MAY 2018 M.Sc. in Civil Engineering Ç.ÖZGE ÖZELMACI DURMAZ

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AN EXPERIMENTAL INVESTIGATION ON THE EFFECT OF WATER/CEMENT RATIO ON THE COMPRESSIVE STRENGTH OF READY MIXED CONCRETE DESIGNED BY CHEMICAL ADMIXTURE AND DIFFERENT CEMENTS

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Ç.ÖZGE ÖZELMACI DURMAZ

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Supervisors:

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Ç.Özge ÖZELMACI DURMAZ

ABSTRACT

AN EXPERIMENTAL INVESTIGATION ON THE EFFECT OF WATER/CEMENT RATIO ON THE COMPRESSIVE STRENGTH OF READY MIXED CONCRETE DESIGNED BY CHEMICAL ADMIXTURE AND DIFFERENT CEMENTS

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In this study, an experimental investigation was conducted to investigate effect of water/cement (w/c) ratio on the compressive strength of ready mixed concrete designed by using a chemical admixture and 3 different cements. For each cement type, 5 mixtures were designed with w/c ratios varying from 0.3 to 0.7 without using admixture and 3 mixtures were designed with w/c ratios varying from 0.5 to 0.3 by adding admixture. Compressive strength tests were carried out on the 50 mm cubic specimens at the ages of 7 and 28 days. Tests results revealed that when w/c ratio decreased from 0.7 to 0.5, compressive strength increased about 168.2%, 181.9% and 148.0% for each cement type. Compressive strength reduced with decrease in w/c between 0.5 and 0.3. It was attributed to the influence of insufficient mixing, placing and compaction of concrete as result of the hand mixing method. Superplasticizer was used to improve workability without changing the w/c ratio and significant increases in compressive strength values were observed for w/c of 0.3 about 228.2%, 272.5% and 144.8%. Results showed that cement type has an important role on the compressive strength irrespective of w/c ratio. Compressive strength values of the samples having w/c ratio of 0.5 at the age of 28 days were found to be 26.2, 44.4 and 48.7 MPa for CEMIV, CEMII and CEMI respectively.

Keywords: Ready mixed concrete, water / cement ratio, workability, compressive strength

ÖZET

KİMYASAL KATKI VE FARKLI ÇİMENTOLAR KULLANILARAK TASARLANMIŞ HAZIR BETONLAR İÇİN SU/ÇİMENTO ORANININ BASINÇ DAYANIMINA ETKİSİ ÜZERİNE DENEYSEL BİR ÇALIŞMA

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56 Sayfa

Bu tez çalışmasında, kimyasal katkı ve farkli çimentolar kullanılarak tasarlanmiş hazir betonlar için su/çimento oranının basınç dayanımına etkisi araştırılmıştır. Bu amaçla üç tip çimento ve bir kimyasal katkı maddesi kullanılmış ve s/ç oranı katkı kullanılmadan hazırlanan karışımlar için 0,7 ve 0,3 aralığında katkı eklenerek hazırlanan karışımlar için ise 0,5 ve 0,3 arasında belirlenmiştir. 50 mm küp olarak hazırlanan 24 farklı karışım için 7 ve 28'inci günlerinde deneyler gerçekleştirilmiştir. S/ç oranı 0,7'den 0,5'e düştüğünde, üç farklı harç için basınç dayanımının % 168,2,% 181,9 ve% 148,0 oranında arttığı gözlemlenmiştir. Bununla birlikte, s/ç oranının 0,5'ten 0,3'e düşürülmesiyle basınç dayanımı azalmıştır. Bu durum elle karıştırma metodunun sonucu olarak yetersiz karıştırma, sıkıştırma ve homojen olarak yanlış yerleştirilme etkisine atfedilmiştir. S/ç oranını değiştirmeden karışımın işlenebilirliğini arttırmak için ise akışkanlaştırıcı kullanılmıştır. S/ç oranı 0,3 olan akışkanlaştırıcı ilavesi ile hazırlanan karışımlar için basınç dayanımının % 228,2, % 272,5 ve% 144,8 arttığı gözlemlenmiştir. Sonuçlar çimento tipinin basınç dayanımı üzerinde önemli etkisi olduğunu göstermiştir. 0,5 s/ç oranına sahip betonların 28 günlük basınç dayanımları CEMIV, CEMII ve CEMI için sırasıyla 26.2, 44.4 ve 48.7 MPa olarak bulunmuştur.

Anahtar kelimeler: Hazır beton, su/çimento oranı, işlenebilirlik, basınç dayanımı

To My Family…

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CHAPTER 1

INTRODUCTION

Since the humanity began, people have invented and developed for the binding materials used in the construction. After many years of experience and knowledge, Portland cement was discovered in 1824. After these years, progress has been made on the development of cement production, application and test methods. Since production and application is easy, durable and safe, concrete has started to be used as main building material. In 1914, a truck mixer for concrete transportation was developed, and ready-mixed concrete became widely used. In short time, ready-mixed concrete was produced and used in many countries. As a result of being more easy and safe, using of ready mixed concrete gained acceleration to concrete industry. Thanks to the developments recorded in the concrete industry, performance properties of ready mixed concrete have been more important.

The expected performance of concrete is evaluated separately according to the concrete being fresh or hardened state. One of the important characteristics of concrete is its compressive strength as a hardened state property of concrete, provides information about all the characteristics of concrete [1-2].

Compressive strength of concrete depends on many factors such as positive or negative. The factors include particle size distribution and chemical composition of cement, strength and amount of cement, water and cement ratio (W/C ratio), type and gradation of aggregate, quality of concrete materials, maintenance of concrete, use of chemical and mineral additives, actual reaction temperature, proportions of materials, method of production, method of mixing and replacement, degree of compaction, size and shape of specimen, condition of curing [3-4].

Water-cement ratio is defined as a ratio between mass of water and mass of cement and it has an important role in compressive strength. Excess water content affect compressive strength negatively and it causes decreasing of value of cement mortar strength. However, if the amount of water is insufficient, it is resulted as having poor workability As a result of this knowledge, determination of optimum water content and w/c ratio is important data for compressive strength and directly design of concrete. In the cement paste composed of water and cement, the smaller the ratio of water to cement provides more intensive, stronger, more durable and more sustainable concrete [5].

A certain number of studies have been done to improve the concrete properties. Developments about using methods, testing, modeling and predicting the properties have been obtained. However, there is no detailed study of the effect of the water / cement ratio on the compressive strength of different cement types and chemical compounds. For this reason, it is difficult to estimate the compressive strength for concrete formed by using different cement types and chemical compounds. More studies have to be done in order to contribute to both the ready mixed concrete sector and the coefficients required by the literature.

According to this knowledge, main objective of the thesis presented herein is to investigate the effect of the water-cement ratio on the compressive strength of ready mixed concrete made with different cements and chemical admixtures. For this purpose, concrete compressive strength which have different proportions of w/c were determined by using universal testing machine.

As the content of the thesis, aim and objectives of the thesis are introduced in the first chapter. Then, in the second chapter of thesis, a literature survey was conducted on ready mixed concrete. As the main subject of thesis, effect of water / cement ratio on the compressive strength was explained in the third chapter. Experimental study and procedure were described in fourth chapter that were included materials, mixtures, casting, curing conditions, and test methods. Indication, evaluation, and discussion of the test results are presented in fifth chapter. Conclusion of the thesis and recommendation for future studies are given in last chapter.

CHAPTER 2

READY MIXED CONCRETE

Concrete produced by mixing of materials at the desired rate with the aid of computer control in the mixer or at the concrete plant and delivered to the consumer as a 'fresh state concrete' is called as ready mixed concrete. The basic point which separates the ready mixed concrete from concrete prepared by manually in site is, the ready mixed concrete is a computer controlled production and a prepared concrete by mixing in concrete plant under better control conditions. As a result of preparing under the factory conditions, the fresh concrete production can be achieved as close to real values [6].

2.1 Concrete Making Materials

Making materials of a ready mixed concrete are Portland cement, water and coarse and fine aggregates. The cement paste, which is composed of cement and water, solidifies with the time, binds the aggregate granules (sand, gravel, crushed stone) and sticks, thus allowing the concrete to gain strength. Therefore, strength of concrete depends on strength of aggregate granules and cement paste and adherence between the aggregate granules and the cement paste. Chemical admixtures and mineral admixtures (cementitious materials) improve the performance of concrete and can be used if required [7].

2.1.1 Portland Cement

Limestone and clay are mixed at certain ratios and baked at high temperature occur a clinker. The result of mixing and grinding of the obtained clinker with gypsum and other additives consist a binder is called as Portland cement [8]. When the cement mixed with water, the hydration process begins. The cement particles are partially dissolve in water. Dissolved components react with water at different speed and rates. During the reactions, heat is released and new particles observed.

The resulting new particles cause the cement paste to harden and bind the aggregates with the cement paste and it can sustain its strength and stability even in water. To gain the strength, mission of the cement in concrete is to cover the surface of the aggregate granules and to fill the gaps between the granules and to perform as a binding. Ability of cement paste to perform as binder and filler between aggregate particles is very important effect for the strength of the concrete [9].

According to explained information above, it is possible to obtain the set of concrete and to gain the strength by forming of binds between the aggregates and by the hydration of the cement. The development of hydration that is depended on water and temperature and the heat it releases are very important because of its effect on the properties of concrete. For this reason, the properties of the constituents of cement affect the strength of concrete directly.

The properties of cement paste are related to the properties of the materials that composed of the cement. Compaction and maintenance conditions of cement paste, water / cement ratio, hydration of cement affect the strength of concrete. As the cement dosage increases within certain limits in concrete, the concrete compressive strength also increases. Concrete produced with high strength cement are known to have high strength. The rate and amount of binding of cement paste depends on perfection of the hydration between cement and water. Speed and rate of hydration depends on the cement composition, the cement content and the amount of cement used in the concrete as well as the temperature and humidity conditions [10].

The two main constituent groups formed in the baking of clinker (silicates-aluminates) and the post-addition gypsum (sulfate) directly affects the process of hydration reaction. Chemical properties and effects of components are quite different. The common property of these three components is containing calcium (Ca). Cement main constituents are shown in Table 2.1. Contributions of the cement constituents for strength are shown in Figure 2.1.

Table 2.1 Main Compounds of Portland Cement [8]

Name of Constituents	**Oxide Composition**	**Abbreviation**
Tricalcium Silicate	$3CaO.SiO_2$	C_3S
Dicalcium Silicate	$2CaO.SiO_2$	C_2S
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium Aluminoferrite	$4CaO.Al_2O_3.\ Fe_2O_3.$	C_4AF

Silicates constitute about 75% of clinker. While C_3S constitutes about 55% of the cement volume and has effect on the early strength, C_2S constitutes about 20% of the volume of the cement and there is an effect on the strength with the time. Aluminates constitute approximately 20% of cement. During hydration, C_3A reacts very fast and this is controlled by plaster. To produce volume of cement about 3-5%, gypsum is added to the cement during the grinding process.

Sulphate needed to control the C_3A reaction is provided by addition of gypsum. There are lots of components other than silicates and aluminates in the cement content. However, the effects of these components for the hydration process are not significant. In the process of mixing, aluminates and plaster dissolve and react very quickly in water. Due to the rapid reaction, high heat output observes during mixing. In this process, the gypsum reacts with aluminates and water to form a gypsum gel around the cement particle to prevent the reacting of aluminates very quickly and reduce the temperature. It prevents the concrete from setting suddenly. Silicates dissolve very slowly in water and have no immediate effects on setting. For this reason, during the mixing of the concrete, the aluminates are the dominant compound. For the 2-4 hours after mixing process, it is possible to transport and place the concrete in plastic form due to the effect of gel layer. Workability of concrete is sufficient for 2-4 hours after the mixing, while the duration can be changed by chemical admixtures. When the water becomes oversaturated with calcium ions, new hydration products begin to form and the temperature increases. As a result of binding of new products with each other and aggregate the concrete begins to harden. After the setting starts, the interventions on the concrete cause the permanent segregation. After the concrete has hardened and set, the reaction starts to slow down and the heat output decreases considerably. The hydration products continue to increase and the concrete becomes harder and stronger in time. This period continues for a very long time if unsolved cement particles and water are found in concrete. Strength and durability increase for a long time.

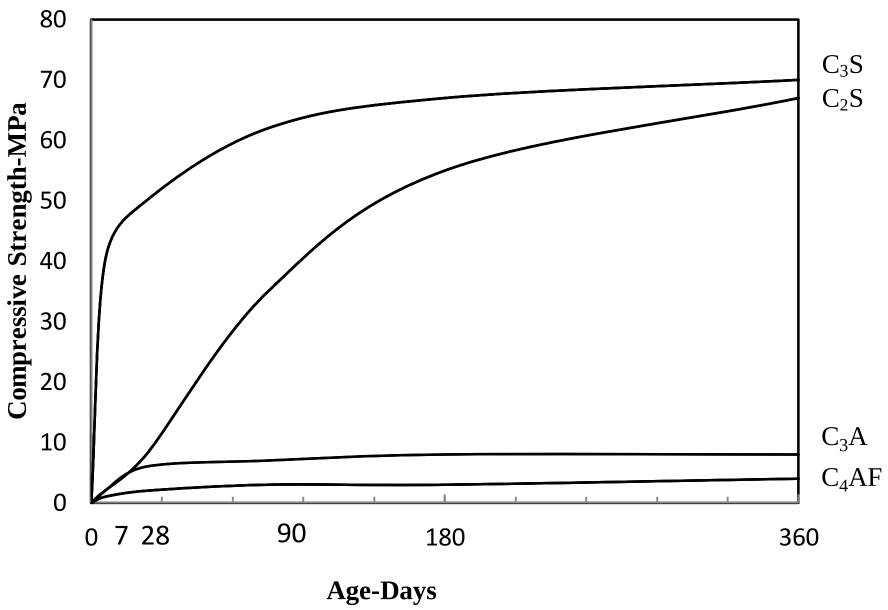


Figure 2.1 Development of Strength of Pure Compounds [11]

C_3S and C_2S are more effective compounds for the strength of hydrated cement. An approximate rule is that C_3S contributes to strength development for the first four weeks and C_2S affects the strength gain after from 4 weeks. However, C_3S and C_2S contribute approximately equally to ultimate strength at the age about one year. Actually, the role of C_3A is still controversial and it has little effect as negligible for the strength while it prevents agglomeration of cement. But it is required for the manufacturing of cement. C_4AF has no effect for the strength properties of cement, but it may delay the progress of hydration of other compounds. [12-13].

2.1.2 Water

Mixing water is wetting the surface of cement and aggregate granules so that the concrete materials can easily be mixed and placed, as result it provides the workability of concrete. Mixing water is also provides the hydration by reacting with cement. To provide workability of concrete and cement hydration, water is a very sensitive and important raw material why the amount and quality of water can affect all properties of fresh and hardened concrete. Since the concrete strength is directly affected by the w/c ratio, the amount of water is also an important influence on the strength.

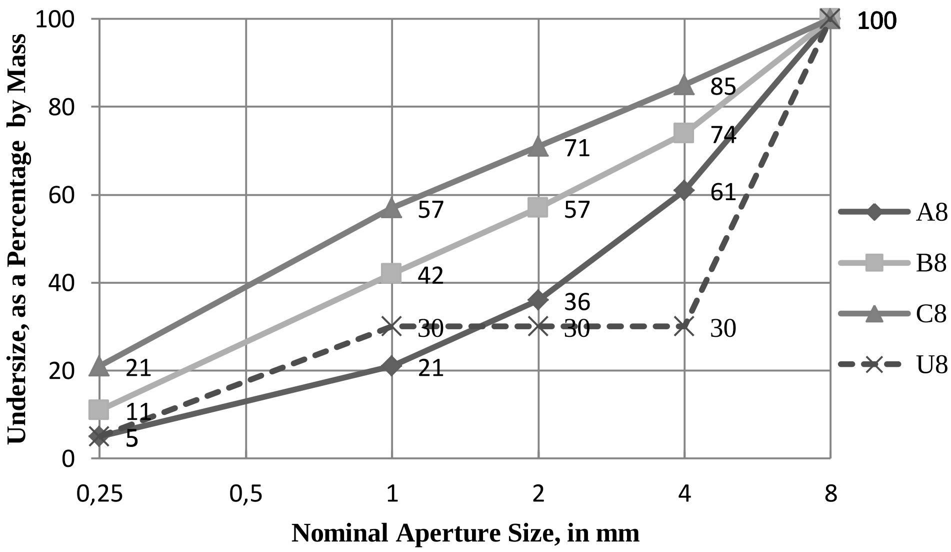
While all drinkable water is suitable for use in concrete, it is not necessary that the water to be used should be drinkable. If the water provides that some preliminary tests requirements, good quality concrete can be produced with non-drinking waters. Water to be used in concrete production should be analyzed according to the standards and the content should be determined. Mixing water should be as clean as possible, it should not contain organic and waste materials that may damage the concrete. The presence of undesirable substances in water affects the rate of reaction between cement and water, as result it affects setting time, strength and durability of concrete.

2.1.3 Aggregates

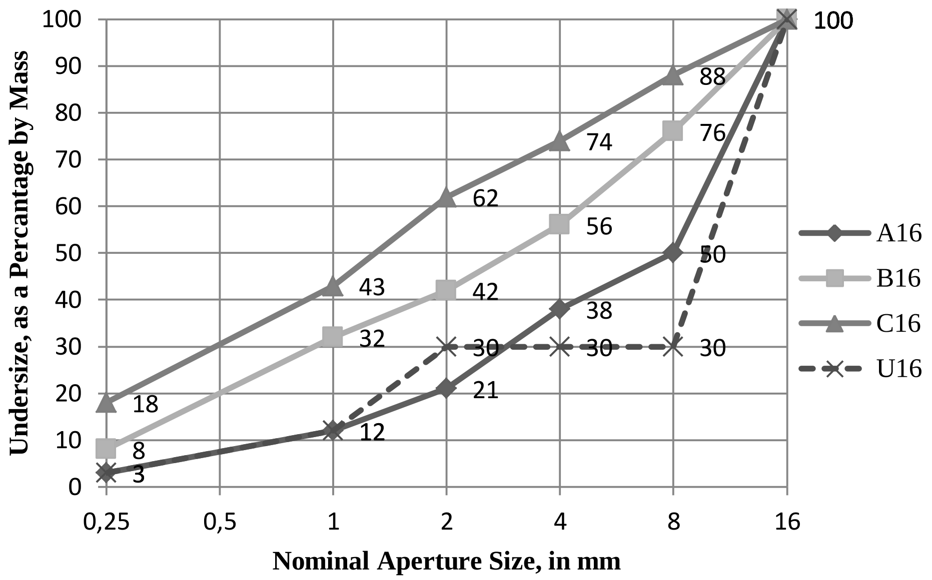
Aggregates are essential concrete making materials that used in concrete production with water and cement and they consist the about 60-75 % of the absolute volume and 79-85 % of the mass of concrete [14]. These are crushed materials obtained with various grain sizes and classified as fine or coarse aggregates according to the sizes. Aggregates are classified also natural or crushed aggregates according to their origin. The classification of aggregates used in the construction of concrete, properties of aggregates especially gradation and the largest grain size, water absorption capacity, specific weight and unit weight are necessary parameter in order to determine the mixing ratio of concrete.

As a result of having larger volume fraction of concrete, the properties of aggregates and interaction between other materials directly affect the durability, strength and mechanical behavior of concrete [15-16]. Therefore, choosing of used aggregates correctly before the design, play a major role for obtaining desired performance properties of concrete [17].

The relationship between cement paste and aggregate particles has physical and mechanical characteristic and it is called as adherence. Adherence between cement paste and aggregate particles, type of used aggregates and surface properties of aggregates directly affect the workability and mechanical behavior of the concrete [18-20]. If excess amount fine aggregate is used in while concrete is being mixed, the workability is increased but the water requirement is also increased. As the water requirement increases, the water / cement ratio also increases and the strength of concrete decreases. In this case, the cement ratio must be increased, but this situation will result as shrinkage. If the coarse particles are used excess amount, the workability is reduced and segregation occurs. Therefore, accurate determination of aggregate gradation is very important for concrete. The aim of the making gradation for aggregate is to determine amount and particle size of materials in the aggregate and to control whether these ratios are within the limits of ideal granulation. Aggregate granulation is determined by the sieve analysis method and it is tested whether these ratios are within the limits of ideal granulation.



a)



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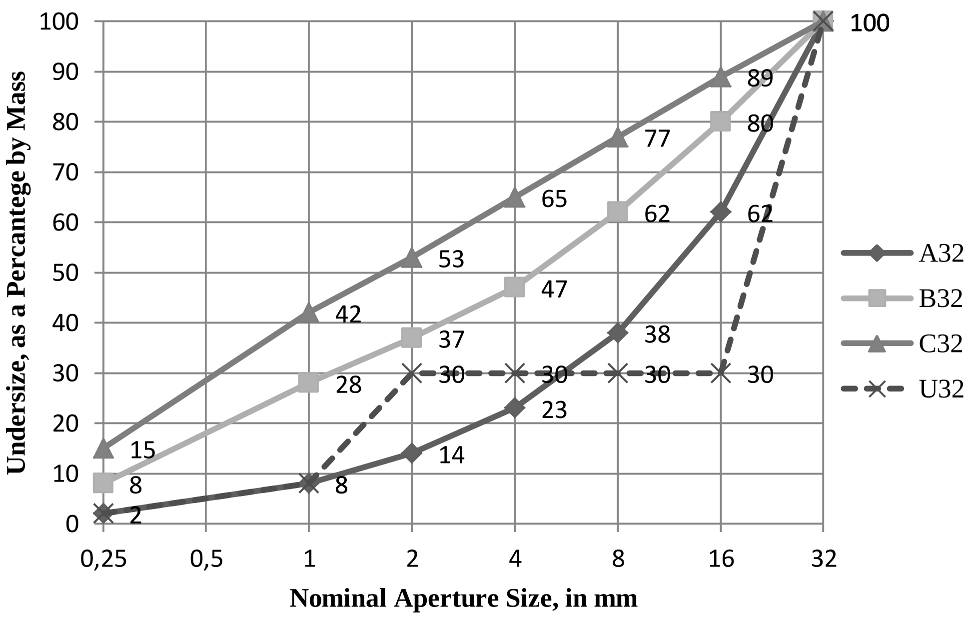


c)

Figure 2.2 The Ideal Granulation Limits According to the Aggregate Sieve Analysis for Maximum Aggregate Size a) 8mm b) 16mm and c) 32 mm [21]

The curves A, B, C shown are continuous granulation boundary curves. It is desirable that the aggregate granulation be between A and C curves. Regions between A and B and region 4 between B and C is taken name as usable regions.

Aggregates in the field with granulation curves falling in regions outside the A and C curves should never be used in concrete construction. Interrupted granulation curves that do not contain moderate-sized particles should be located between the U-curve forming the bottom boundary and the A-curve. There are four ideal granulation limit curve according to the maximum aggregate size as 8, 16, 32 and 63 mm.

2.1.4 Admixtures

Admixtures are organic and inorganic substances that are added to concretes in very low quantities and composed to concrete with water, aggregate and cement. Admixtures are added to mixture before or during mixing stage. In general admixtures are separated to two groups as mineral admixtures and chemical admixtures. Classifications of admixtures are made according to chemical and functional physical characteristic of admixtures [22]. To improve to the properties of the fresh and hardened concrete and cement, admixtures are used in concrete by replacing with cement mass. Admixtures are usually added to reduce cost of construction, to ensure the quality of concrete during mixing, transporting, placing and curing stages and to obtain concrete properties more effectively [23].

2.1.4.1 Chemical Admixtures

Chemical admixtures are essential materials to obtain special concretes such as high fluidity concrete, high strength concrete and underwater concrete. They mainly used to increase the fluidity of the concrete to reach early and high resistance, to provide impermeability and freeze resistance, and to change the setting time by arranging water / cement ratio [24-26]. There are various types of chemical admixtures such as plasticizers, super plasticizers, water-reducers, accelerators, set retarders, air entraining admixtures and some special admixtures for special purpose.

The most widely used chemical admixtures are plasticizers and superplasticizers which are used to reduce the amount of water effectively without changing the consistency, or to increase the slump without changing the amount of water [27]. Plasticizers can achieve higher strength by reducing the w/c ratio, reduce hydration heat by reducing the amount of cement and provide easy placing and workability. In a study, superplasticizer was used for reducing water demand and enhancement strength about 100-250 % at 28 days [28].

To measure the workability of concrete several testing methods are available and one of them is flow table test that carried out to determine concrete consistency. To perform the test, a cone mold is placed in the center of plate. Mold is filled in two steps and each layer of specimen is compacted with a tamping rod. The plate is lifted a distance of 40 mm and dropped 15 times with the attached handle. At the end of test, horizontal spread of the concrete is measured. At a constant water/cement ratio, superplasticizers can increase the workability by raising the slump from 75 mm to 200 mm.

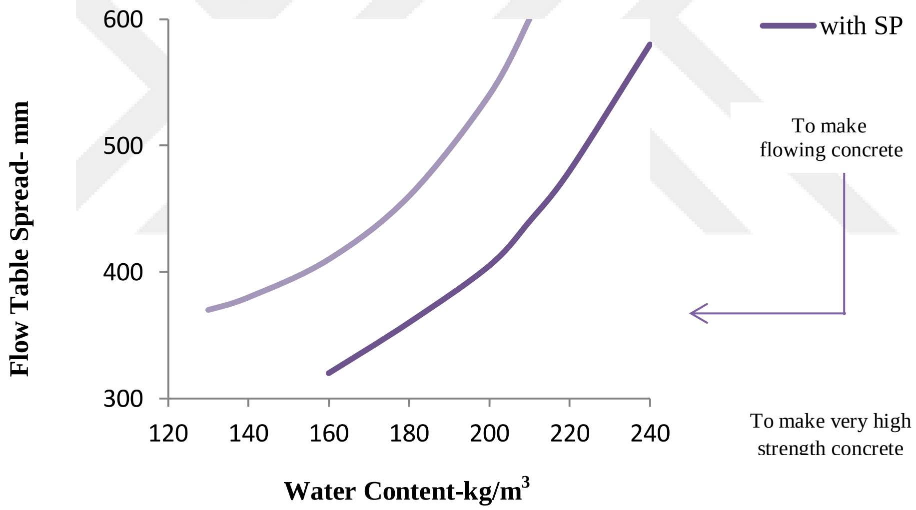


Figure 2.3 The Relation between Flow Table and Water Content of Concrete with and without Plasticizers [29]

The plasticizers have porous structure and are soluble in water. They can reduce the surface tension of the water, prevent the cement agglomeration by dragging the air into the concrete, reduce the internal friction by facilitating the sliding of the granules in the concrete over each other and improve the workability of concrete.

2.1.4.2 Mineral Admixtures

Mineral admixtures are used to reduce the porosity and permeability, to decrease the bleeding of concrete, to increase its fluidity and to increase the strength and durability of hardened concrete, to improve transport property of concrete in this respect [30-32]. Mineral admixtures have many types such as pozzolan, fly ash, ground granulated blast furnace slag, rice husk, silica fume. If the admixtures are used excessively, they may create adverse effects or they may not be useful if they are used less than necessary [33].

2.2 Mix Design

It is a recognized fact that the most critical point of the concrete production process is the correct mix design of the concrete. Mix design can be defined as combination of optimum proportions of used materials and requirements of concrete properties for an application. For the purpose of obtaining the fresh and hardened properties of concrete at the desired level, the mix design of the concrete and the optimum usage of the constituent materials should be determined very well. The most critical property when determining the concrete mix design is the compressive strength in general. With the compressive strength, workability and durability are also major factors affecting the mix design. Durability and compressive strength of the concrete are characteristic of the hardened concrete properties and workability is characteristic of the fresh concrete properties. However, the properties of the hardened concrete are also directly affected by the concrete mix design and fresh concrete properties. For this reason, hardened concrete properties can be predicted in part due to the mix design [34-36].

Before making the concrete mixture design, data and information about material properties are taken from the constituent materials to be used. The dimensions of the element, the environmental effects that the element will be exposed, permeability, strength, durability, density, workability, etc. that the element should have properties are determined. Aggregate grain size distribution, water / cement ratio, amount of water, cement, air and admixture are taken from table or calculated. The mixture designed by calculation is tested with the sample prepared in accordance with this mixing, if the difference between the test results and the calculation is observed, the calculation is corrected according to the difference [37].

According to TS802 processes to be followed when the mix design of concrete, are as shown below [38]:

Maximum aggregate grain size is select which is related to the type and size of the narrowest section of the structural element to be used for concrete. The maximum grain sizes that can be used for some element dimensions have been given on a table in TS802 and some requirements about the reinforcement range have been described in TS802. Selection of maximum grain size can be made by taken into consideration of tables and formulas.

The grain distribution of the concrete which will form the concrete should be selected in usable areas depending on the maximum grain size according to the figures which are shown in TS 706 EN 12620 [21].

Water/cement ratio is selected by taking into consideration the figures in TS802, which shows the compressive strengths depending on the concrete classes, the largest water / cement ratios to be selected according to external influences, and the water/cement ratios depending on the 28 day compressive strengths.

The approximate amount of required water and air and value of the slump that can be used in the calculation of 1m3 concrete mix should be selected in accordance with TS802.

The amount of mixture elements to be found in 1m3 concrete is calculated by the following relation.

$$\frac{C}{\delta c} + W + \frac{Wa}{\delta a} + A = 1000 \text{ dm3} \quad [38]$$

In here:

C = mass of the cement (kg)

δc = density of the cement (kg / dm3)

W = volume of the water (dm3)

Wa = percentage of the aggregate (kg)

δa = density of the aggregate (kg / dm3)

A = total air volume in the concrete (dm3)

2.3 Fresh Concrete Properties

Cement, water and coarse and fine aggregates are mainly constituents materials used in concrete and the mixture which is composed of cement and water, is called as cement paste. While cement paste is initially a plastic material, this plastic property decreases with time as a result of the effect of chemical reactions that starting immediately between cement and water. A few hours laters cement paste solidifies and finally becomes entirely hardened. The plastic concrete at the beginning is placed in the desired mold and the result is a hardening material is obtained at the desired size. The state of concrete which is protected its plastic property is defined as fresh state of the concrete. Properties which are expected from the fresh state concrete, it must easily be mixed, transported, placed, compacted and easy to surface finishing. During these operations it is required that the aggregates and cement mortar must not separate. While the fresh concrete placed in its mold, tendency of the water to rise up must be as low as possible. The homogeneous structure of the concrete must be protected. The length of the time from immediately after the material has mixed and until it lost its plasticity, must not be longer than necessary [39-40].

2.3.1 Workability

All properties that concrete required to be easily mixed, transported, placed, compacted and easy to surface finishing, are defined as workability of concrete [41-42]. The workability of fresh concrete is depends on the grading and grain shape of aggregate, the proportions of coarse and fine aggregates, the quantity and quality of the materials, the presence of entrapped air, the use of admixtures and the consistency of fresh concrete. Consistency of a concrete defined as the ability of fresh concrete to move and it is related to the amount of water in the mixture. Slump Test ASTM C143 applied to characterize the concrete consistency and evaluate workability of concrete for desired application [43-45].

Table 2.2 Slump and Compacting Factor Test Values and Uses in Concrete Workability [43]

Degree of Workability	Slump (mm)	Compacting Factor	Use for which concrete is suitable
Very Low	0-25	0,78	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand-operated machines.
Low	25-50	0,85	Roads vibrated by hand-operated machines. At the more workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration or lightly reinforced sections with vibration.
Medium	50-100	0,92	At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration.
High	100-175	0,95	For sections with congested reinforcement. Not normally suitable for vibration, for pumping and tremie placing.
Very High	Collapsed	Not Applicable	Flow table test is more suitable.

Workability of a fresh concrete is generally involved to its flow properties which is called as its rheology. Two parameters which are relates to flow properties of fresh concrete are plastic viscosity and yield stress[46-47]. First term is yield stress and it represents the stress which is necessary to start or product flow which is also defined as static and dynamic yield stress. Whereas second term is plastic viscosity and it signifies the increase in shear stress with increasing shear rate when the yield stress has been exceeded.

Workability is the most essential property of fresh concrete. After the hydration of the cement, as the amount of water added to provide fluidity for fresh concrete increases, the fluidity of fresh concrete increases, the amount of capillarity pores and permeability increase, but the strength and durability of the concrete decreases [48]. Otherwise, fresh concrete which do not have enough fluidity and workability, sufficient strength and durability cannot obtained due to weakness of homogenous mixing and placing. Placing property of concrete can provide by using plasticizers and superplasticizers without changing of water-cement ratio [49-51].

2.3.2 Segregation

Segregation is defined as tend to separate of coarse aggregate from mortar. There are lots of results of the segregation and can affect the durability and strength of the concrete, continues to be one of the significant issue in the fresh concrete [52].

The tendency of the concrete mixture to segregation is not related to each individual factor independently. It is related to integrated effect of interaction between density difference between mortar and coarse aggregate and interaction between specific surface of coarse aggregate [53].

In the situation of low water content, available concrete mixture for transportation, pouring, casting, placing and compacting without causing segregation due to the water deficiency to lubricate the particles. As a result of this condition, the amount, distribution, shape and size of the voids in the concrete may change and the concrete compressive strength may decrease.

2.3.3 Bleeding

Fresh cement is a heterogeneous paste, containing a liquid and various solid phases. Different particle size distribution and different density are exist in the solid phases. The particle interaction and particle-water interface characteristic changes, due to absorbed organic molecules on the surface of the solid particles. Bleeding and segregation are results of tendency of not only water, but also fine particles to move to their balance position under the effects of gravity and these parameters. Balancing of the particles is generally resulted from the moving downof big particles and tendency of liquid and fine particles to rise up. For a fresh mixture, bleeding is simply defined as the tendency of free water to move rise up [54]. For bleeding, another reason is that the cement is gathered together. The cement particles which come into contact with the water are wetted together instead of getting wet one by one and it retains more water than necessary for hydration. During mixing, this water moves to up after a while.

As a result of bleeding negative effects occurs in concrete. With the upward movement of water, the resistance of concrete to frost is reduced. Strength of concrete against the erosion is weak due to the accumulation of fine grains above. Coarse granules and reinforcement are on the bottom, water and fine granules are above, so the adherence between the particles is weaken. Speed and time of bleeding depend on the concrete compression method, the thickness of the concrete section and the content of the concrete. Bleeding adversely affects the quality of fresh concrete and durability after the concrete hardened [55].

A standard test method which is named as ASTM C232 is used for determining the effects of variables on bleeding of concrete. It also provides a procedure for determination of amount of mixing water that causes of bleeding from freshly mixed concrete [56].

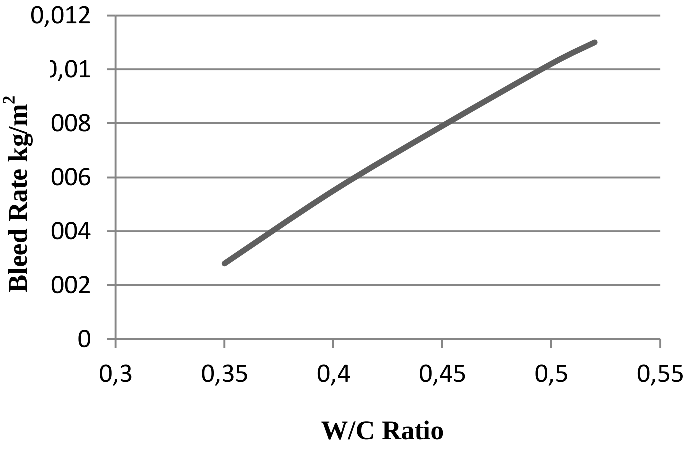


Figure 2.4 Bleeding Rate Per Unit Thickness of Concrete (cm) Versus Water-Cement Ratio [57]

2.3.4 Uniformity

Uniformity in fresh concrete means that sameness and being entirely similar. In a prepared concrete blend which is the total amount of material that will form a concrete, the materials must have a good distribution, and coarse aggregates must not be concentrated in a zone. The workability, unit weight, strength and other properties of a concrete in a blend must be completely same to the workability, unit weight, strength and other properties of the concrete in the other regions of the blend. Similarity of properties of concrete in different regions of blend are called as uniformity [8,40].

In a concrete blend, the use of worn pallets in the mixer, the long or short duration of the mix, and the overloading of the mixer affect the uniformity directly. The uniformity between different concrete blends, is directly influenced from the change of the proportion of the materials forming the concrete for any reason, the change of the amount, type, shape and gradation of the aggregate, the change of cement type, the change of the environment and temperature, the mixing method of the material and the mixer used in the mixing.

2.3.5 Unit Weight

Unit weight is a property of fresh state concrete that is defined as weight of fresh concrete in a unit volume. The unit weight of concrete is an important factor to control the quality of concrete produced.

The high or low value of the unit weight of fresh concrete depends on the properties of the materials forming the concrete, the amount of air voids in the concrete and the design of the concrete mixture. High value of unit weight of the concrete provide by forming the concrete with aggregates which have high specific gravity. Weak aggregate granulation, small maximum aggregate size and the lack of fresh concrete compacting are the main factors that increase the amount of voids in the concrete and thus decrease the unit volume.

2.3.6 Setting Time

Observing the freshly poured concrete at an early age is a desirable ability for long-term performance estimation and quality control. In order to have the desired performance and quality, the mix of the materials forming the concrete must have a certain composition that will reach an appropriate setting time at early age after the concrete forming process [58].

Two important parameters that characterize the material properties of early-age concrete are the initial and final settling times. Setting is defined as the onset of rigidity in fresh state concrete, and is usually viewed as a transitional period between states of fresh and hardened. The initial setting time of concrete refers to the time required for a cementitious material to harden up to a certain compressive strength and concrete begins to lose its plasticity in initial setting time. The final setting time of concrete indicates the time to develop strength and stiffness begins, and at that time the plasticity of the concrete is completely lost [59-60].

Setting time is key parameter of concrete construction fields that helps to improve different concrete processes such as transporting, placing, compacting and finishing of the concrete. The placement of the concrete in a mold depends on the time of the concrete which causes the concrete to harden [61-62].

Setting time determination for cement paste and mortar samples provides usually with two method which are Vicat needle based on ASTM C191 and penetration resistance test based on ASTM C403, respectively. Both Vicat and penetration resistance tests are completely arbitrary measurements that simply define initial and final setting times based on subjective resistance values in prepared paste and mortar samples, yet do not exactly to any specific change in concrete properties [63-65].

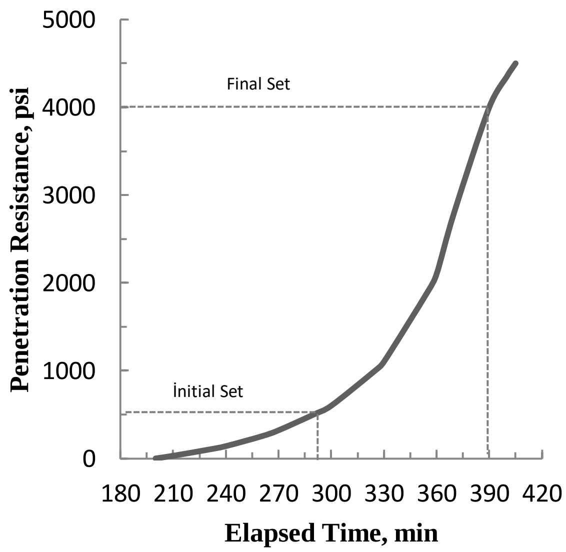


Figure 2. 5 Plot of Penetration Resistance versus Elapsed Time and Hand Fit Curve Used To Determine Time of Setting [65]

2.4 Hardened Concrete Properties

Concrete is construction material which formed by homogenous mixing of cement, water, aggregate and if required chemical or mineral additives. It has plastic consistency in the beginning and can be shaped but concrete solidifies with time to gain strength. In this case where concrete is completely hardened to gain the strength and cannot shaped, is defined as hardened state concrete.

In the hardened state concrete, the concrete must have high strength value of enough to withstand the predicted structural and service loads. It must have resistance to environmental effects such as weather effect, chemical effects and abrasion effects. It must not affect and damaged during its own reaction (between cement and aggregate). If concrete is formed with high quality materials and appropriate proportions and mixing, handling, placing and finishing are done properly in fresh condition, the concrete will have sufficient strength and durability in its hardened state [1].

2.4.1 Strength

Concrete is a brittle material and can change its shape and break due to the load that will applied on it. The maximum resistance of concrete that can show against the cracking and deformation is defined as the strength of the concrete. The loads applied on concrete in different directions can caused to different effects on the concrete. Ability to resist deformation and cracking under load which will cause impact as compressive, tensile, bending and shear effects are defined as compressive strength, tensile strength, bending strength and shear strength, respectively. Ability of resisting under the effect of repeated loads is also defined as fatigue strength. The compressive strength is the most important mechanical property of concrete, because concrete is a brittle material and the highest value strength of concrete is the compressive strength, the lowest is the tensile strength. In practice, concrete is assumed to have no tensile stress and it can crack immediately, and concrete is run only in the compression.

The most essential and easily tested experimentally property of hardened concrete is the compressive strength and it is parallel to other hardened concrete properties. If a concrete has high compressive strength, it means the concrete is hard, strong, durable, impermeable and has resistant to external influences [66].

The standards which are named as TS12390-3 and ASTM C31-39, are test methods used for obtaining the compressive strength of hardened state concrete [67-68]. Compressive strength tests are applied on standard cylinder or cube samples.

Although samples in different sizes are used for compressive strength test, the most widely accepted sample sizes are 150mm x 300m cylinders and 150mm x 150mm x 150mm cube samples for determining the compressive strength of concrete. In addition to widely used sample sizes, 100mm x 200mm cylinder or 100mm x 100mm x 100mm cube samples can be used for compressive strength test. The compressive strength evaluation by using the samples which have smaller size is more effective due to provide easy handling of samples and reducing in material consumption. Smaller cube samples are preferred to apply compressive strength test because of reducing the required effort of testing machine capacity [69-70].The compressive strength is evaluated on 3, 7 and 28 day of concrete samples after the casting in laboratory conditions.

The compressive strength of hardened concrete is dependent on cement strength, aggregate strength and adherence between aggregate and cement. Also water cement ratio, properties of aggregate, cement and water, use of chemical and mineral admixtures, mixing and placement methods and curing affect the compressive strength of hardened concrete [71-73].

2.4.2 Durability

Durability is as important as strength property of hardened concrete. The durable concrete can be defined as the concrete has capacity to withstand the possible deterioration forces acting on the concrete after curing in a certain environment [74-75].

Concrete needs to resistance against to chemical and physical influences that will cause deterioration throughout its service life. Water, oxygen, carbon dioxide, acid, sulphate, salt and chlorine leaking into the concrete may cause chemical changes in the concrete. Chemical affect cause the concrete to expand and deteriorate which is reaction between the alkalis and the aggregates in the concrete. Physical factors are such as forces, wetting-drying, freezing-thawing, warming-cooling and abrasion that cause concrete deterioration and reducing durability [76].

Physical and chemical factors affect the reinforced concrete elements in a negative way. Main factor affecting the chemical and physical processes is transportation of water in cracks and voids concrete due to increased permeability and porosity [77]. The transportation of water and harmful substances into concrete and their interaction with concrete is very important in terms of the deterioration process of the concrete [78]. The deteriorate concrete becomes more porous and reinforcements in the concrete are affected by corrosion and abrasion [79]. As a result, concrete is damaged and the service life of the concrete is reduced.

The permeability of the concrete is largely depends on the permeability between cement paste and aggregate-paste interface because of the aggregate is covered with cement paste and normally contains a small amount of void. Cracks in the cement paste and in concrete are mostly observed due to insufficient compaction and curing, excessive water bleeding that does not enter into a chemical reaction, evaporation, or air-entraining addition. To resistance of concrete to withstand deterioration effects, many factors must be provided such as the strength of the aggregate, the shape, surface roughness, the maximum grain size ,granulation of aggregates and the porosity and the water permeability of the concrete. Reducing the permeability of concrete is provided by the reduced water / cement ratio as much as possible by the use of chemical admixtures.

Water absorption capacity and permeability of hardened state concrete affects the strength of concrete and reduce the durability of concrete against to abrasive physical and chemical events it may observed during its service life. The water absorption properties and permeability of concrete depend on the total amount of voids in the hardened state concrete and condition of being a connection between them or not. These voids can be classified as capillaries and gel voids formed in the cement paste after cement hydration, entrained air bubbles in concrete, voids formed by bleeding and rising up of the water, voids formed between aggregate particles due to the shrinkage, voids caused by aggregate structure and air bubbles in concrete occurs during concrete mixing [80].

In the hardened state concrete, if the voids are not completely filled with water, the water ingress in the voids when the concrete comes into contact with the water and this process continues until the concrete becomes saturated with water. Physical ingression of water into these voids in concrete is defined as the water absorption property of concrete and the amount of water absorption is mainly related to the total volume of voids in the concrete. The total volume of voids is influenced by many factors such as water cement ratio, aggregate type, curing time and condition, size of concrete element. Water absorption capacity directly affects the durability of concrete and concretes with high water absorption capacity have lower strength property.

Harmful liquids and gases that come into contact with the concrete surface can penetrate into the voids in the concrete due to factors such as pressure or humidity difference. Harmful substances in liquids and gases that penetrate into the concrete may affect the structure of the concrete negatively [81]. Penetration of water and harmful substance into the concrete due to the voids of concrete and permeability cause damage and deterioration of the concrete. Concrete should be impermeable as much as possible to prevent damages and deterioration of the concrete, especially in structures that are in contact with water. Durability problems of the concrete start due to the permeability property of concrete. If a concrete formed as impermeable, water and harmful liquids that cause many durability problems cannot penetrate into the concrete. In concretes that are impermeable or very low in permeability, freezing-thawing events or reactions that chemically decompose the concrete cannot observe into the concrete [82].

2.4.3 Volume Stability

Volume stability is generally desired properties of concrete, because the change of volume can cause significant deformation in structure of concrete during its service life. Generally the volume change is the expansion or shrinkage of concrete that are resulted from the wetting and drying process. Decreasing of water in the concrete due to physical or chemical reasons that cause to change of the concrete volume is called shrinkage of concrete [3].

Changing the volume of concrete by losing water can be seen in both fresh and hardened state of the concrete. In fresh concrete, shrinkage is a physical event that occurs due to the bleeding of water on the concrete surface or due to the ingression of water in molds which concrete placed in. The physical shrinkage is called plastic shrinkage when fresh state concrete has not yet lost its plasticity. When the plastic shrinkage occurs on the concrete, cracks are observed in random directions and very rapid evaporation is the most important cause of plastic shrinkage [83].

Shrinkage which occurs in hardened state concrete can causes from the chemical and physical reasons. Drying, carbonation and hydration of cement are the main causes of water loss of concrete, which are called drying shrinkage, carbonation shrinkage and hydration shrinkage, respectively. Drying shrinkage occurs when the temperature is high, the humidity is low or the wind is fast by the water evaporation with in time. Carbonation shrinkage is related to the loss of water in the calcium hydroxide in the cement, and hydration shrinkage is related to water loss in the gaps due to the loss of water required for hydration [84].

Creep is the other important factor that causes volume change in concrete and it is defined as the sustained deformation that occurs due to the loads applied on the materials with in time. Concrete cannot move to its original dimensions even after the load is lifted and the deformation continues permanently due to the creep. Creep causes the volume and dimension change in concrete but it does not cause the concrete to fail or break [85].

CHAPTER 3

EFFECT OF WATER/CEMENT RATIO ON THE COMPRESSIVE STRENGTH

The ratio of mass of water to mass of cement in 1 m^3 concrete is defined as water cement ratio (w/c). The w/c ratio in a concrete mixture is the most important factor on the concrete strength and durability. According to the Abrams law, the compressive strength of concrete is inversely proportional to the ratio of w/c [8,40,71].

If the excess water is used, the amount of capillary voids and permeability generally increase, strength and durability of the concrete decreases [86].

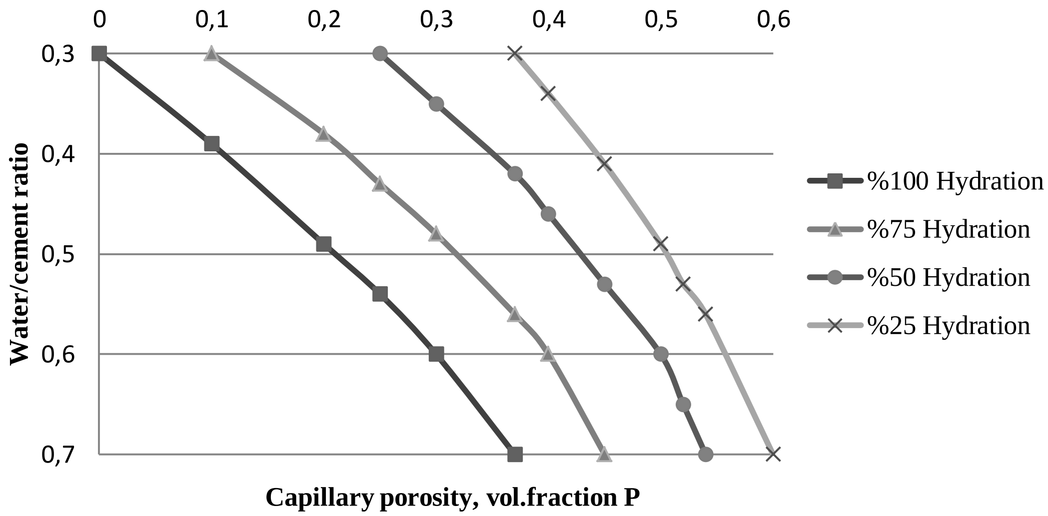


Figure 3. 1 The Influence of W/C Ratio and Degree of Hydration on the Capillary Porosity of Cement Paste [3]

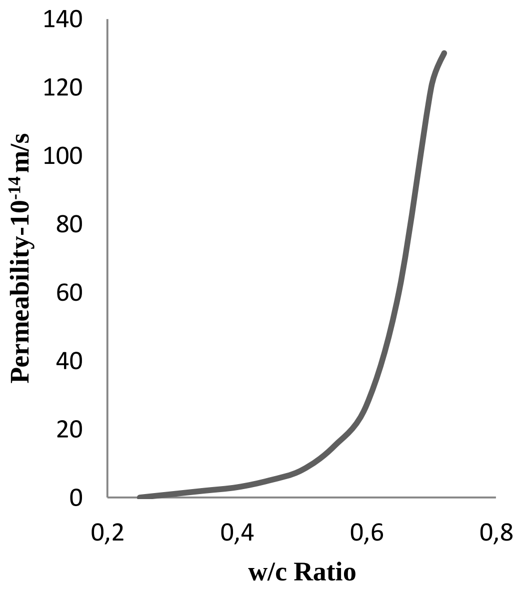


Figure 3. 2 Relationship between Permeability and Water/Cement Ratio for Mature Cement Pastes [87]

However, when water is used less amount, w/c ratio decreases and the concrete will be difficult to its compaction and workability, which will cause the strength to decrease. For the standard tests conducted on specimens, the strength is expected inversely proportional to the w/c ratio of the mixture, if the concrete assumed as fully compacted. However, in practice, for the concrete which has lower w/c ratio, some voids may contained in concrete due to insufficient compaction and significantly reduces its strength. In summary, the strength of concrete which has lower w/c ratio, is extremely lower than expected value due to improper compaction of concrete [88]. For the most applications, the water cement ratio is used a range from 0.45 to 0.60. The minimum water cement ratio is observed as the 0.5 that required to obtain workable cement paste [89].

The role of water in a concrete mixture, it wets the coarse and fine aggregates in the concrete composition and performs the hydration reaction with the cement to make the concrete harden and gain its strength. In addition, water provides to workability for a concrete mixture. As a result of this knowledge, the higher w/c ratio results lower strength value, lower w/c ratio results weak workability and weak adherence between the aggregate grains and cement since the surfaces of the aggregate granules will not be fully wetted if the mixture does not have enough water to make reaction of hydration [90-91].

In a cement paste composed of water and cement, if the w/c ratio is smaller, the cement paste becomes more plastic proportionally to w/c ratio. The cement paste which is obtained with the plastic consistency are gives positively results for the compressive strength, the resistance to external factors and the volume stability. While the concrete mixture is designed, the w/c ratio of concrete is selected according to the various climates, the area which the concrete is pouring and the desired compressive strength.

Certainly there are some negative effects of using less amount of water is added into the concrete. In this case, it is difficult to uniformly place the concrete into the mold. However, difficulty of uniformly placing of concrete into the mold can be eliminated by adding the admixtures to provide plasticizing into the concrete mixture. In order to increase the compressive strength of the concrete, the water / cement ratio should be kept as small as possible, but workability of concrete should be provide by using admixtures that effect the consistency and workability of concrete.

The concrete strength is not obtained at the desired value due to the water cement ratio even if all other factors affect the strength of the concrete are properly designed and it shows the most important factor affecting the concrete strength is the water / cement ratio. Even if a high level of cement and acceptable aggregate granulation is used in concrete design, the desired strength value cannot be reached if the water / cement ratio is high [92]. As the water / cement ratio increases, the strength values of the concrete for all ages decrease.

The water used in the concrete mixture has two main tasks. The first is to provide the water needs required for performing the chemical reactions during cement hydration and the second is to make the concrete mixture so fluid as to place the mold, which is to keep the concrete in plastic consistency. When selecting the w/c ratio, amount of water is tried to be at least greater than the sum of these two water needs. The w/c ratio affects all the physical properties of the concrete, mainly strength and permeability. Increasing the w/c ratio reduces the compressive strength and the durability of the concrete against the external factors [93]. The relationship between water-cement ratio and the 28 day compressive strength of concrete is as shown in the figure below [94].

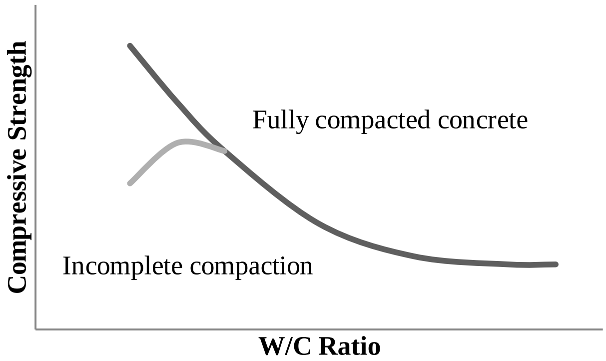


Figure 3. 3 Relationship between Compressive Strength and Water to Cement Ratio [94]

CHAPTER 4

EXPERIMENTAL STUDY

4.1 Experimental Program

The aim of this study is to investigate the effect of w/c ratio on compressive strength for concrete samples prepared by different cements and with and without plasticizing admixture. In accordance with this purpose, 3 different type of cement and a plasticizing admixture were used to prepare concrete mixes. Totally 24 mixes were prepared with different w/c ratio and different type of cement and prepared with or without admixtures. The compressive strength values of the specimens were determined at the ages of 7 and 28 days.

4.2 Material Properties

In this section the required properties of used materials in concrete mix design will be explained.

4.2.1 Portland Cement

Three ordinary Portland cement were used; CEMI-42,5, CEMII-52,5 and CEMIV-32,5. Chemical composition and some properties of the cement used in the study are presented in the Table 4.1.

Table 4.1 Chemical composition and some physical properties of the cement used in the study

Chemical Analysis (%)	Portland Cement (CEMII)
CaO (%)	58,65
SiO_2 (%)	21,72
Al_2O_3 (%)	5,60
Fe_2O_3 (%)	3,54
MgO (%)	3,34
SO_3 (%)	2,45
K_2O (%)	0,67
Na_2O (%)	0,53
LOI (Loss of Ignition) (%)	2,92
Specific Gravity	3,13
Blanine Fineness (cm^2/g)	4010

Chemical Analysis (%)	Portland Cement (CEMIV)
CaO (%)	41,85
SiO_2 (%)	29,72
Al_2O_3 (%)	8,83
Fe_2O_3 (%)	6.06
MgO (%)	4,47
SO_3 (%)	2,06
K_2O (%)	0,88
Na_2O (%)	1,18
LOI (Loss of Ignition) (%)	4,40
Specific Gravity	2,95
Blanine Fineness (cm^2/g)	4929

Chemical Analysis (%)	Portland Cement (CEMI)
CaO (%)	63,91
SiO_2 (%)	18,90
Al_2O_3 (%)	4,71
Fe_2O_3 (%)	2,96
MgO (%)	2,05
SO_3 (%)	3,22
K_2O (%)	0,68
Na_2O (%)	0,24
LOI (Loss of Ignition) (%)	4,14
Specific Gravity	3,10
Blanine Fineness (cm^2/g)	3750

4.2.2 Chemical Admixtures

A chemical admixture, superplasticizer (SP) was used in the experimental program. The properties of superplasticizer as reported by the supplier, presented in Table 4.2.

Table 4.2 Properties of Chemical Admixture

Properties	Superplasticizer
Name	POLITON ARG 01 4171-W
Color	Light Brown
Density(gr/cm^3)	1,076
Solid Content (%)	25,83
PH	4,70
Cloride Content(%)	<0,1
Alkali Content	<10

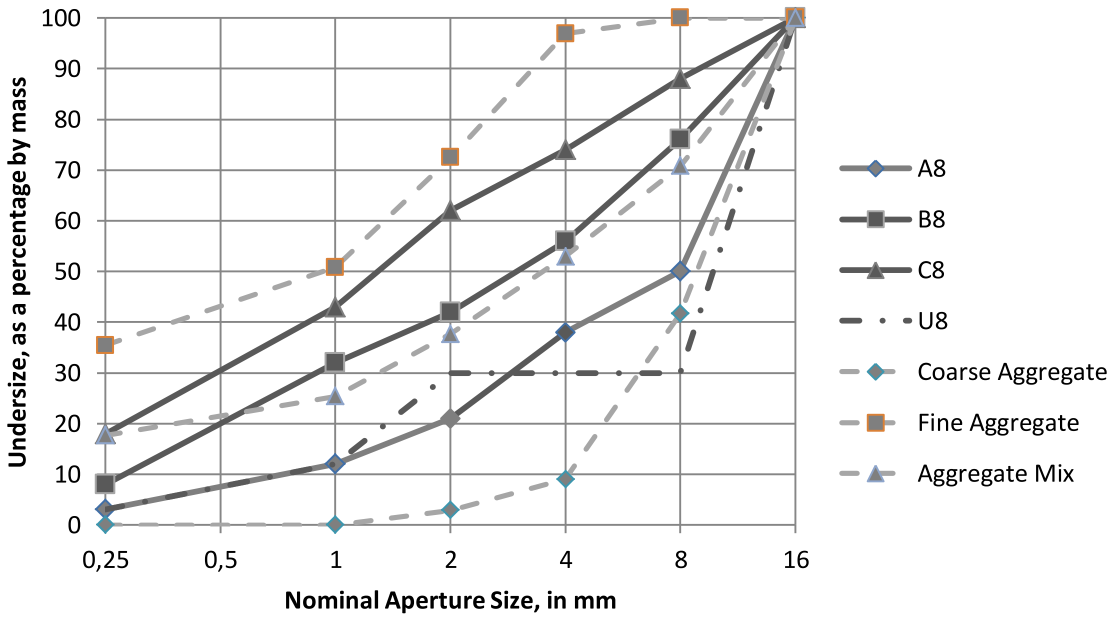
4.2.3 Aggregates

The particle size distribution and specific gravities of coarse and fine aggregates used in concrete production are listed in Table 4.3. Grading curves of the aggregates used in concrete production are listed in Figure 4.1.

Table 4.3 Sieve analysis and some physical properties of the aggregates used in the study

Sieve Size (mm)	Coarse Aggregate (%)	Fine Aggregate (%)
16	100	100
8	41,7	100
4	9,0	96,9
2	2,9	72,5
1	-	50,8
0.5	-	35,4
0.25	-	24,2
0.125	-	16,9
Specific gravity	2,61	2,60

Figure 4.1 Grading curves of the aggregates used and standard reference curves



4.3 Experimental Procedure

4.3.1 Mix Design

Different concrete mixes consisting of 3 different cements, with or without chemical admixtures were prepared to determine the effects of w/c ratio on the compressive strength of concrete. The w/c ratios were selected as 0.3, 0.4, 0.5, 0.6 and 0.7 for samples prepared without using superplasticizer (SP). For samples prepared by using SP, the w/c ratios were selected as 0.3, 0.4 and 0.5. The maximum aggregate size was 15 mm for all mixes. Design of different concrete mixtures are given in Table 4.4.

Table 4.4 The Amount of Concrete Making Materials in Mix Design for a) CEMII, B) CEMIV and c) CEMI

Materials	Mixtures							
	Mix1	**Mix2**	**Mix3**	**Mix4**	**Mix5**	**Mix6**	**Mix7**	**Mix8**
Cement	887,61	665,18	502,52	478,01	455,77	880,16	660,99	500,12
Water	246,12	242,56	224,62	261,46	294,88	244,05	241,03	223,54
Fine Agg.	572,01	666,80	755,61	718,76	685,33	567,21	662,60	752,01
Coarse Agg.	568,65	662,88	751,17	714,53	681,30	563,88	658,70	747,59
SP	0,00	0,00	0,00	0,00	0,00	8,80	6,61	5,00
Unit weight	2274,38	2237,42	2233,91	2172,75	2117,28	2264,10	2229,93	2228,26
W/C Ratio	**0,3**	**0,4**	**0,5**	**0,6**	**0,7**	**0,3**	**0,4**	**0,5**

Materials	Mixtures							
	Mix1	**Mix2**	**Mix3**	**Mix4**	**Mix5**	**Mix6**	**Mix7**	**Mix8**
Cement	872,21	656,49	497,54	473,50	451,68	865,01	652,41	495,19
Water	241,85	239,39	222,39	259,00	292,23	239,86	237,90	221,34
Fine Agg.	562,08	658,09	748,13	711,99	679,17	557,45	654,00	744,60
Coarse Agg.	558,78	654,22	743,74	707,80	675,18	554,17	650,15	740,22
SP	0,00	0,00	0,00	0,00	0,00	8,65	6,52	4,95
Unit weight	2234,92	2208,20	2211,80	2152,29	2098,26	2225,14	2200,99	2206,31
W/C Ratio	**0,3**	**0,4**	**0,5**	**0,6**	**0,7**	**0,3**	**0,4**	**0,5**

Materials	Mixtures							
	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6	Mix7	Mix8
Cement	885,13	663,79	501,72	477,29	455,12	877,72	659,61	499,33
Water	245,43	242,05	224,26	261,07	294,45	243,38	240,53	223,19
Fine Agg.	570,41	665,40	754,41	717,67	684,34	565,64	661,22	750,82
Coarse Agg.	567,06	661,49	749,98	713,46	680,32	562,31	657,33	746,41
SP	0,00	0,00	0,00	0,00	0,00	8,78	6,60	4,99
Unit weight	2268,03	2232,74	2230,38	2169,48	2114,24	2257,83	2225,29	2224,75
W/C Ratio	**0,3**	**0,4**	**0,5**	**0,6**	**0,7**	**0,3**	**0,4**	**0,5**

4.3.2 Preparation of Specimens

Mixtures were used different cement types, different water cement ratios, and admixture, prepared by hand mixing method. For the mixtures without using SP, firstly cement, fine aggregate and coarse aggregate were mixed for a period of time. After that, all of the water was added in mixture and it continued to be mixed for a while. For the admixtures used SP, cement, fine aggregate and coarse aggregate were mixed for a period of time. Then 75% of the water was added and mixing was continued. After that, 1% of the cement was added into the remaining water added into the mixture.

When the mixture was ready, it was poured into the lubricated molds. The cube molds which have dimensions of 50x50x50 mm were used for this experiment (Figure 4.2). For each mix set, totally six samples were taken. Three of samples were taken for 7th day and three samples were taken for 28th days for testing. After the prepared samples were poured into the molds, they kept in laboratory for 24 hours. Then, samples were demoulded and stored in water for curing of samples at 23±2oC until the age of testing (Figure 4.3).

Figure 4.2 Molds Kept in Laboratory for 24 hours

Figure 4.3 Curing of Specimens until Age of Testing

4.3.3 Determination of Compressive Strength

For determination of compressive strength of mixtures 50cm cubic specimens were utilized. Compressive strength tests were carried out on the specimens at the ages of 7 and 28 days. The test was performed using a universal testing machine (Figure4.4).

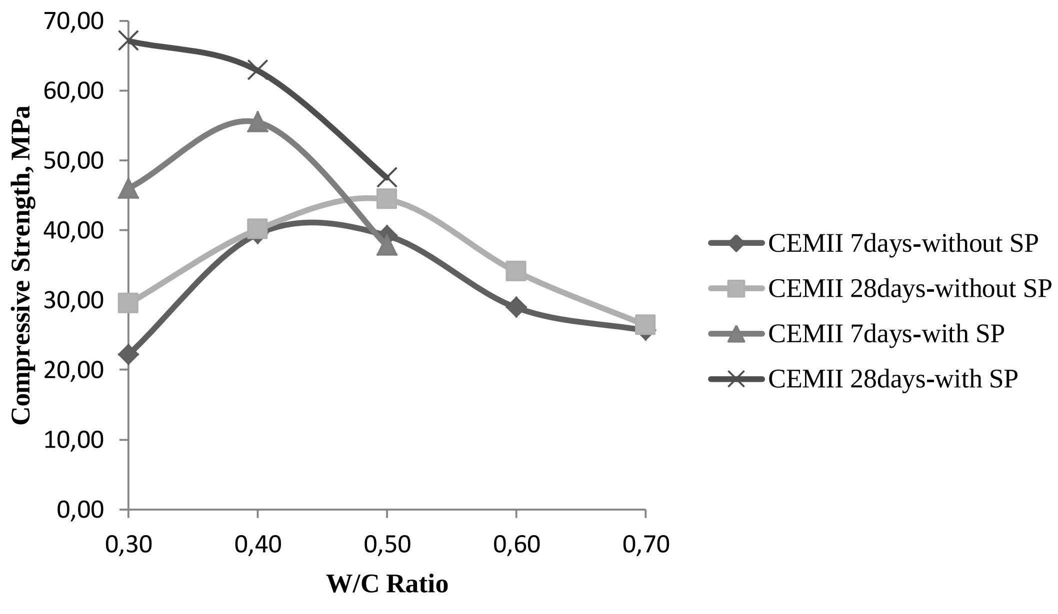
Figure 4.4 Universal Testing Machine

CHAPTER 5

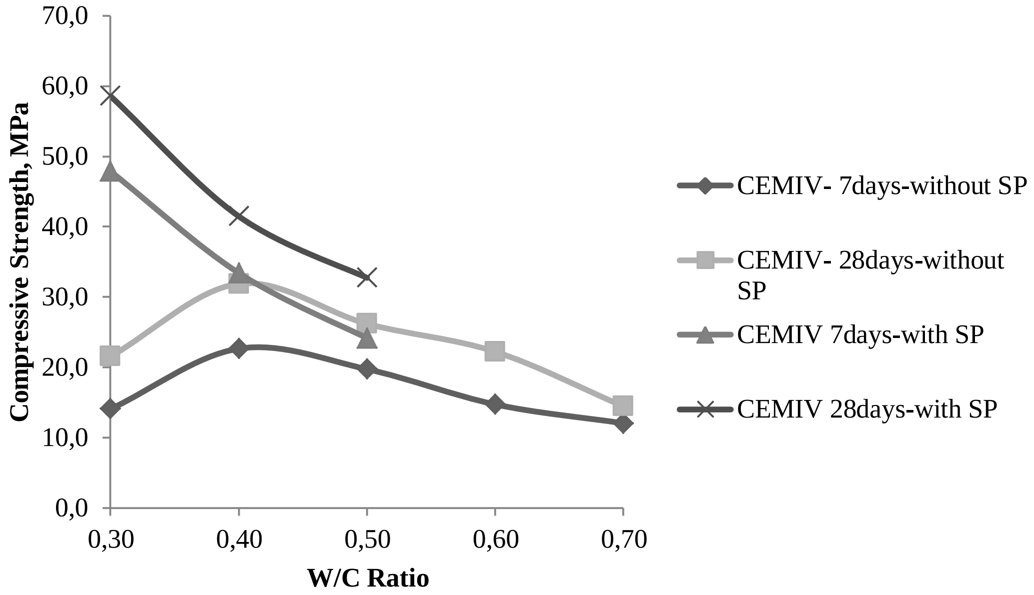
RESULTS AND DISCUSSIONS

The influence of water-cement ratio on the compressive strength was investigated in many studies. Authors observed that increased water cement ratio from 0.45 to 0.60 caused to increasing porosity up to 150% and decreasing compressive strength about 75.6% [5]. It was examined that water cement ratio changed in inverse proportion to compressive strength in concrete [86]. Results indicated that the compressive strength decreased with increased water cement ratio and sufficient ratio is observed as 0,5 to obtain a cement mortar workable [89].

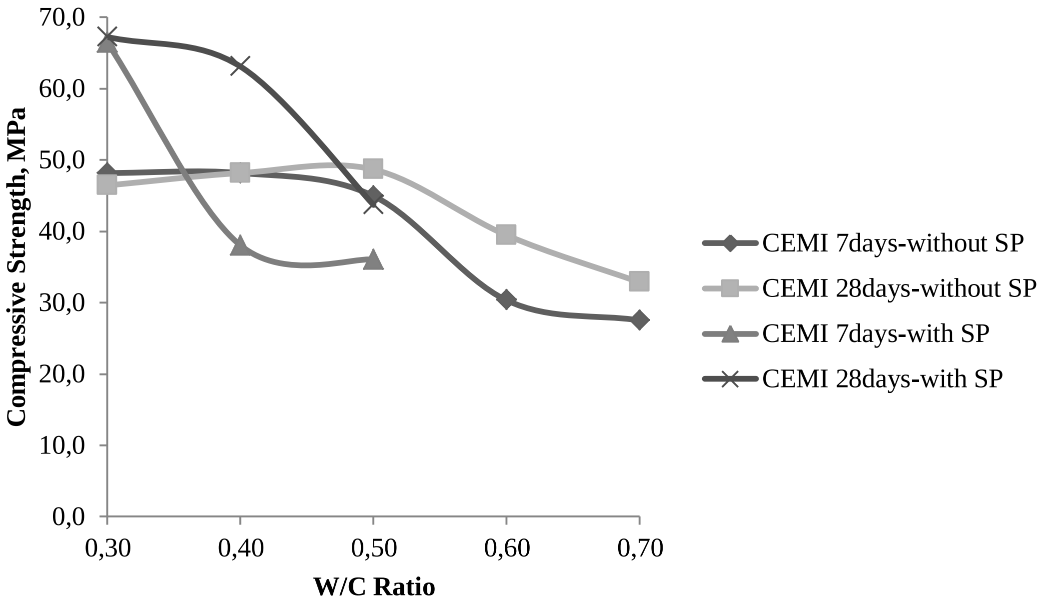
Compressive strength of the concretes according to water cement ratio which were obtained in this study are presented in the Figure 5.1. In figures, compressive strength values of concretes designed without using SP and compressive strength values of concretes prepared by adding SP were shown separately.



a)



b)

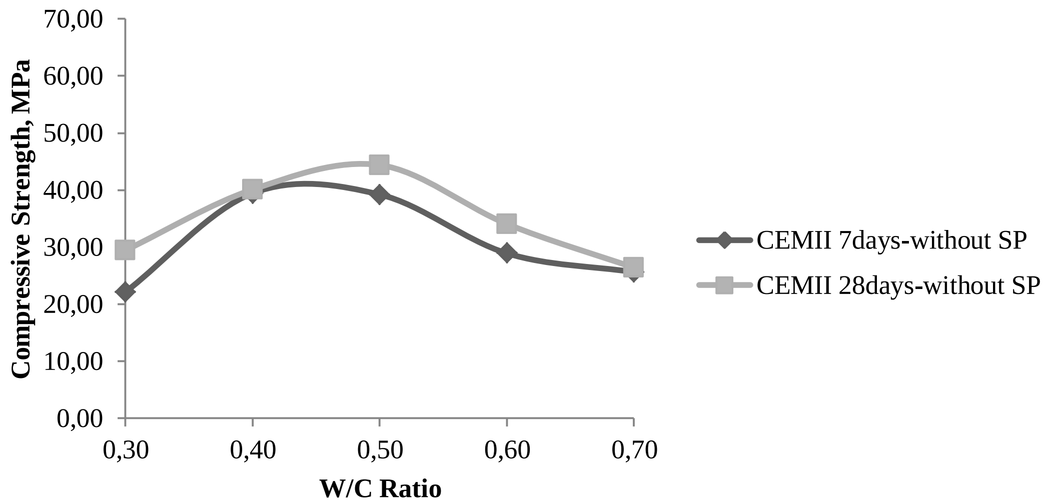


c)

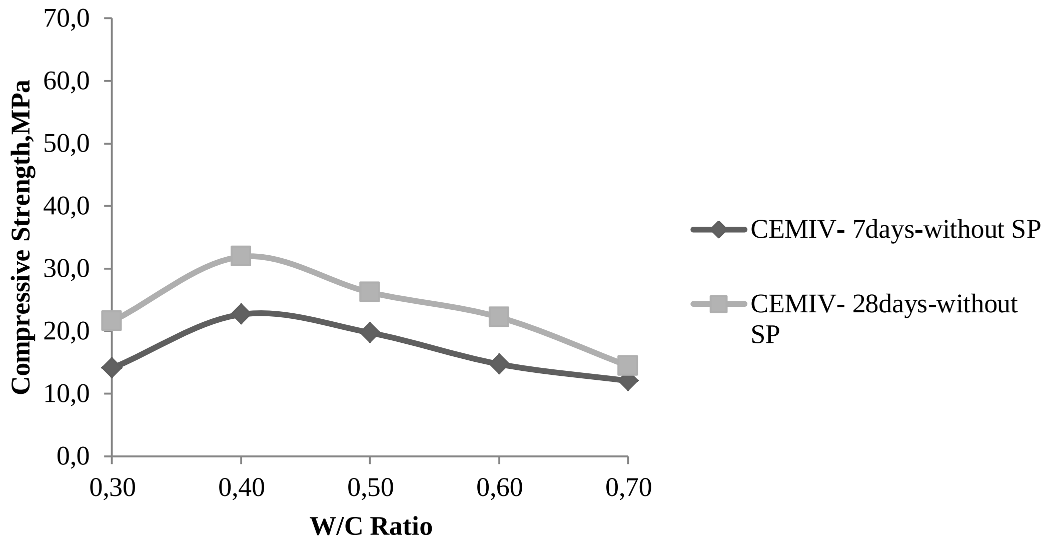
Figure 5.1 Relationships between Compressive Strengths and W/C Ratio of a) CEMII b) CEMIV and c) CEMI

Test result indicated that when the water cement ratio decreased from 0.7 to 0.5, compressive strength increased. However, compressive strength reduced or remained constant for lower w/c ratios such as 0.4 and 0.3 According to the literature, lower water-cement ratio causes higher compressive strength. However, due to the negative effect of lower workability, compressive strength decreased for lower water-cement ratio as 0,4-0,3. It was attributed to the influence of insufficient mixing and placing of concrete homogeneously. According the result of this study, sufficient water-cement ratio to obtain workable cement observed between the values 0,4-0,5.

Relationship between w/c ratio and compressive strength of the concretes prepared without using SP were presented in the Figure 5.2. As a result, decreased water cement ratio from 0,7 to 0,5 caused to increase of compressive strength about 168,2%, 181,9% and 148,0% for three different mixes. On the other hand, decreasing of compressive strength was observed for water cement ratio from 0,5 to 0,3 as contrary to expectations.



a)



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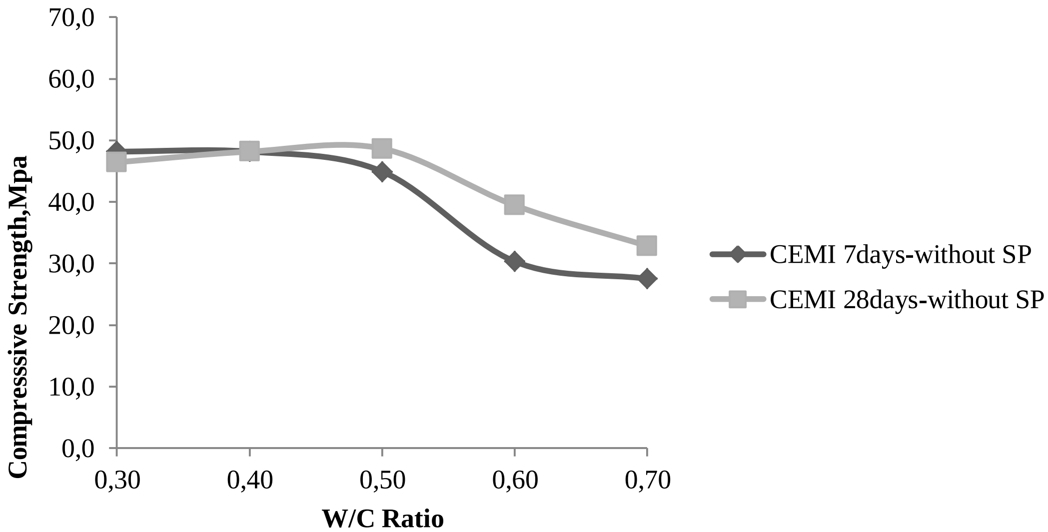


c)

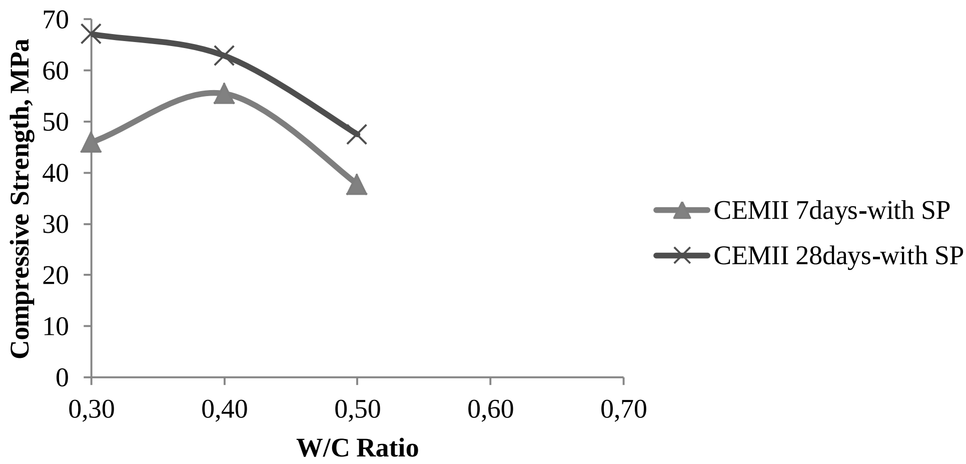
Figure 5.2 Relationships between Compressive Strengths and W/C Ratio of a) CEMII b) CEMIV and c) CEMI without using SP

In many studies, effect of workability on the compressive strength of concrete was investigated. Results show that if the concrete had low water cement ratio, mixing and placing were not provide sufficiently. Therefore, compressive strength of concrete decreased due to lack of water [94]. Researchers investigated the effect of plasticizers and superplasticizers on the workability and observed that the admixtures provided workability without changing water-cement ratio in concrete mixture [50-51].

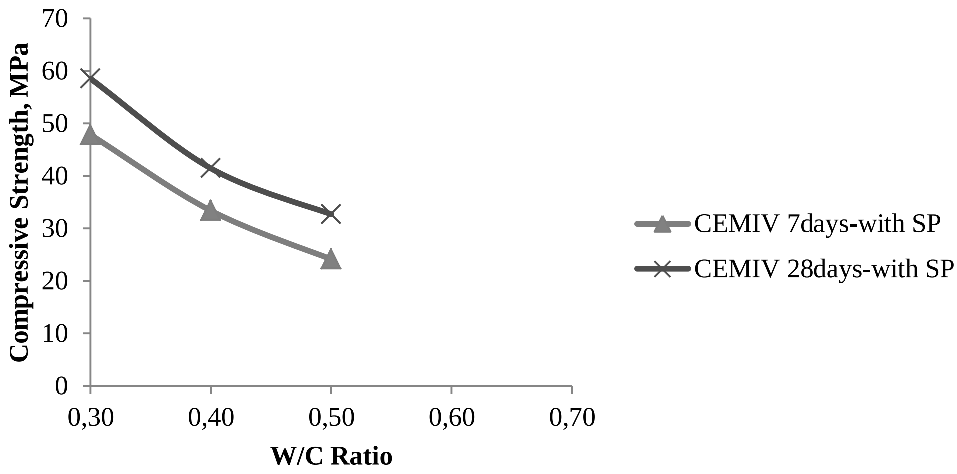
In this study, results indicated that the workability of concretes affect directly compressive strength. Unexpectedly decreasing of compressive strength was attributed to difficulty of mixing, impossibility of obtaining homogenous mixed concretes and insufficient placing of concretes into the molds. Weakness of workability also caused to observation of differences in the compressive strengths of samples that prepared with same water cement ratio.

In order to provide increasing in compressive strength with decreasing water cement ratio in accordance with the literature, the negative effect of workability must be eliminated. For this purpose, a chemical admixture called as superplasticizer was used to improve workability of mixture without changing the water cement ratio. Results indicated that the superplasticizer provided sufficient workability for samples and increasing of compressive strength observed with decreased water cement ratio as expected.

Relationship between w/c ratio and compressive strength of the concretes prepared by adding SP were presented in the Figure 5.3. For the 0,3 water cement ratio, significant increase in compressive strength was observed for concretes prepared with and without using of chemical admixture. Compressive strength of concretes prepared by adding chemical admixture reached 228,2%, 272,5% and 144,8% of compressive strength of concretes prepared without using chemical admixture.



a)



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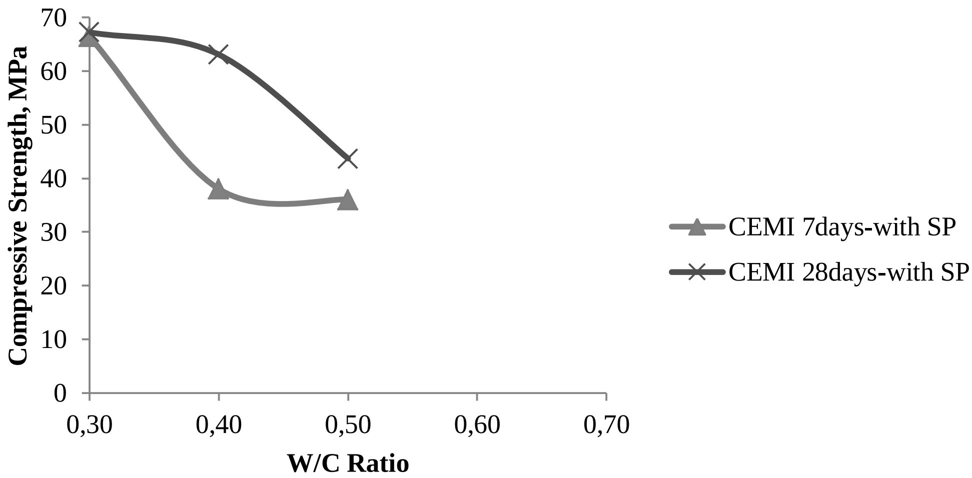
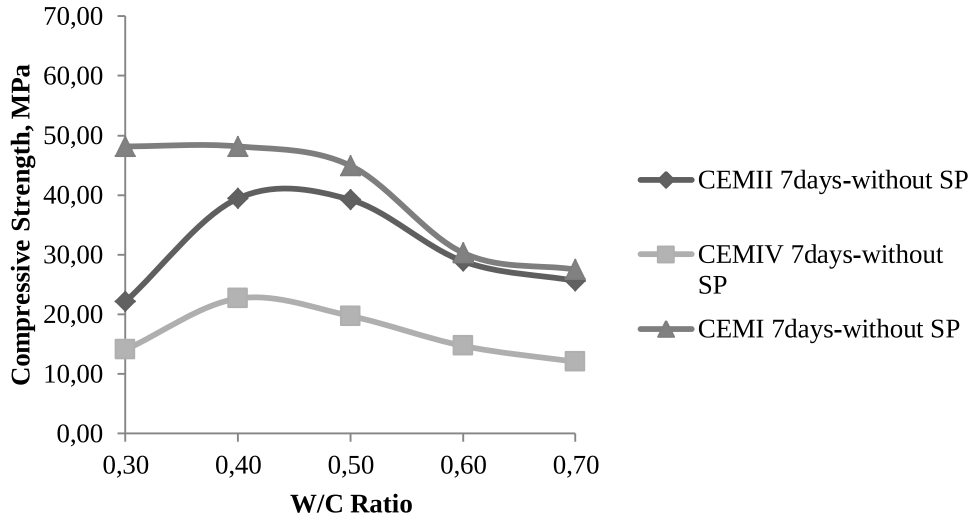


c)

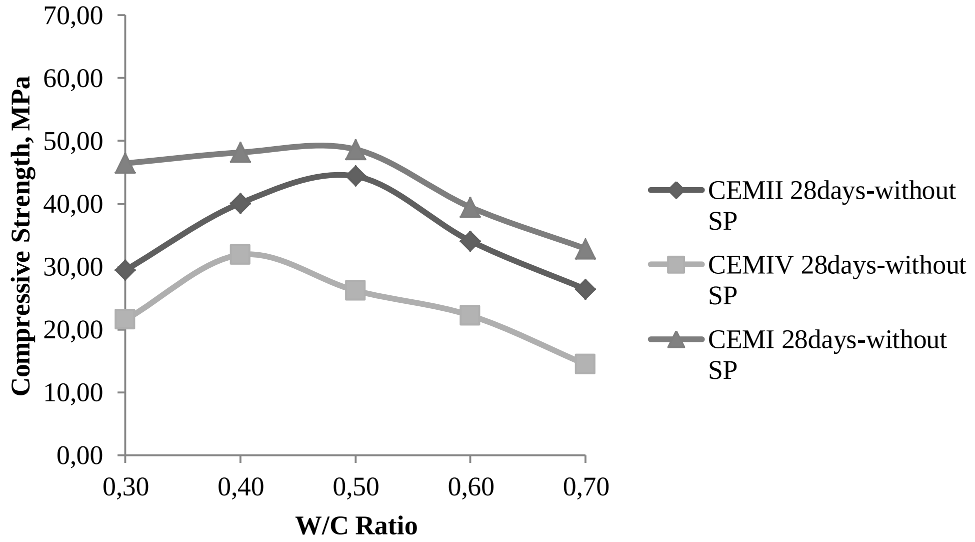
Figure 5.3 Relationships between Compressive Strengths and W/C Ratio of a) CEMII b) CEMIV and c) CEMI by adding SP

Ability of cement paste to perform as binder and filler between aggregate particles is an important effect for the strength of the concrete [9]. The properties of cement paste which are related to the properties of the materials that composed of the cement affect the strength of concrete directly. Compaction and maintenance conditions of cement paste, water / cement ratio, hydration of cement affect the strength of concrete [10]. In general, concretes produced with high strength cement are known to have high strength.

Compressive strength of concrete at a given age is also dependent on type of cement. The relationships between w/c ratio and compressive strength for different cements were shown in Figure 5.4.



a)



b)

Figure 5.4 Relationships between Compressive Strengths and W/C Ratio According to Cement Type at a) 7^{th} days b) 28^{th} days

Test results revealed that cement type has an important role on the compressive strength irrespective of w/c ratio for both 7 and 28 days. For example, the compressive strength values of the samples having w/c ratio of 0.5 at the age of 28 days were found to be 26.2, 44.4 and 48.7 MPa for CEMIV, CEMII and CEMI respectively. It was also observed that for lower w/c ratios such as 0.3 and 0.4, the mixing and placing of fresh concrete were affected by cement type. It was attributed to the fineness of cement.

As it was mentioned above for lower w/c ratios, such as 0.3 and 0.4 the fresh concrete suffered from mixing, placing and compacting due to lack of workability. Moreover, this caused considerable reductions in compressive strength values of the specimens. In order to overcome this problem and eliminate the effect of consolidation on the compressive strength, plasticizing admixture was utilized for the mixtures produced by w/c ratios of 0.3, 0.4 and 0.5. Figure 5.5 indicates the relationships between w/c ratio and compressive strength of concrete designed by different cements with trendlines, R^2 values and relevant formulas.

It was clear that for all cements, the compressive strength increased when the w/c ratio reduced. The R^2 values indicated that these relationships can be explained by given formulas.

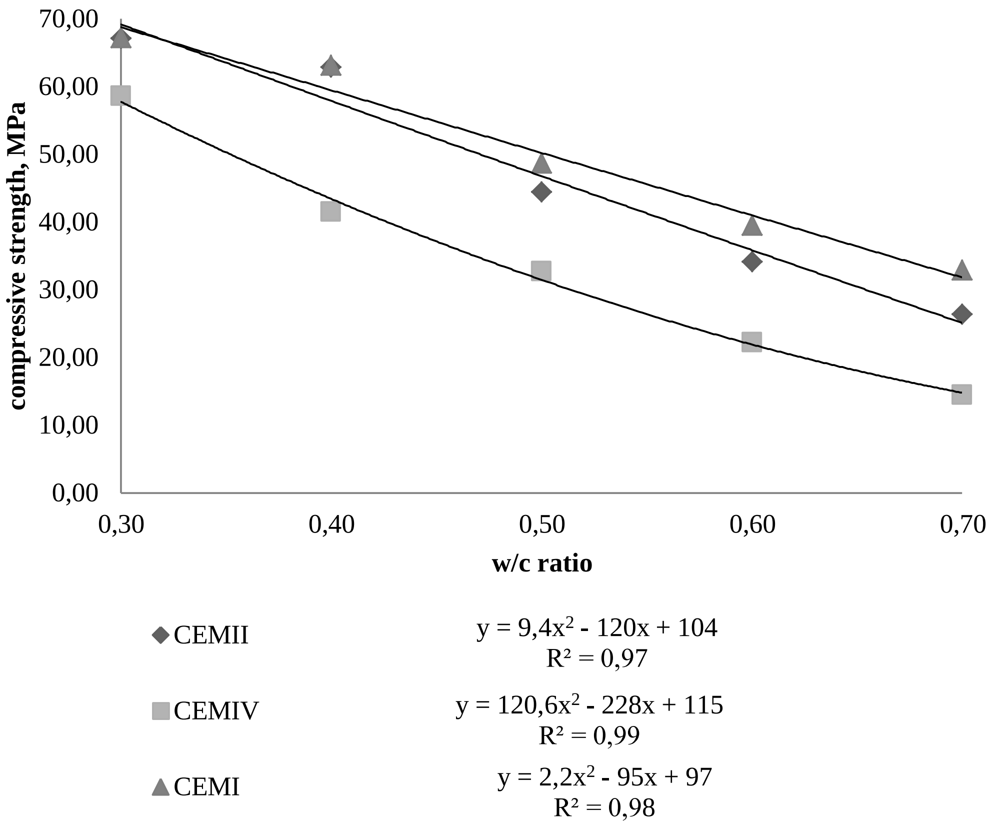


Figure 5.5 Trendline of Relationships between Compressive Strengths and W/C Ratios According to Cement Types

CHAPTER 6

CONCLUSIONS

The effects of w/c ratio on the compressive strength of concrete were investigated and the following conclusions were drawn out from this experimental study;

1. When the water/cement ratio decreased from 0.7 to 0.5, compressive strength increased for concrete mixtures designed without using plasticizing admixture. However, compressive strength reduced or remained constant for lower w/c ratios such as 0,4 and 0,3. It was attributed to the lack of workability of the mixes causing placement and compaction problems.

2. According to the literature, lower water-cement ratio causes higher compressive strength. However, compressive strength of mixtures decreased for lower w/c ratio as 0,4-0,3. It was attributed to the influence of insufficient mixing, placing and compaction of concrete homogeneously as result of hand mixing method. Even though the superplasticizer was used for mixtures to eliminate the effect of insufficient compaction, insufficient mixing and placing were effective on compressive strength of mixtures prepared by using CEMII type cement. It could be attributed to the fineness of cement.

3. The compressive strength increased as the w/c ratio reduced when the effect of compaction on the compressive strength was eliminated by utilizing superplasticizer. Calculated R^2 values indicated that generated formulas obtained from trendlines could explain the relationship between the w/c ratios and compressive strength.

4. Cement type played an important role on the compressive strength of concrete irrespective of w/c ratio of the mixes. Highest strength values were obtained for the mixes produced by CEMI cement and there was a little difference between the compressive strength values of mixes produced by CEMI and those of mixes produced by CEMII.

5. The mixing and placing of fresh concrete were affected by cement type for lower w/c ratios such as 0.3 and 0.4 and it could be attributed to the fineness of cement.

REFERENCES

[1] Zongjin L. 2011. Advanced Concrete Technology. New Jersey: John Wiley and Sons Inc. 624 p.

[2] Wang, X.-Y., Park, K.-B. (2017). Analysis of the compressive strength development of concrete considering the interactions between hydration and drying. *Cement and Concrete Research*. **102**, 1–15.

[3] Mehta PK., Monteiro PJM. 2006. Concrete: Microstructure, Properties and Materials. 3rd edition. New York: McGraw-Hill Companies. 659 p.

[4] Fládr, J., Bílý, P. (2018). Specimen size effect on compressive and flexural strength of high-strength fibre-reinforced concrete containing coarse aggregate. *Composites Part B*: *Engineering.* **138**, 77–86.

[5] Kim, Y.-Y., Lee, K.-M., Bang, J.-W., Kwon, S.-J. (2014). Effect of w/c ratio on durability and porosity in cement mortar with constant cement amount. *Advances in Materials Science and Engineering.* **1**, 1-11.

[6] Newman J., Choo BS. 2003. Advanced Concrete Technology: Processes. 1st edition. Oxford: Butterworth-Heinemann Elsevier. 704 p.

[7] Behnood, A., Behnood, V., Gharehveran, M.M., Alyamac, K.E. (2017). Prediction of the compressive strength of normal and high-performance concretes using M5P model tree algorithm. *Construction and Building Materials*. **142**, 199–207.

[8] Neville AM, Brooks JJ. 2010. Concrete Technology. 2nd edition. New Jersey: Prentice Hall. 442 p.

[9] Panesar, D.K., Aqel, M., Rhead, D., Schell, H. (2017). Effect of cement type and limestone particle size on the durability of steam cured self-consolidating concrete. *Cement and Concrete Composites.* **80**, 175-189.

[10] Hewlett PC. 2004. Lea's Chemistry of Cement and Concrete. 4th edition. Oxford: Butterworth-Heinemann, Elsevier. 1057 p.

[11] Bogue RH. 1955. Chemistry of Portland Cement. New York: Reinhold. 793 p.

[12] Zhang, Y.M., Napier-Munn, T.J. (1995). Effects of particle size distribution, surface area and chemical composition on Portland cement strength. *Powder Technology.* **83**, 245-252.

[13] Wu, S., Sun, K., Zhao, H., Zhang, F. (2018). Quantitative invalidation characterization of Portland cement based on BSE and EDS analysis. *Construction and Building Materials*. **158,** 700–706.

[14] Mamlouk MS., Zaniewski JP. 1999. Materials for Civil and Construction Engineers. California: Addison Wesley Longman Inc.

[15] Topçu, I. B., Uygunoglu, T. (2010). Effect of aggregate type on properties of hardened self-consolidating lightweight concrete (SCLC). *Construction and Building Materials*. **24**, 1286–1295.

[16] Su, N., Hsu, K.-C., Chai, H.-W. (2001). A simple mix design method for self-compacting concrete. *Cement and Concrete Research.* **31(12),** 1799–1807.

[17] Khaleel, O. R., Al-Mishhadani, S. A., Abdul Razak, H. (2011). The Effect of Coarse Aggregate on Fresh and Hardened Properties of Self-Compacting Concrete (SCC). *Procedia Engineering.* **14**, 805–813.

[18] Kılıç, A., Atis¸ C.D., Teymen, A., Karahan, O., Ozcan, F., Bilim, C., Ozdemir, M. (2008). The influence of aggregate type on the strength and abrasion resistance of high strength concrete. *Cement and Concrete. Composites* **30 (4),** 290-296.

[19] ACI Committee 363. American Concrete Institute. 2010. Report on High-strength Concrete. 363R-10. Farmington Hills, MI.

[20] Qudoos, A., Atta-ur-Rehman, Kim, H.G., Ryou, J.S. (2018). Influence of the surface roughness of crushed natural aggregates on the microhardness of the interfacial transition zone of concrete with mineral admixtures and polymer latex. *Construction and Building Materials.* **168**, 946–957.

[21] TS 706 EN 12620+A1. Turkish Standard. 2010. Aggregates for Concrete. TSE. Bakanlıklar, Ankara.

[22] Hewlett, PC. 1988. Cement Admixtures: uses and applications. London: Longman Scientific & Technical. 166 p.

[23] Kosmatka, SH., Kerkhoff, B., Panarese, WC. 2002. Design and control of concrete mixtures. 14th edition. IL: Skokie , Portland Cement Association.358 p.

[24] Łaz´niewska-Piekarczyk, B. (2013). The influence of chemical admixtures on cement hydration and mixture properties of very high performance self-compacting concrete. *Construction and Building Materials.* **49,** 643–662.

[25] Plank, J., Sakai, E., Miao, C.W., Yu, C., Hong, J.X. (2015). Chemical admixtures-Chemistry, applications and their impact on concrete microstructure and durability. *Cement and Concrete Research*. **78**, 81–99.

[26] Jimma, B. E., Rangaraju, P. R. (2015). Chemical admixtures dose optimization in pervious concrete paste selection – A statistical approach. *Construction and Building Materials*. **101**, 1047–1058.

[27] Shetty, MS. 2006. Concrete Technology: Theory and Practice. Multicolor Illustrative Edition. India, S.Chand and Co. Ltd. 656 p.

[28] Mangane,M. B., Argane, R., Trauchessec, R., Lecomte, A. 2018. Influence of superplasticizers on mechanical properties and workability of cemented paste backfill. *Minerals Engineering.* **116**, 3–14.

[29] Meyer, A. (1979). Experiences in the use of superplasticizers in Germany, in Superplasticizers in Concrete. *American Concrete Institute.* ACI SP-**62,** 21–36. Detroit, MI.

[30] Hassan KE, Cabrera JG, Maliehe RS. (2000). The effect of mineral admixtures on the properties of high-performance concrete. *Cement and Concrete Composites* **22(4),** 267–71.

[31] Kaikea, A., Achoura, D., Duplan, F., Rizzuti, L. (2014). Effect of mineral admixtures and steel fiber volume contents on the behavior of high performance fiber reinforced concrete. *Materials and Design.* **63**, 493–499.

[32] Zhimin, H., Junzhe, L., Kangwu, Z. (2012). Influence of Mineral Admixtures on the Short and Long-term Performance of Steam-cured Concrete. *Energy Procedia.* **16**, 836 – 841.

[33] Le, H. T., Ludwig, H.M. (2016). Effect of rice husk ash and other mineral admixtures on properties of self-compacting high performance concrete. *Materials and Design.* **89**, 156–166.

[34] Le, H.T., Muller, M., Siewert, K., Ludwig, H.-M. (2015). The mix design for self-compacting high performance concrete containing various mineral admixtures. *Materials and Design.* **72**, 51–62.

[35] Ma, K., Feng, J., Long, G., Xie, Y., Chen , X. (2017). Improved mix design method of self-compacting concrete based on coarse aggregate average diameter and slump flow. *Construction and Building Materials.* **143**, 566–573.

[36] Vakhshouri, B., Nejadi, S. (2016). Mix design of light-weight self-compacting concrete. *Case Studies in Construction Materials.* **4**, 1–14.

[37] ACI Committee 211. American Concrete Institute. Reapproved 2002. Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. ACI 211.1-91.

[38] TS 802. Turkish Standard. 1985. Design Concrete Mixes. TSE. Bakanlıklar, Ankara.

[39] Kovler, K., Roussel, N. (2011). Properties of fresh and hardened concrete. *Cement and Concrete Research.* **41**, 775–792.

[40] Neville AM. 2011. Properties of Concrete. 5th edition. New York: Pearson Education Limited. 846 p.

[41] Şahin, R., Taşdemir, M.A., Gül, R., Çelik, C. (2007). Taze Beton Özelliklerinin Optimizasyonu. *Atatürk Üniv. Ziraat Fak. Derg.* **38 (2),** 127-135.

[42] Khayat KH. 1999. Workability, testing, and performance of self-consolidating concrete. *ACI Materials Journal.* Title no. 96-M43.

[43] ASTM C 143/C 143M-03. American Society for Testing and Materials. 2012. Standard test method for slump of hydraulic cement concrete. ASTM International. West Conshohocken, PA.

[44] Cook, M. D., Ley, M. T., Ghaeezadah, A. (2014). A workability test for slip formed concrete pavements. *Construction and Building Materials.* **68,** 376–383.

[45] Li, Z. (2007). State of workability design technology for fresh concrete in Japan. *Cement and Concrete Research.* **37,** 1308–1320.

[46] Ferraris, C.F., Brower, L.E., (2003). Comparison of concrete rheometers. *Concr. Int.* **25 (8),** 41-47.

[47] Koehler, E.P. 2009. Use of rheology to specify, design, and manage selfconsolidating concrete. Proceedings of the Tenth ACI International Symposium on Recent Advances in Concrete Technology and Sustainability Issues. Sevilla, Spain.

[48] Topçu, I. B., Bilir, T. (2009). Experimental investigation of some fresh and hardened properties of rubberized self-compacting concrete. *Materials and Design.* **30**, 3056–3065.

[49] Laskar, A.I., Talukdar, S. (2008). Rheological behavior of high performance concrete with mineral admixtures and their blending. *Construct and Building Materials* **22(12),** 2345–54.
[50] Yudenfreund, M., Odler, I., Brunauer, S. (1972). Hardened portland cement pastes of low porosity. I: Materials and experimental methods. *Cement and Concrete Research* **2,** 313–30.
[51] Yudenfreund, M., Skalny, J., Mikhail, R.S., Brunauer, S. (1972). Hardened portland cement pastes of low porosity. II: Exploratory studies, dimensional changes. *Cement and Concrete Research* **2,** 331–48.
[52] ACI Committee 238. American Concrete Institute. 2008. Report on Measurements of Workability and Rheology of Fresh Concrete. Farmington Hills, MI.
[53] Navarrete, I., Lopez, M. (2017). Understanding the relationship between the segregation of concrete and coarse aggregate density and size. *Construction and Building Materials.* **149,** 741–748.
[54] Han, J., Wang, K. (2016). Influence of bleeding on properties and microstructure of fresh and hydrated Portland cement paste. *Construction and Building Materials*. **115**, 240–246.
[55] Yim, H. J., Kim, J. H., Kwak, H.-G. (2014). Experimental simulation of bleeding under a high concrete column. *Cement and Concrete Research*. **57** , 61–69.
[56] ASTM C232 / C232M-14. American Society for Testing and Materials. 2014. Standard Test Method for Bleeding of Concrete. ASTM International. West Conshohocken, PA. www.astm.org
[57] Poole, T.S. (2006) .Guide for Curing Portland Cement Concrete Pavements II. *FHWA-HRT-05-038. Federal Highway Administration,* McLean, VA.
[58] Abolpour, B., Afsahi, M.M., Hosseini, S.G. (2015). Statistical analysis of the effective factors on the 28 days compressive strength and setting time of the concrete. *Journal of Advanced Research.* **6**, 699–709.
[59] Zhu, J., Cao, J.N., Bate, B., Khayat, K.H. (2018). Determination of mortar setting times using shear wave velocity evolution curves measured by the bender element technique. *Cement and Concrete Research.* **106**, 1–11.

[60] Garnier, V., Corneloup, G., Sprauel, J.M., Perfumo, J.C. (1995). Setting time study of roller compacted concrete by spectral analysis of transmitted ultrasonic signals. *NDT&E Int.* **28**, 15–22.

[61] Dave, N., Misra, A. K., Srivastava, A., Kaushik, S.K. (2017). Setting time and standard consistency of quaternary binders:The influence of cementitious material addition and mixing. *International Journal of Sustainable Built Environment.* **6,** 30–36.

[62] Brooks, J.J., Johari, M.A., Mazloom, M., (2000). Effect of admixtures on the setting time of high strength concrete. *Cement and Concrete Composites* **22 (4),** 293–301.

[63] Hu, J., Ge, Z., Wang, K. (2014). Influence of cement fineness and water-to-cement ratio on mortar early-age heat of hydration and set times. *Construction and Building Materials.* **50**, 657–663.

[64] ASTM C191–08. American Society for Testing and Materials. 2010. Standard test methods for time of setting of hydraulic cement by Vicat needle. ASTM International. Easton, MD.

[65] ASTM C403-08. American Society for Testing and Materials. 2010. Standard test method for time of setting of concrete mixtures by penetration resistance. ASTM International. Easton, MD.

[61] Dave, N., Misra, A. K., Srivastava, A., Kaushik, S.K. (2017). Setting time and standard consistency of quaternary binders:The influence of cementitious material addition and mixing. *International Journal of Sustainable Built Environment.* **6,** 30–36.

[62] Brooks, J.J., Johari, M.A., Mazloom, M., (2000). Effect of admixtures on the setting time of high strength concrete. *Cement and Concrete Composites* **22 (4),** 293–301.

[63] Hu, J., Ge, Z., Wang, K. (2014). Influence of cement fineness and water-to-cement ratio on mortar early-age heat of hydration and set times. *Construction and Building Materials.* **50**, 657–663.

[64] ASTM C191–08. American Society for Testing and Materials. 2010. Standard test methods for time of setting of hydraulic cement by Vicat needle. ASTM International. Easton, MD.

[65] ASTM C403-08. American Society for Testing and Materials. 2010. Standard test method for time of setting of concrete mixtures by penetration resistance. ASTM International. Easton, MD.

[66] Baradan B, Yazıcı H, Aydın S. 2015. Beton. 2. Baskı. İzmir: Dokuz Eylül Üniversitesi Mühendislik Yayınları No:334.

[67] ASTM C39. American Society for Testing and Materials. 2008. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.ASTM International. Easton, MD.

[68] TS EN 12390-3. Turkish Standard. 2003. Testing hardened concrete - Part 3 : Compressive strength of test specimens. Ankara.

[69] An, M-Z., Zhang, L.-J., Yi, Q.-X. (2008). Size effect on compressive strength of reactive powder concrete. *Journal of China Univ. Min. Technol.* **18,** 279–82.

[70] Li, M., Hao, H., Shi, Y., Hao, Y. (2018). Specimen shape and size effects on the concrete compressive strengthunder static and dynamic tests. *Construction and Building Materials.* **161,** 84–93.

[71] Erdoğan YT. 2003. Beton. 2.Baskı. Ankara: ODTÜ Yayıncılık. No:760 p.

[72] Le, H. T. N., Poh, L. H., Wang, S., Zhang, M.-H. (2017). Critical parameters for the compressive strength of high-strength concrete. *Cement and Concrete Composites*. **82**, 202-216.

[73] Wu, K.-R., Chen, B., Yao, W., Zhang, D. (2001). Effect of coarse aggregate type on mechanical properties of high-performance concrete. *Cement and Concrete Research.* **31**, 1421 – 1425.

[74] Baradan, B., Aydın, S. (2013). Betonun Dürabilitesi (Dayanıklılık, Kalıcılık). *Hazır Beton.* 54-68.

[75] Matarul, J. and Mannan, M. A. and Mohammad Ibrahim Safawi, M. Z. and Ibrahim, A. and Jainudin, N.A. and Yusuh, N.A. (2016). Performance-based Durability Indicators of Different Concrete Grades Made by the Local Ready Mixed Company: Preliminary Results. *Procedia - Social and Behavioral Sciences*. **22,** 620 – 625.

[76] Wang, D., Zhou, X., Meng, Y.F. Chen, Z. (2017). Durability of concrete containing fly ash and silica fume against combined freezing-thawing and sulfate attack. *Construction and Building Materials.* **147,** 398–406.

[77] Spiesz, P., Yu, Q.L., Brouwers, H.J.H. (2013). Development of cement-based lightweight composites – Part 2: Durability-related properties. *Cement & Concrete Composites.* **44,** 30–40.
[78] Wagner, C., Villmann, B., Slowik, V., Mechtcherine, V. (2017). Water permeability of cracked strain-hardening cement-based composites. *Cement and Concrete Composites.* **82,** 234-241.
[79] Liu, J., Qiu, Q., Chen, X., Xing, F., Han, N., He, Y., Ma, Y. (2017). Understanding the interacted mechanism between carbonation and chloride aerosol attack in ordinary Portland cement concrete. *Cement and Concrete Research.* **95,** 217–225.
[80] Sicakova, A., Draganovska, M., Kovac, M. (2017). Water absorption coefficient as a performance characteristic of building mixes containing fine particles of selected recycled materials. *Procedia Engineering.* **180,** 1256 – 1265.
[81] Nilsson, L.-O., Poulsen, E., Sandberg, P., Sorensen, H.E., Klinghoffer, O. (1996). Hetek, Chloride penetration into concrete, State-of-the-art, transport processes, corrosion initiation, test methods and prediction models. The Report No. 53. Road Directorate, Copenhagen. p. 151.
[82] Basheer, L., Kropp, J., Cleland, D.J. (2001). Assessment of the durability of concrete from its permeation properties: a review. *Construction and Building Materials.* **15** , 93-103.
[83] Yang, K., Zhong, M., Magee, B., Yang, C., Wang, C., Zhu, X., Zhang, Z. (2017). Investigation of effects of Portland cement fineness and alkali content on concrete plastic shrinkage cracking. *Construction and Building Materials.* **144,** 279–290.
[84] Zhang, J., Ding, X., Wang, Q., Zheng, X. (2018). Effective solution for low shrinkage and low permeability of normal strength concrete using calcined zeolite particles. *Construction and Building Materials.* **160**, 57–65.
[85] Wang, X.F., Fang, C., Kuang, W.Q., Li, D.W., Han, N.X., Xing, F. (2017). Experimental investigation on the compressive strength and shrinkage of concrete with pre-wetted lightweight aggregates. *Construction and Building Materials.* **155,** 867–879.
[86] Şimşek, O. 2004. Beton ve Beton Teknolojisi. Seçkin Yayıncılık, Ankara. 247s.
[87] Powers, T. C., Copeland, L. E., Hayes, J. C., Mann, H. M. (1954). Permeability of Portland Cement Paste. *J. Amer. Concr. Inst.* **51,** 285- 298.

[88] Tuncan, M., Arioz, Ö., Ramyar, K., Karasu, B. (SERES 2007). Effect of compaction on assessed concrete strength. *Conference: The IV. Ceramic, Glass, Enamel, Glaze and Pigment Seminar with International Participation.* Eskisehir, Turkey.

[89] Singh, S.B., Munjal, P., Thammishetti, N. (2015). Role of water/cement ratio on strength development of cement mortar. *Journal of Building Engineering.* **4,** 94-100.

[90] Živica, V. (2009). Effects of the very low water/cement ratio. *Construction and Building Materials.* **23(12),** 3579-3582.

[91] Postacıoğlu B. 1986. Beton. Cilt I-II. Matbaa Teknisyenleri Basımevi. İstanbul.

[92] Haach, V.G., Vasconcelos, G., Lourenco, P.B. (2011). Influence of aggregates grading and water/cement ratio in workability and hardened properties of mortars. *Construction and Building Materials.* **25,** 2980–2987.

[93] Yalçın, H., Gürü, M., 2006. Çimento ve Beton. Palme Yayıncılık, 406s.

[94] Mindess, S., Young, J.F., Darwin, D. Concrete. 2nd ed. 2003. Upper Saddle River, NJ. Prentice Hall. xi, 644 p.