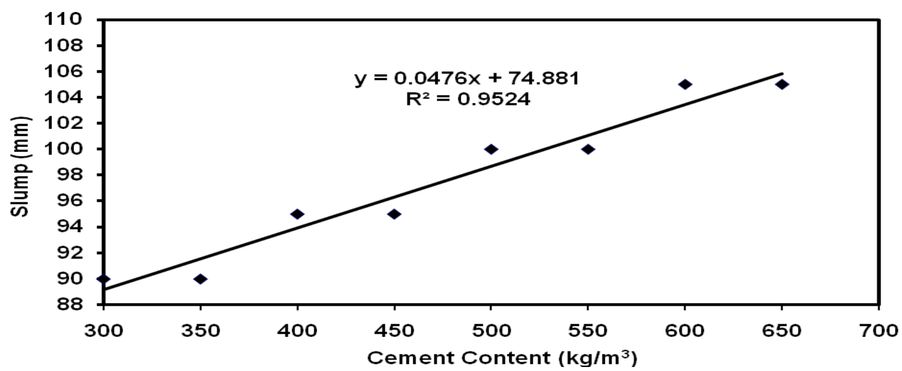

Figure 8. Effect of cement content on slump test results.

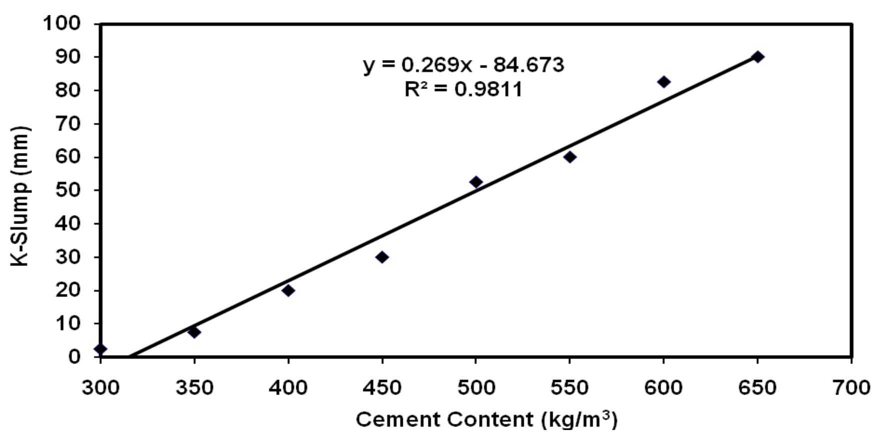

Figure 9. Effect of cement content on K-slump test results.

content of angular and rough texture of the aggregate particles is decreased, and hence, the mixture water requirement is reduced. This increase in K-slump is obtained to be 36 times higher than K-slump of Mix 1.

Compacting factor

A linear relation is obtained between compacting factor and cement content with a regression coefficient of 0.9812

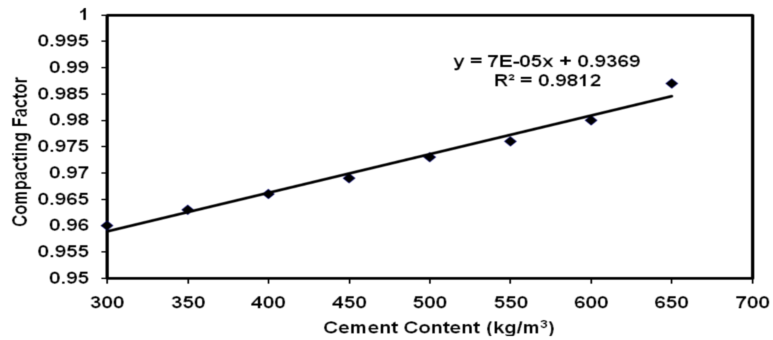

Figure 10. Effect of cement content on compacting factor test results.

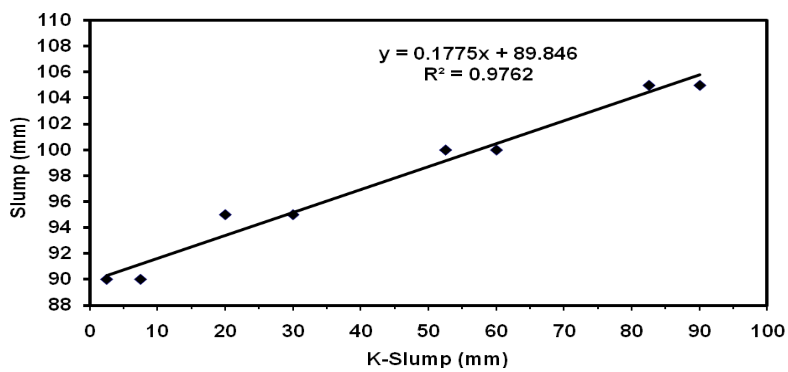

Figure 11. Relation between slump and K-slump test results.

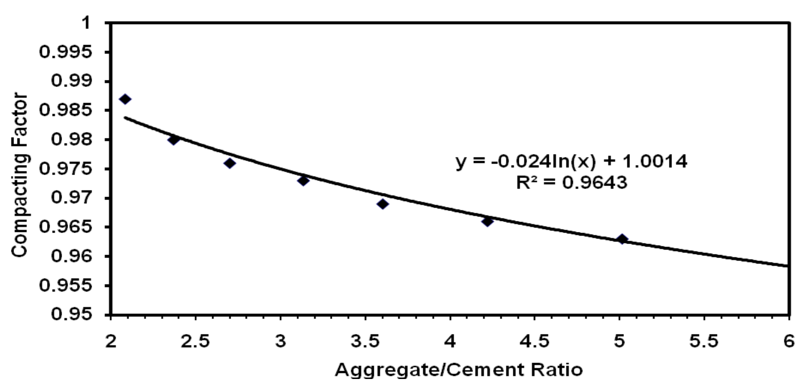

Figure 12. Relation between aggregate/cement ratio and compacting factor.

0.9812 as shown in Figure 10. As cement content increases, compacting factor also increases. This is due to the fact that, increasing the amount of cement in the concrete increases the amount of fine materials, increases water content and reduces the amount of aggregates. Therefore, increasing the amount of cement and decreasing the aggregate content will allow this excess water to increase compacting factor value.

Comparison of test results

A linear relationship between slump and K-slump test results is shown in Figure 11. Therefore, K-slump test could be a guide for the slump prediction of fresh concrete mixture.

The effect of aggregate/cement ratio on compacting factor results is shown in Figure 12. There is a logarithmic

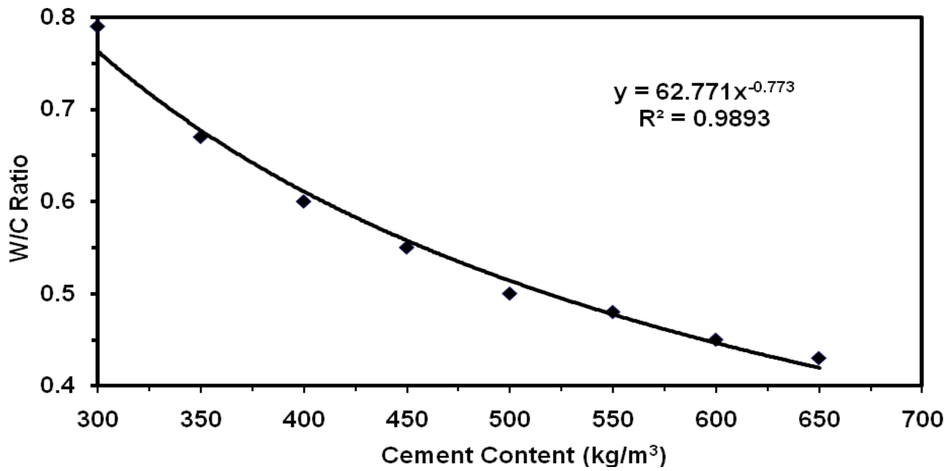

Figure 13. Relation between w/c ratio and cement content.

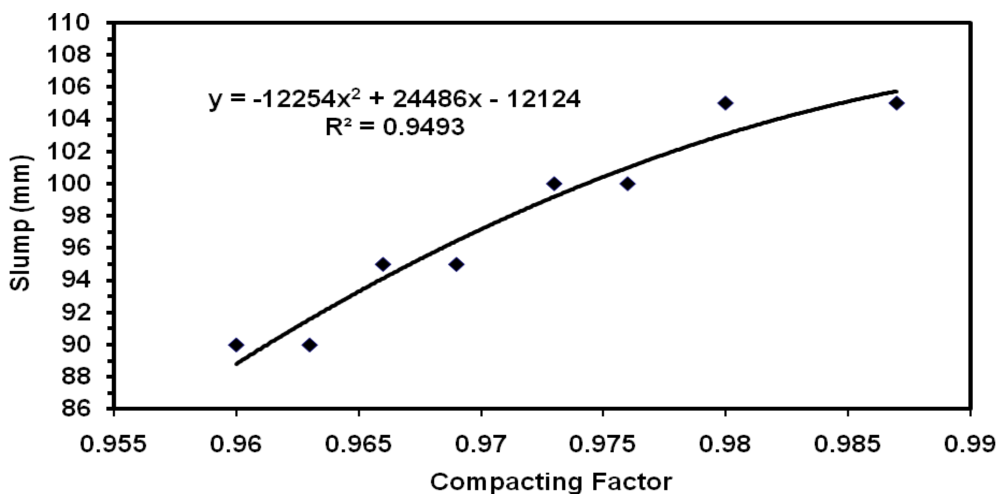

Figure 14. Relation between slump and compacting factor.

relation between compacting factor and aggregate/ cement ratio with a correlation coefficient of 0.9642.

Decreasing the aggregate/cement ratio increases the compacting factor due to the increase in the amount of fines (cement) in the mix and decreasing aggregate content, which acts as lubricant and leads to a decrease in the internal friction between the aggregates particles, and as a result, compacting factor increases.

Very lean mixtures tend to produce harsh concrete with poor workability. Rich mixtures are more workable than lean mixtures, but concrete containing a very high proportion of cement can be sticky (Gani, 1997).

A logarithmic relationship between water/cement ratio and cement content with a correlation coefficient of 0.9893 is shown in Figure 13. In order to design different levels of strength with restricted slump values, the relation in Figure 13 can be used. This relation is valid for mixes made of ordinary Portland cement without chemical or mineral admixtures. It is well known that the strength of concrete increases with increase in cement content because the water/cement ratio can be decreased without loss in workability (Murdock et al., 1991).

Relation with a correlation coefficient of 0.9493 between slump and compacting factor is as shown in Figure 14. This relation can be used if one of these equipment is not available.

A linear relation is obtained with a correlation coefficient of 0.9727 between unit weight and compacting factor as shown in Figure 15. This relation can be used if

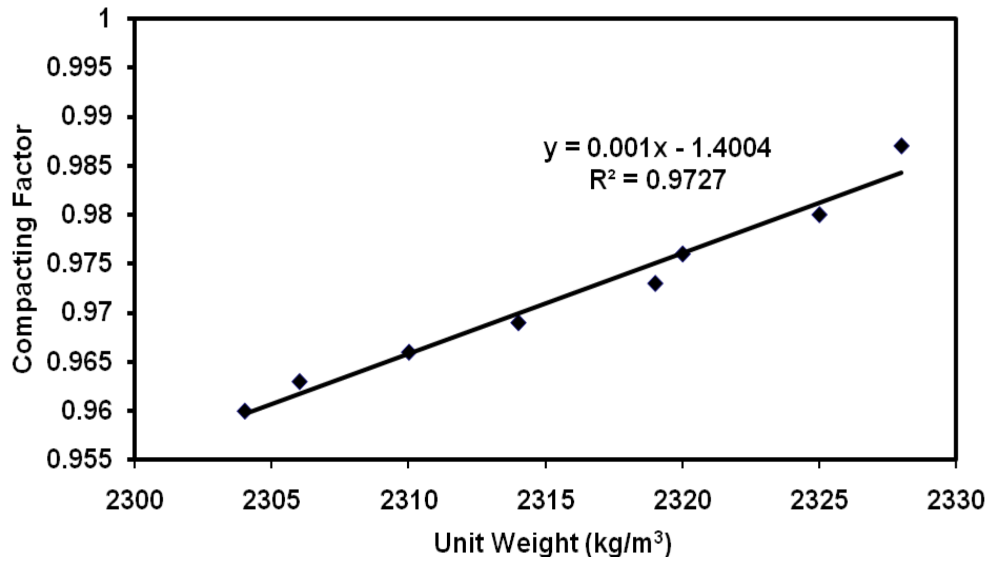

Figure 15. Relation between unit weight and compacting factor.

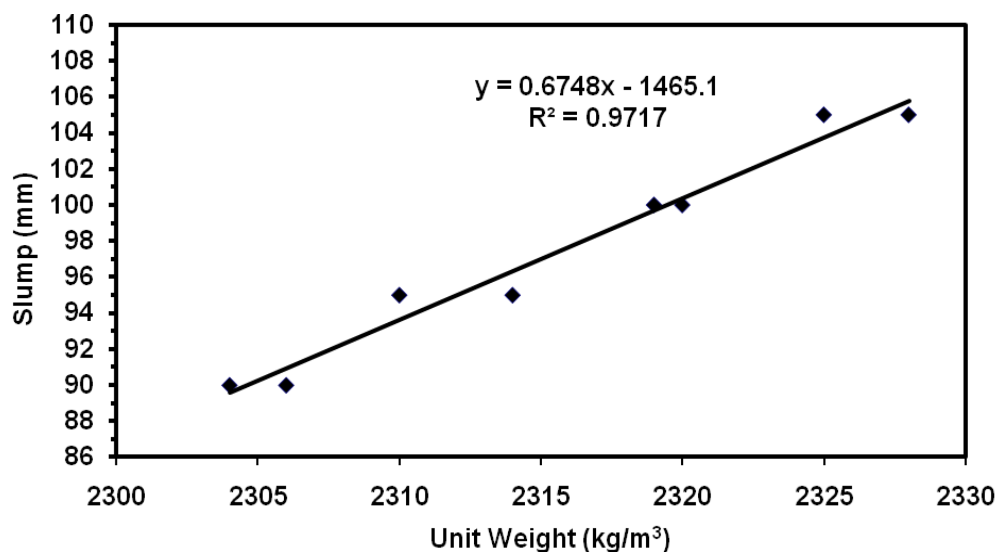

Figure 16. Relation between slump and unit weight.

the compacting factor apparatus is not available. There is a linear relation between slump and unit weight with a correlation coefficient of 0.9717 as shown in Figure 16. This relation can be used if the slump apparatus is not available by using any cylinder with known volume.

Second order relation is obtained between compacting factor and VeBe time as shown in Figure 17. This relationship can be used if one of these equipment is not available. Relationships between different testing methods are dependents upon the mixture characteristics.

Compacting factor is closely related to the reciprocal of workability, and VeBe time is a direct function of workability. The VeBe time test, measures time needed to achieve full compaction of concrete (Neville and Brooks, 2002).

A relationship is obtained, with a correlation coefficient of 0.9503, between the VeBe time and slump as shown in Figure 18. From this figure it can be seen that, as the slump of fresh concrete increases the VeBe time decreases. The influence of richness of mixes on VeBe

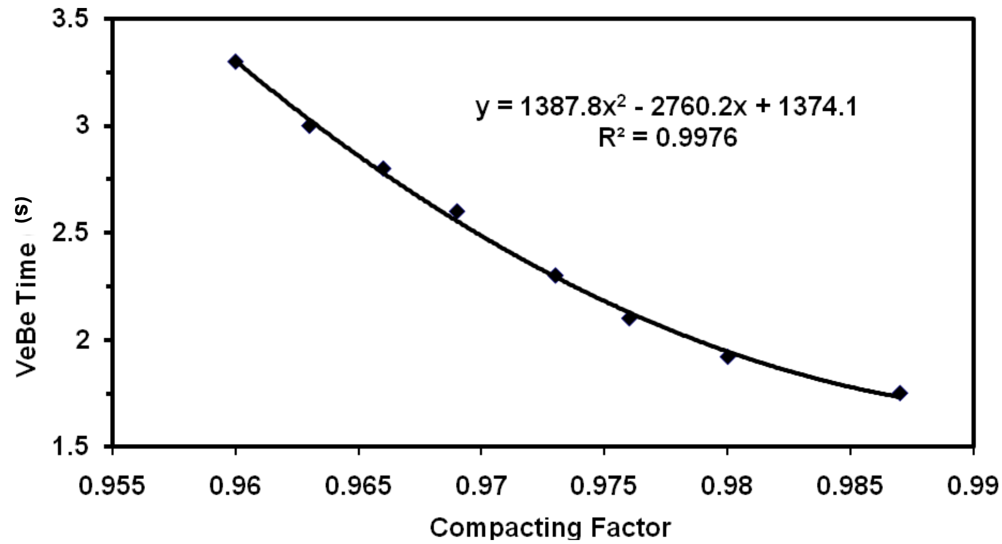

Figure 17. Relation between VeBe time and compacting factor.

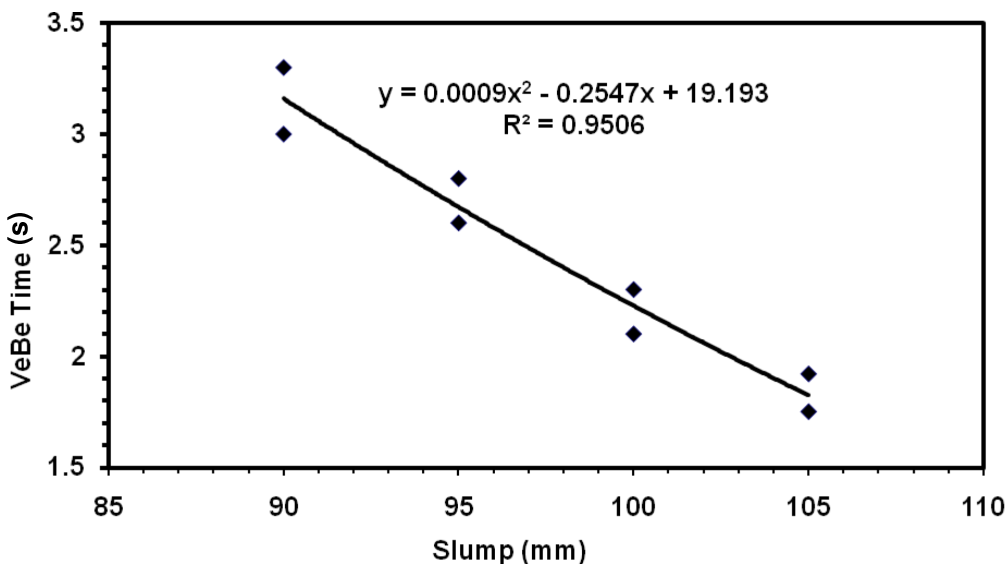

Figure 18. Relation between VeBe time and slump.

time is clear.

Setting time of mortar

Setting time test results are shown in Figure 19. Regression analyses were carried out for natural logarithm (elapsed time versus penetration resistance) as shown in Figure 20. These relations with correlation coefficients are as shown in Figure 20. The correlation coefficients of these relations vary between 0.9653 and 0.9980.

The highest initial setting time is obtained to be 267 min for Mix 1. This increase in initial setting time is 1.35 times higher when compared with initial setting time of Mix 8. The highest final setting time is obtained to be 397 min for Mix 1. This increase, in final setting time is 1.28 times higher when compared with Mix 8. It is observed that the use of higher amount of cement leads to a decrease in setting time of mortar. This decrease in setting times is

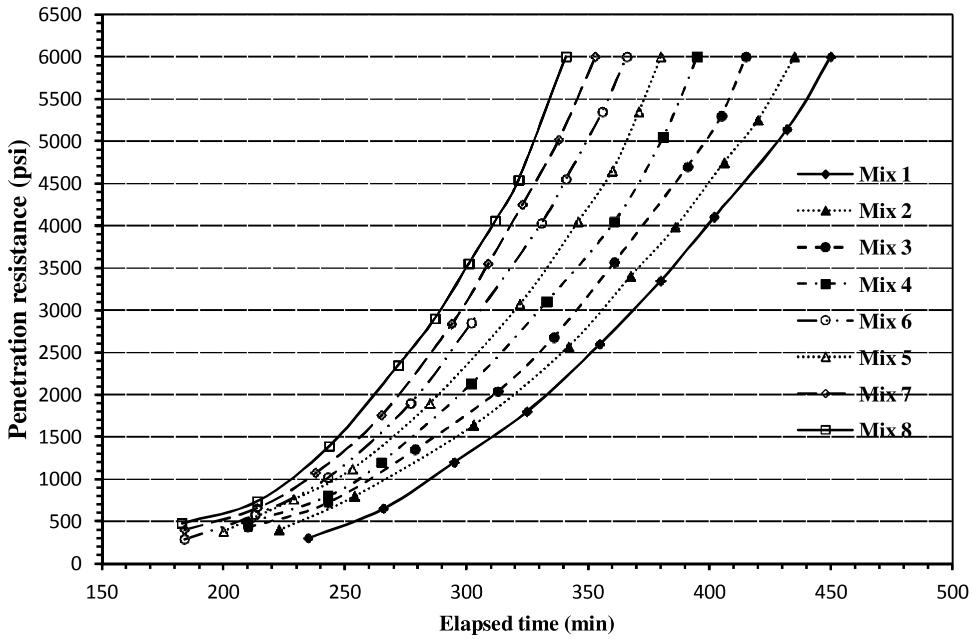

Figure 19. Effect of cement content on initial and final setting times for concrete mixtures (initial set measured at 3.5 MPa (500 psi); final set measured at 27.6 MPa (4000 psi)).

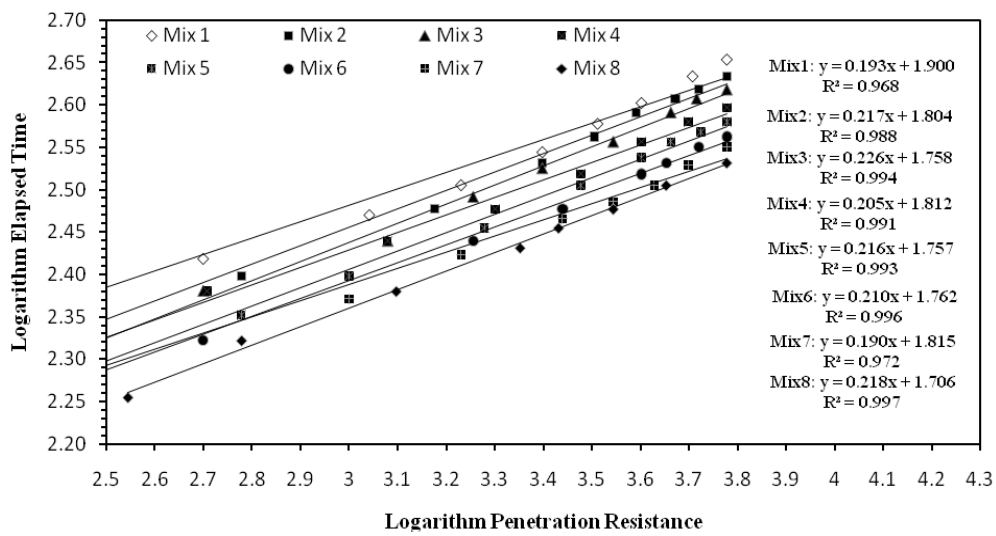

Figure 20. Regression analyses for elapsed time versus penetration resistance for eight different concrete mixtures.

about 3% when 50 kg of cement added in each mix as compared to previous concrete mixture (each addition of 50 kg cement per 1 m^3 of concrete leads to 3 % decrease in setting time).

Temperature variations in concrete for the eight different mixtures during setting time measurements are shown in Figure 21. Figure 21 shows the variation of temperature at initial and final setting times of mortars. From this figure it can be seen clearly that increases in cement content causes increase in the temperature at both initial and final setting times.

Conclusions

Some relations are established among fresh concrete

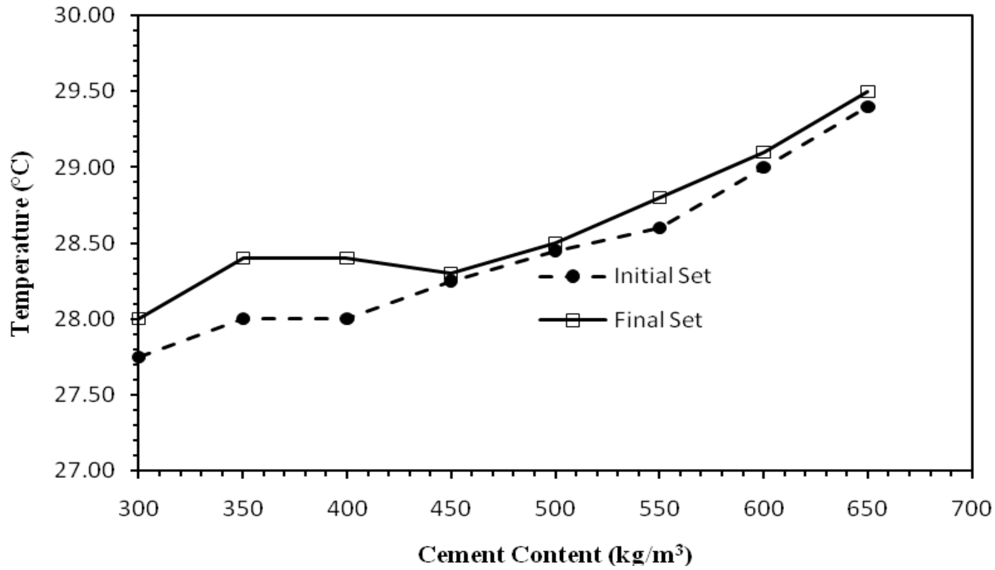

Figure 21. Temperature variation against cement content during measurement of initial (IS) and final setting times (FS).

properties with good correlation coefficients. These relations include: cement content versus VeBe time, unit weight, slump, K-slump, compacting factor and w/c ratio; slump versus K-slump, compacting factor, unit weight and VeBe time; compacting factor versus aggregate/ cement ratio, unit weight and VeBe time; penetration resistance versus elapsed time.

From these relations the following can be concluded:

1. As cement content increases unit weight increases slightly.
2. As cement content increases slump increases.
3. As cement content increases K-slump values increases.
4. As cement content increases compacting factor also increases.
5. Decreasing the aggregate/cement ratio increases the compacting factor.
6. A linear relation between slump and unit weight is obtained.
7. Second order relation is obtained between compacting factor and VeBe time.
8. Slump of fresh concrete increases and the VeBe time decreases.
9. In general, increasing cement content increases the unit weight and workability but reduces the VeBe time and setting time of mortar.
10. It is observed that the use of higher amount of cement leads to a decrease in setting time of mortar. This decrease in setting times is about 3% when 50 kg of cement is added per 1 m^3 in each mix as compared to previous concrete mixture.
11. K-slump can be used instead of cone slump to predict the workability and consistency of concrete. K-slump could be used to predict the VeBe time of fresh concrete.
12. The previous study could be performed for very low and very high workable mixes as a future research work. Also, measurement of temperature development of fresh concrete against time should be done in order to determine the maturity relations for all the mixes.

Nomenclature: ACI, American concrete institute; **ASTM,** American society for testing and materials; **BS,** British standard; **TS,** Turkish standards, **IS,** initial setting time; **FS,** final setting time; **w/c,** water/cement ratio; **PÇ52.5,** Portland cement 52.5; **L.O.I.,** loss on ignition; **SSD,** saturated and surface dry.

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