PREDICTING LONG TERM STRENGTH OF ROLLER COMPACTED CONCRETE CONTAINING NATURAL POZZOLAN BY STEAM CURING

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

ÖZLEM ASLAN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

SEPTEMBER 2006

Approval of the Graduate School of Natural and Applied Sciences

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ABSTRACT

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September 2006, 74 pages

Roller Compacted Concrete (RCC) is new technology gaining popularity in the recent years due to its low cost, rapid construction, and using opportunity of by-products. RCC is widely used in the world. However, the use of RCC has been restricted to construction of few cofferdams, and limited to local use in dam construction up to date.

In this thesis, two types of cement, two types of natural pozzolan, aggregates with varying gradations, and a type of water reducing chemical admixture were used. Prior to carrying out the tests, the chemical and physical properties of materials were determined. Additionally, steam curing was applied to the test specimens in order to get long term compressive strength at early ages. Differences between steam cured specimens and normal cured specimens have been discussed in the discussion part.

In the study, the results indicate that usage of water reducing chemical admixture improves compressive strength of RCC. Moreover, it is revealed that usage of fine material is essential to obtain desired results since the amount of cementitious materials is considerably low in RCC. Steam curing is known as its property of providing long term compressive strength at early ages. It was observed that application of steam curing in CEM I type cement used RCC mixtures generated expected results. However, in CEM IV type cement used RCC mixtures compressive strength results did not behave in the same manner.

Key words: Roller Compacted Concrete, Natural Pozzolan, Steam Curing, Long Term Compressive Strength

ÖZ

DOĞAL PUZOLAN İÇEREN SİLİNDİRLE SIKIŞTIRILMIŞ BETONUN BUHAR KÜRÜ UYGULANARAK UZUN VADEDEKİ DAYANIMININ TAHMİN EDİLMESİ

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Eylül 2006, 74 sayfa

Silindirle Sıkıştırılmış Beton (SSB), sağladığı düşük maliyet, hızlı inşa imkanı ve yapımında atık malzeme kullanılabilmesi gibi avantajlarıyla son zamanlarda popülerlik kazanan bir teknolojidir. SSB dünyada yaygın bir şekilde kullanılmaktadır. Ancak, bugüne kadar Türkiye’deki SSB uygulamaları birkaç batardo ve bazı baraj gövdelerindeki lokal kullanımlarla sınırlıdır.

Bu araştırmada iki tip çimento, iki tip doğal puzolan, çeşitli gradasyonlara sahip agrega grupları, ve bir tip su azaltıcı kimyasal katkı kullanılmıştır. Deney malzemelerinin kimyasal ve fiziksel özellikleri belirlenmiştir. Bunlara ek olarak, SSB’un uzun vadedeki basınç dayanımını erken yaşta tespit edebilmek amacı ile araştırma numunelerine buhar kürü uygulanmıştır. Buhar kürü uygulanan ve uygulanmayan numunelerin erken yaştaki basınç dayanımları arasındaki farklar incelenmiştir.

Bu çalışmanın sonuçları, su azaltıcı katkı kullanımının SSB'un basınç dayanımını geliştirdiğini göstermiştir. Bunun yanında, SSB'nda bağlayıcı malzeme miktarı çok az olduğu için, ince malzemelerin kullanımı istenen sonuçların elde edilebilmesi için çok önemlidir.Buhar kürü uygulanarak, betonda erken yaşlarda uzun vadedeki basınç dayanımı belirlenmektedir. CEM I portland çimentosu kullanılarak oluşturulan betonlarda buhar kürü uygulanması beklenen sonuçları vermiştir. Ancak, CEM IV çimentosu kullanılarak oluşturulan betonlarda aynı davranış gözlenmemiştir.

Anahtar Kelimeler: Silindirle Sıkıştırılmış Beton, Doğal Puzolan, Buhar Kürü, Uzun Vadedeki Basınç Dayanımı

To My Parents

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Assoc.Prof. Lutfullah Turanlı for his suggestions, guidance, recommendations and support throughout the study. I also would like to express my sincere gratefulness to Research Assistant Burak Uzal for his continuous support.

I would like to give sincere thanks to my dear friends Nur and Mesut Aşık for their valuable support during preparation of the thesis.

I would like to thank to staff of Turkish Cement Manufacturers Association for their help and support. Thanks are also extended to Ali Yıldırım and Harun Koralay, the personnel of Materials of Construction Laboratory for their help during experiments. Also, I would like to thank to Kolin İnşaat A.Ş. for the supply of the materials.

Finally, I would like to give my special thanks to my parents and my sister Ebru for their understanding, encouragement and endless support.

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ASTM	American Society for Testing and Materials
ACI	American Concrete Institute
RCC	Roller Compacted Concrete
SSB	Silindirle Sıkıştırılmış Beton
RCD	Roller Compacted Dam
w/c	water/cement ratio
w/cm	water/cementitious materials
RCCP	Roller Compacted Concrete Pavement
SSD	Saturated Surface Dry

CHAPTER 1

INTRODUCTION

1.1 General

Roller Compacted Concrete (RCC) is a type of concrete compacted by roller compaction: it is the concrete that, in its unhardened state, will support a roller while being compacted. By definition RCC is simply a concrete that has a consistency which allows it to be spread with a bulldozer and compacted with a vibratory roller. RCC can be placed at very high production rates and it can be more economical.

RCC can have a much broader range of material properties than conventionally placed concrete. Ordinary Portland cement, types of blended cement, types of mineral admixtures, aggregates not meeting grading requirement for normal concrete and water can be used for making RCC. Special care should be given to selection of materials that will produce a concrete which will support external compaction equipment.

RCC differs from conventional concrete principally in its consistency requirement. For effective consolidation, the concrete mixture must be dry enough to prevent shrinkage of the vibratory roller equipment but wet enough to permit adequate distribution of the binder mortar in concrete during the mixing and vibratory compaction operations.

1.2 Objectives and Scope of The Study

The main advantage of RCC is reduced cost and time for construction. Mixture materials and proportioning of those materials for RCC differ from conventional concrete. RCC must maintain a consistency that will support a vibratory roller while being able to be compacted by a vibratory roller.

This study is performed with the material obtained from Kolin İnşaat A.Ş., from the project coded: 2005-03-03-2-00.97 and signed between METU and the firm. The aim of the project is to obtain the optimum RCC mixture to generate compressive strength of 7 MPa in the long term at project site, Akköy-I Dam and Hydroelectric Plant Construction.

In this study natural pozzolan is used for making RCC. Several mixture designs are prepared to achieve the optimum proportioning with available materials for RCC. These materials are experimentally investigated. Moreover steam curing is applied to test specimens in order to determine long-term compressive strength values for time saving.

CHAPTER 2

THEORETICAL CONSIDERATIONS ON ROLLER COMPACTED CONCRETE

2.1 General

ACI Committee Report 207.5R-2 defines roller compacted concrete (RCC) as a concrete of no-slump consistency in its unhardened state that is transported, placed, and compacted using earth and rockfill construction equipment. RCC is a concrete that, in its unhardened state, will support a vibratory roller while being compacted. RCC differs from granular soil cement, for which similar placement methods may be used, primarily in that it contains coarse aggregate and develops properties similar to conventionally placed concrete. The report explains RCC as most important development in concrete dam technology in the past quarter century. The use of RCC has allowed many new dams to become economically feasible due to the reduced cost realized from the rapid construction method. It has also provided design engineers with an opportunity to economically rehabilitate existing concrete dams that have problems with stability, and has improved embankment dams with inadequate spillway capacity by providing a means by which they can be safely overtopped [1].

2.2 Development of RCC

The development of RCC caused a major shift in construction practice of mass concrete dams and locks. The traditional method of placing, compacting, and consolidating mass concrete is at best a slow process. Improvements in earth-moving equipment made the construction of earth and rock-filled dams speedier and, therefore more cost-effective.

In 1970, Professor Jerome Raphael pointed out that fill material has only 10 percent of the cohesion of mass concrete. It would be feasible, therefore, to design an optimum gravity dam that took advantage of the excellent cohesion of mass concrete, with the advantage of rapid transportation and consolidation of fill material [2].

2.3 Properties of RCC

2.3.1 General

RCC is a concrete that is placed by non-traditional methods that allow and require a drier or stiffer consistency than traditional concrete. RCC can have a much broader range of material properties than conventionally placed concrete. Aggregates not meeting requirements for normal concrete can be used for production of RCC. Moreover RCC can be placed at very high production rates and it can be more economical [3].

RCC is often mixed in a continuous process rather than in batches. Early projects delivered the RCC primarily with dump trucks but most current projects use conveyors. It is spread in layers and final compaction is given with a vibratory roller. Usually a 10 ton roller intended for asphalt and granular base is used for compaction because of its high productivity, high frequency, low amplitude vibration and very high compactive energy. Usually the layer thickness is 300 mm, where it can change between 200 and 400 mm [3].

RCC is usually mixed using high-capacity continuous mixing or batching equipment, delivered with trucks or conveyors, and spread with one or more bulldozers in layers prior to compaction [1].

RCC is regarded as a construction technology rather than a design criterion or a design technology. RCC uses a concrete of no-slump consistency in its unhardened state which is transported, placed and compacted using earth and rockfill construction equipment [4].

This technology has been used in many dams in the world successfully. The use of RCC in construction of gravity and arch dams continues to increase. The mix is spread in thin layers over the whole or part length of the dam. This enables the construction to proceed rapidly [4].

As RCC mix designs are conventional and produce high strength and density, it can be useful for pavements, rehabilitation works, replacement and protection of structures. This technology is best suited for multi-layer construction with a high ratio of surface to thickness such as pavements and dams [4].

RCC may be considered for application where no slump concrete can be transported, placed and compacted using earth-fill construction equipment. Applications of RCC to date have centered on dams instead of concrete gravity and earth-fill dams. It can also be used for pavements to accommodate heavily loaded vehicles traveling at low speeds. These include hardstands for tracked vehicles, truck and aircraft parking areas. Moreover RCC may be used for street paving, highways and parking lots. In addition to that, RCC can be used for emergency repairs and rehabilitation of earth-fill dams. For several dam projects, the use of RCC may result in a more economical layout of project attributes such as an over-the-crest spillway as opposed to a side-channel spillway [5].

A goal of mass-concrete mixture proportioning, which is also applicable to RCC mixture proportioning, is to provide a maximum content of coarse aggregate and a minimum amount of cement while developing the required plastic and hardened properties at the least overall cost [2]. Optimum RCC proportions consist of a balance between good material properties and acceptable placement methods. This includes minimizing segregation. In implementing a specific mixture-proportioning procedure, the following considerations regarding plastic and hardened properties should be addressed.

2.3.2 Workability

Sufficient workability is necessary to achieve compaction or consolidation of the mixture. Moreover, sufficient workability is necessary to provide an acceptable appearance when RCC is to be compacted against forms.

Workability is most affected by the paste portion of the mixture including cement, pozzolan, aggregate fines, water and air. When there is sufficient paste to fill aggregate voids workability of RCC mixtures is measured on a vibratory table with a Vebe apparatus in accordance with ASTM C 1170 [1].

Workability has a composite nature as a property, and it depends on type of construction and methods of placing, compacting, and finishing. Thus there is no single method to measure workability. The Vebe test is appropriate for mixtures with low consistency [2]. Figure 2.1 shows the Vebe vibrating table equipped with rotating arm and guide sleeve.

The Vebe equipment was developed by Swedish engineer V. Bährner. It consists of a vibrating table, a cylindrical pan, a slump cone, and a glass or plastic disk attached to a free moving rod that serves a reference end point. While performing the test, the cone is placed in the pan, filled with concrete and then removed. The disk is brought into position on top of the concrete cone, and the vibrating table is set into motion.

The time required to remold the concrete from the conical to the cylindrical shape is a measure of the consistency and is reported as Vebe time in seconds [2].

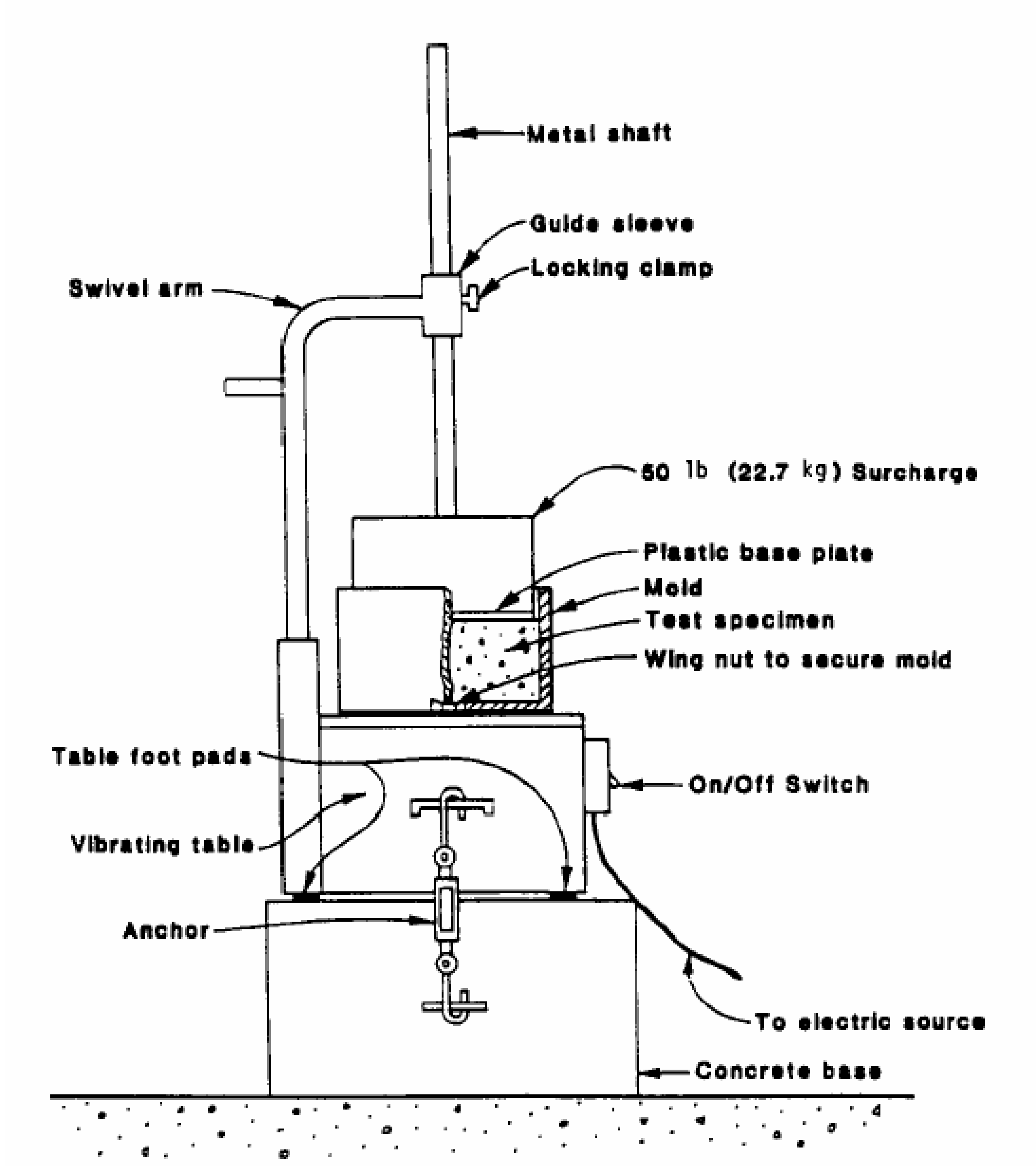

Figure 2.1 The Vebe Vibrating Table [6] (equipped with rotating arm and guide sleeve)

The Vebe test procedure produces a Vebe time for a specific mixture, and is used in a similar way as the slump test for conventional concrete. RCC mixtures with the degree of workability necessary for ease of compaction and production of uniform density from top to bottom of the lift, for bonding with previously placed lifts, and for support of compaction equipment, generally have a Vebe time of 10 to 45 sec [1].

The water demand for a specific level of workability is influenced by the size, shape, texture and gradation of aggregates, the volume and nature of cementitious and fine materials [1].

2.3.3 Compressive Strength

Compressive strength is generally regarded as the most convenient indicator of the quality and uniformity of the concrete. Therefore, the design compressive strength is usually selected based on the level of strength necessary to satisfy compressive tensile and shear stresses plus durability under all loading conditions [1].

RCC strength depends upon the quality and grading of the aggregate, mixture proportions, as well as the degree of compaction. There are differing basic strength relationships for RCC, depending on whether the aggregate voids are completely filled with paste or not. The water-cement ratio (w/c) law, as developed by Abrams in 1918, is only valid for fully consolidated concrete mixtures. Therefore, the compressive strength of RCC is a function of the water-cementitious materials ratio (w/cm) only for mixtures with a Vebe time less than 45 sec [1]. Figure 2.2 shows this general relationship. For drier consistency (all voids not filled with paste) mixtures, compressive strength is controlled by moisture-density relationships. There is an optimum moisture content that produces a maximum dry density for a certain comparative effort [1].

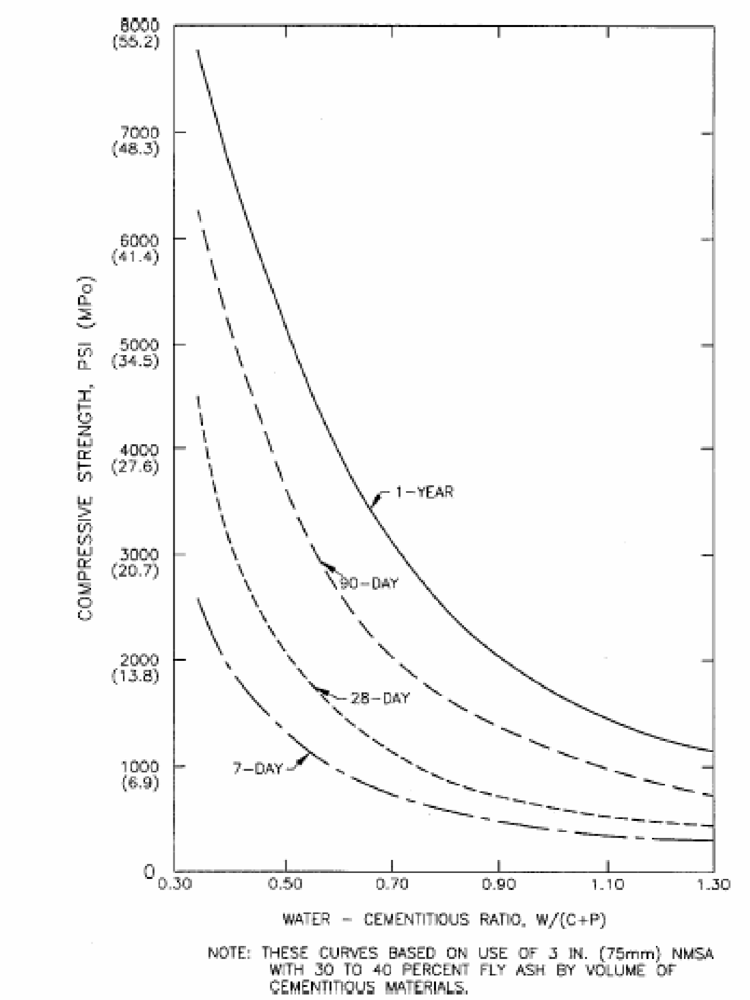

Figure 2.2 Compressive Strength versus cementitious materials [1]

The rapid placing rates common in RCC construction can place construction loads on concrete before it reaches its initial set, and early-age testing of performance may be needed for the design. The designer should maintain an awareness of the potential impact of low early age strength on construction activities [1].

Compressive strength tests are performed in the design phase to determine mixture proportion requirements and to optimize combinations of cementitious materials and aggregates. Compressive strength is used to satisfy design loading requirements and also as an indicator of other properties such as durability.

Pozzolan can delay the early strength development of RCC. Higher pozzolan contents cause lower early strengths. However, mixtures proportioned for later age strengths such as at 180 days or 1 year, can use significant quantities of pozzolan [1].

RCC mixtures with low cementitious contents may not achieve required strength levels if aggregate voids are not completely filled. For these mixtures, the addition of nonplastic fines or rock dust has been beneficial in filling voids, thus increasing the density and strength.

2.3.4 Unit Weight

Many RCC mixtures, due to lack of entrained air and lower water content, result in a slightly higher density compared to conventional air-entrained mass concrete made with the same aggregate. Fully compacted RCC has a low air content (generally 0.5 to 2.0%) and a low water content. More solids occupy a unit volume and the increased density is approximately 1 to 3% more than conventional concrete and generally exceeds 2400 kg/m^3 [1].

2.3.5 Segregation

A major goal in proportioning the RCC mixtures is to produce a cohesive mixture while minimizing the tendency to segregate during transportation, placing and spreading. Well-graded aggregates with a slightly higher fine aggregate content than conventional concrete are essential for nominal maximum size aggregate greater than 37.5 mm. If not proportioned properly, RCC mixtures tend to segregate more because of the more granular nature of the mixture. This situation is controlled by the gradation of aggregate, moisture content and adjusting fine material content in lower cementitious content mixtures. Higher cementitious content mixtures are usually more cohesive and less likely to segregate [1].

2.3.6 Permeability

Most concerns regarding permeability of RCC are directed at lift-joint seepage. Higher cementitious content or high workability mixtures that bond well to fresh lift joints will produce adequate water tightness. On the other hand, lower cementitious content or low workability mixtures are not likely to produce adequate water tightness without special treatment, such as use of bedding mortar between lifts [1].

2.3.7 Heat Generation

For massive structures proportioning of RCC should consider the heat generation of the cementitious materials. To minimize the heat of hydration, care should be taken in the selection and combination of cementing materials used. The amount of cementitious material used in the mixture should not be more than necessary to achieve the necessary strength level. Proportioning should incorporate those measures which normally minimize the required cementitious material content, such as appropriate maximum size of aggregate and well graded aggregates [1].

2.3.8 Durability

The RCC mixture should provide the required degree of durability based on material properties, exposure conditions and expected level of performance. RCC should be free of deleterious effects of alkali-aggregate reactivity by proper evaluation and selection of materials. Freezing-thawing resistance and erosion should not be a major concern during mixture proportioning provided that high quality conventional concrete is used on the upstream, crest and downstream faces and on the spillway surfaces [1].

2.3.9 Construction Conditions

Construction requirements and equipment should be considered during mixture proportioning. Some construction methods, placement schedules, and equipment selections are less damaging to compacted RCC than others. A higher workability mixture may result in a compacted RCC surface that tends to rut from rollers. Placing conditions with many obstacles requiring smaller compaction equipment benefit from mixtures with high workability [1].

2.4 RCC Mix Design Methods

2.4.1 General

Hansen and Reinhardt [7] explains two approaches in RCC mix design methods, which are soils (or geotechnical) approach, and concrete approach. In fact, there is no distinct line separating the two philosophies. Basically, concrete design method RCC mixtures have a more fluid consistency as measured by a Vebe test. These mixes can be described as more workable than those developed using the soils approach, yet both philosophies produce a zero slump concrete. The high-paste RCC dam and the Japanese method can be considered as concrete approach. Upper Stillwater Dam, Elk Creek Dam, and all Japanese RCD (Roller compacted dam) are examples of concrete approach RCC mixture dams. On the hand, Willow Creek Dam, Copperfield Dam, Middle Fork Dam and Monksville Dam are examples of the soils approach which were built with lean RCC mixtures [7].

The soils philosophy considers RCC as a cement-enriched soil or aggregate whose mix design is based on moisture-density relationship. The goal is to determine an optimum moisture content for a laboratory compactive effort that corresponds to effort applied by the rollers in the field for a specified aggregate and cementitious material content. In this approach paste does not generally fill all the voids in the aggregate after compaction [7].

The concrete approach considers RCC mix as a true concrete where strength is inversely proportional to its water-cement ratio. Using less water with a constant amount of cement produces concrete with higher compressive strength and related properties. This approach is based on the concept that there is sufficient paste in the RCC mix to more than fill all the voids in the aggregate. The RCC mix should not contain that much paste that a measurable slump is produced or excess paste is brought to the surface with only a few passes of the vibratory roller [7].

2.4.2 Mixture Proportioning Methods

A number of mixture proportioning methods have been used for RCC throughout the world. Due to location and design requirements of the structure, availability of materials, mixing and placing equipment used, and time constraints, these methods show differences. Most mixture proportioning methods are variations of two general approaches: 1) a w/cm approach with the mixture determined by solid volume; and 2) a cemented aggregate approach with the mixture determined by either solid volume or moisture-density relationship. Both approaches are intended to produce quality concrete suitable for roller compaction and dam construction.

RCC mixture proportions can use the convention used in traditional concrete where the mass of each ingredient contained in a compacted unit volume of the mixture is based on saturated surface dry aggregate condition. A practical reason for use of this standard convention is that most RCC mix plants require that mixture constituents be so identified for input to the plant control system [1].

2.4.2.1 Corps of Engineers Method

This proportioning is based on w/cm ratio and strength relationship. The mixture quantities are calculated from solid volume determinations as used in conventional concrete proportioning. The w/cm and equivalent cement content are established from figures based on strength criteria using Figure 2.2 and Figure 2.3. The approximate water demand is based on maximum size aggregate and desired modified Vebe time. A recommended fine aggregate content as percentage of total aggregate volume is based on maximum size and nature of the coarse aggregate. This method also provides ideal combined coarse aggregate gradings and fine aggregate gradings limits incorporating a higher percentage of fine sizes than permitted by ASTM C 33 [1].

2.4.2.2 High Paste Method

This mixture proportioning method was developed by the U.S. Bureau of Reclamation for use during the design of Upper Stillwater Dam. The resulting mixtures from that testing program generally contained high proportions of cementitious materials, high pozzolan contents, clean and normally graded aggregates and high workability. The purpose of the Upper Stillwater Dam mixtures was to provide excellent lift joint bond strength and low joint permeability. The method involves determining w/cm and fly ash-cement ratios for the desired strength level and strength gain. The optimum water, fine aggregate, and coarse aggregate ratios are determined by trial batches, evaluating the Vebe consistency for a range of 10 to 30 seconds. The required volumes and mass of aggregate, cement, pozzolan, water and air are then calculated [1].

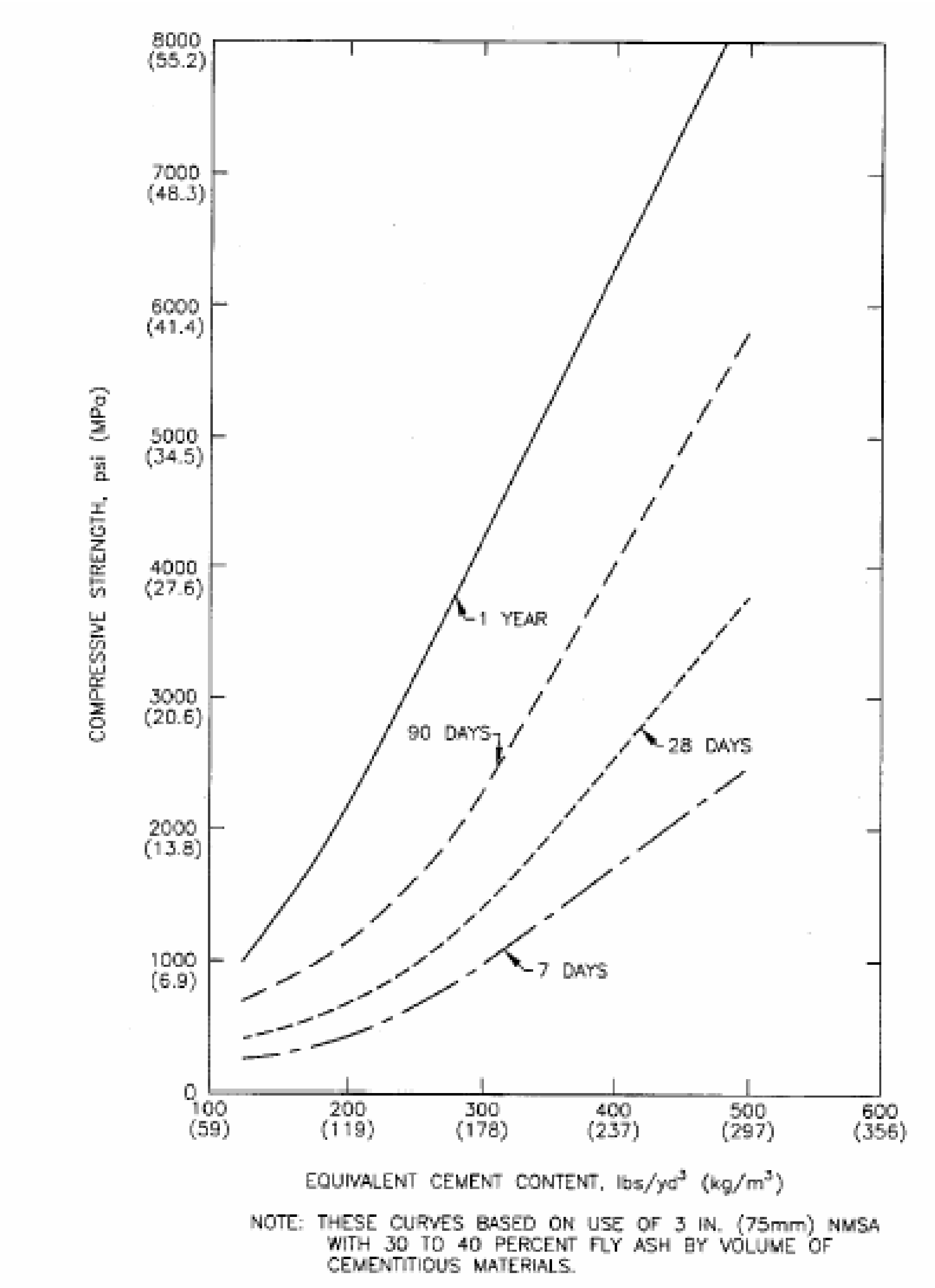

Figure 2.3 Equivalent cement content versus Compressive Strength [1]

2.4.2.3 Roller Compacted Dam Method

The roller compacted dam (RCD) method was developed by Japanese engineers and is used primarily in Japan. The method is similar to conventional concrete proportioning except that it incorporates the use of a consistency meter. The consistency meter is similar to Vebe apparatus, the RCC mixture is placed in a container and vibrated until mortar is observed on the surface. The procedure consists of determining relationships between the consistency, and the water content, sand-aggregate ratio, unit weight of mortar and compressive strength [1].

2.4.2.4 Maximum Density Method

This method is a geotechnical approach similar to that used for selecting soil-cement and cement stabilized base mixtures. Instead of determining the water content by Vebe time or visual performance, the desired water content is determined by moisture-density relationship of compacted specimens.

Variations of this method can be used depending on the mixture composition and nominal maximum size of aggregate. Compaction equipment may be a standard drop hammer, or better suited modified hammer for larger aggregates, or an alternative tamping/vibration method that simulates field compaction equipment.

In this method, a series of mixtures for each cementitious materials content is prepared and batched using a range of water contents. The maximum density and optimum water content are determined from a plot of density versus water content for the compacted specimens at each cementitious materials content. The actual water content to be used in the field is slightly higher (approximately 1%) than the optimum value determined in the laboratory in order to compensate for moisture loss during transporting, placing and spreading [1].

2.5 Advantages and Disadvantages of RCC

There are extensive advantages in RCC dam construction. However there are also some disadvantages that should be recognized. Many advantages are mostly realized with certain types of mixtures, structural designs, production methods, weather and other conditions. Similarly, some disadvantages apply to particular site conditions and designs. Each RCC project must be carefully evaluated based on technical value and cost.

The main advantage of RCC is reduced cost and time for construction [1]. Its lower cost compared to conventional concrete comes from the continuous mixing and hauling, as well as planning simplifications and economy due to shorter construction period [4]. Cost of transporting, placement and compaction of concrete decreases since concrete can be hauled by end dump trucks; spread by bulldozers and compacted by vibratory rollers. Because of low temperature rise, pipe cooling is unnecessary. Since much leaner concrete mixtures are used in RCC projects, cement consumption is lower. Layer placement method decreases formwork costs. RCC costs 25 to 50 percent less than conventional concrete depending on complexity of the structure [2].

In addition to that, RCC dam technology can be implemented rapidly. For emergency projects such as the Kerrville Ponding Dam, RCC was used to build a new dam speedily downstream of an embankment dam that was in danger of failure due to overtopping [1]. Another example of rapid construction advantage of RCC is Conception Dam in Honduras after declaration of a national water supply emergency [1]. RCC dams can be finished 1 to 2 years earlier for large projects compared to mass concrete dams [2].

When suitable aggregates are available near the site, where suitable foundation rock is close to the surface, and when spillway and river diversion requirements are large, RCC usually gains an advantage compared to embankment type dams [1]. In general embankment dams require that spillways to be constructed in an abutment. RCC dams provide spillway to be constructed in the main structure of the dam in an attractive and cost-effective option [2].

Reduced cofferdam requirements is another advantage of RCC dams. Once initiated, an RCC dam can be overtopped with minimal impact and the height of the RCC dam can quickly exceed the height of the cofferdam [1]. Thus the damage caused by overtopping of the cofferdam is less for RCC dams than for embankment dams. Furthermore the cost of the river diversion is less for RCC dams than for embankment dams [2].

RCC technology can be used in dam construction under climates ranging from tropical to arctic, and in climates having seasonal changes. RCC construction is suitable in both developing and industrialized countries, with labor wages changing in the world. The secret of RCC construction is said to be in keeping it as continuous, repetitive and simple as possible [4]. Since concrete placement speed is high, labor and construction equipment utilization is high [2].

Although RCC dams are known to be the most economic when compared to other types of dams, there are conditions that may make RCC more costly. When aggregate material is not practically available RCC may not be appropriate. In addition to that, RCC may not be appropriate when the foundation rock is of poor quality, or not close to surface and where foundation conditions can lead to excessive differential settlement [1].

2.6 Materials of RCC Mixtures

2.6.1 General

A wide range of materials have been used successfully to produce RCC mixtures. Materials used for RCC include cementitious materials (Portland cement and pozzolans), aggregates, water and admixtures [7].

Mixture proportioning methods and objectives for RCC differ from those of conventional concrete. RCC must maintain a consistency that will support a vibratory roller while also being suitable for compaction by a vibratory roller. The aggregate grading and paste content are critical points in mixture proportioning. Specific testing procedures and evaluation methods have been developed that are unique to RCC technology. Regardless of the material specifications selected or mixture-proportioning method, the testing and evaluation of laboratory trial batches are essential to verify the fresh and hardened concrete.

An essential element in the proportioning of RCC for dams is the amount of paste. The paste volume must fill or nearly fill aggregate voids and produce a compactable, dense concrete mixture. Moreover, the paste volume should be sufficient to produce bond and watertightness at horizontal lift joints.

Certain economic benefits can be achieved by reducing the processing requirements on aggregates, the normal size separations, and separate handling, stockpiling and batching of each size range. However, it is pointed out that the designer must recognize that reducing or changing the normal requirements for concrete aggregates must be weighed against greater variation in RCC properties. Moreover changing the normal requirements for concrete aggregates should be accounted for by a more conservative selection of average RCC properties to be achieved [1].

It is reported that much of the guidance on materials provided in ACI 207.1R (Mass Concrete) may be applied to RCC. However, because some material constraints may not be necessary for RCC, the application is regarded as less demanding, more material options are possible [1]. The report advises the designer to evaluate the actual materials for the specific project and the proportions under construction, design the structure accordingly, and provide appropriate construction specifications [1].

2.6.2 Cement

RCC technology does not require a special type of cement. However, when RCC is to be used in mass concrete, cements with lower heat generation should be preferred [2]. RCC can be made with any basic type of Portland cement. However, for mass application a low heat generation type is required by ACI Committee 207.5R. They include ASTM C 150, Type II (moderate heat of hydration) and Type V (sulfate-resistant) and ASTM C 595, Type IP (portland-pozzolan cement) and Type IS (portland-blast furnace slag cement). Strength development for these cements are usually slower than Type I at early ages, however higher strengths than RCC produced with Type I cement are ultimately produced [1].

Heat generation due to hydration of the cement is controlled by the use of cements with lower heat of hydration, use of less cement, and replacement of a portion of cement with pozzolan or a combination of these. Peak concrete temperature can be reduced by different methods such as reduced placement methods.

The selection of cement type should be based on economics of cement procurement. It may not be cost effective to select a lower heat cement which is not locally available for small and medium sized projects. It must be ensured that cement supply is continuous due to high production capability of RCC [1].

2.6.3 Admixtures

An admixture is a material other than water, aggregates and hydraulic cement that is an ingredient of concrete or mortar and is added to the batch immediately before or during its mixing. Admixtures modify one or more properties of fresh and hardened concrete in such ways as making the concrete more suitable for the work at hand, for economy or energy savings [8].

Concrete admixtures are generally categorized under four main grouping: air-entraining admixtures, chemical admixtures, mineral admixtures and miscellaneous admixtures [8]. For the purpose of this study, only mineral and chemical admixtures will be discussed in detail.

2.6.3.1 Mineral Admixtures

Mineral admixtures are the finely divided materials added to the concrete batch as a separate ingredient either before or during mixing. Finely divided mineral admixtures may be classified into three general types: those which are pozzolanic or mainly pozzolanic with some additional cementitious properties; those which are cementitious such as hydraulic lime, masonry cement, and slag cement; and others such as rock dust [8].

Mineral admixtures that are commonly used for concrete are pozzolanic materials. Sometimes these pozzolanic materials possess self-cementitious properties in addition to their being pozzolanic. Utilization of cementitious mineral admixtures and others such as rock dust is much less than utilization of pozzolanic materials [8].

Pozzolan is a siliceous or siliceous and aluminous material in which itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide to form compounds possessing hydraulic cementitious properties [9].

Pozzolans can be natural or artificial. Volcanic ash, volcanic tuff, volcanic glass, pumicite, and diatomaceous earth are naturally occurring pozzolans. Fly ash, silica fume, ground granulated blast furnace slag, and the ash obtained by burning the rice husk are artificial pozzolans [9].

Fly ash, ground granulated blast furnace slag, and natural pozzolans in a ground state are the commonly used mineral admixtures for concrete. Replacement rate of mineral admixture with concrete is usually 30 to 50 % by weight. Thus, a pozzolanic cement is obtained by mixing the cement, pozzolan, aggregates and water together[9].

The calcium silicate compounds of portland cement produces calcium-silicate-hydrate, and calcium hydroxide. The finely divided pozzolan that takes place as an admixture in concrete reacts with the calcium hydroxide produced as a result of hydration of cement. Thus, additional calcium-silicate-hydrate gels are produced in the concrete mixture [9].

The reaction between the finely divided pozzolan and calcium hydroxide, in the presence of moisture, is shown as follows:

$$\underset{\text{Calcium Hydroxide}}{CH} + \underset{\text{Silicate}}{S} + \underset{\text{Water}}{H} \rightarrow \underset{\text{Calcium Silicate Hydrate}}{C-S-H} \qquad (2.1)$$

The symbols C, H, and S are used as in cement chemistry representing C:CaO, H:H_2O, and S:SiO_2.

The use of finely divided mineral admixtures improves many properties of the fresh concrete and hardened concrete. Moreover, mineral admixtures provide economy. Therefore pozzolans are widely used as admixture in concrete [9]. The use of pozzolan will depend on required material performance as well as on its cost and availability at each project [1].

Use of a pozzolan in RCC mixtures may serve different purposes: as a partial replacement for cement to reduce heat generation, as a partial replacement for cement to reduce cost, and as an additive to provide supplementary fines for mixture workability and paste volume. The rate of replacement may vary from none to 80 percent by mass. RCC mixtures with a higher cementitious material content often use larger amounts of pozzolan to replace portland cement to reduce internal temperature rise that would otherwise be generated and consequently reduce thermal stress [1]. RCC mixtures with low cement content, pozzolans have to be used to ensure an adequate amount of paste for filling aggregate voids and coating aggregate particles. Pozzolan may have limited effectiveness in low cementitious content mixtures with aggregates containing deleterious amounts of clay and friable particles. While the pozzolan enhances the paste volume of these mixtures, it may not enhance the long-term strength development because of insufficient availability of calcium hydroxide released from the portland cement for a pozzolanic reaction [1].

In mix proportion for minimum paste volume one principal function of a pozzolan or added fines is to occupy void space which would otherwise be occupied by cement or water. To occupy void space with water would obviously result in a reduction in concrete strength. The fact that even a small amount of hydrated lime liberated from cement is sufficient to react with large volumes of pozzolans has been demonstrated by agencies such as Tenesse Valley Authority (TVA), U.S.Army Corps of Engineers (USCE), U.S.Bureau of Reclamation (USBR), which have used fly ash to replace some of the fine aggregate as well as to replace cement. The pozzolans not only occupy space but contribute to strength as well. Their contribution to heat generation varies inversely with the ratio of pozzolan to cement such that for a given strength requirement, the mix with the lowest cement content will have the least temperature rise [1].

Mineral admixtures are widely used in RCC. The use of high amounts of mineral admixtures decreases the adiabatic temperature rise of concrete and costs. Moreover, durability of concrete is increased with use of mineral admixtures. Class F fly ash is the most common mineral admixture used in dams in the United States. In other parts of the world Class C fly ash, slag, and natural pozzolan have also been used [2].

2.6.3.2 Chemical Admixtures

In concrete technology, the term chemical admixture is restricted to water-soluble compounds other than air-entraining agents. They are added to the concrete mainly to control setting and early hardening of fresh concrete or to reduce its water requirements. The chemical admixtures are grouped as: water-reducing admixtures, retarding admixtures, accelerating admixtures, water-reducing and retarding admixtures, water-reducing and accelerating admixtures, high-range water-reducing admixtures (plasticizers), and high-range water-reducing and retarding admixtures (superplasticizers) [8].

In general, chemical admixtures show a limited effectiveness in RCC with dry consistency. Air-entraining and water-reducing admixtures are used in RCC that contain high volume of paste. Set-retarder admixtures are used in RCC where concrete lift should remain unhardened to reduce risk of cold joints with the following lift [2].

Chemical admixtures are effective in RCC mixtures that contain sufficient water to provide a more fluid paste. Water reducing admixtures and water reducing and retarding admixtures, when used at very high dosages, reduce water demand, increase strength, retard set, and promote workability in some RCC mixtures. However, the knowledge of the effectiveness in other mixtures, typically with low cementitious materials contents and low workability is limited. It is recommended that the admixtures should be evaluated with the actual RCC mixture before using in the field [1]

Air-entraining admixtures are not commonly used in RCC mixtures because of the difficulty in generating bubbles of the proper size and distribution when the mixture has a no-slump consistency. However, air-entrained RCC has been used on a production basis in China and the U.S. RCC exhibiting a fluid paste consistency has generally been necessary for air-entraining admixtures to perform [1].

2.6.4 Aggregates

The selection of aggregates and the control of aggregate properties and gradings are important factors directly influencing the quality and uniformity of RCC production. Aggregates similar to those of conventional concrete have been used in RCC. In addition to that, aggregates that do not meet the normal standards or requirements for conventional concrete have also been successfully used in RCC dam construction [1]. Based on required concrete performance and demonstrated field and laboratory evaluations, limits on physical requirements and deleterious materials for aggregates to be used in RCC for a specific application should be established prior to construction. The majority of RCC projects have been constructed with aggregates meeting all of the ASTM C 33 requirements, with the exception of an increased amount of fines passing 0.075 mm sieve. Aggregates of marginal quality have been used in RCC on some projects because they were close to site and thereby the most economical source available [1].

A basic objective in proportioning any concrete is to incorporate the maximum amount of aggregate and minimum amount of water into the mixture, thereby reducing the cementitious material quantity, and reducing consequent volume change of concrete. However, in RCC mixtures, the potential for segregation and the means of compaction must also be primary consideration in selecting the maximum aggregate size. Early projects in the U.S. used a 75 mm nominal maximum aggregate size, however a 50 mm nominal maximum aggregate size is less prone to segregation and is becoming more widely used [1].

The combined aggregate gradation should be selected to minimize segregation. The key to controlling segregation and providing a good compactable mixture is having a grading that is consistent and contains more materials passing 4.75 mm sieve than typical in conventional concrete of similar nominal maximum aggregate size.

In conventional concrete, the presence of any significant quantity of flat and elongated particles is usually undesirable. However, RCC mixtures seem to be less affected by flat and elongated particles than conventional concrete mixtures. This is due to the vibratory compaction equipment provides more energy than traditional consolidation methods, and because the higher mortar content in RCC mixture tends to separate coarse aggregate particles. The presence of flat and elongated particles is still undesirable, but amounts up to about 40% on any sieve size with an average below approximately 30% have shown, in field tests, flat and elongated particles to be no significant problem. The U.S. Army Corps of Engineers has a limit of 25 % on the allowable content of flat and elongated particles in any size group. The use of manufactured aggregate (crushed stone) has been found to reduce the tendency for segregation as compared to rounded gravels [1]. Both crushed and natural rounded materials work well, but the ideal combination appears to be angular crushed coarse particles with natural rounded sand. When steep unformed slopes are to be constructed, crushed material becomes more important [3].

Since aggregates greater than 76 mm in diameter cause problems in spreading and compacting the layer, they are seldom used in RCC. Generally maximum aggregate size is limited to 38 mm. The size of coarse aggregate has a significant effect on compaction in small layers. Especially, when large vibratory rollers are used, this effect is in a smaller amount [2].

Gradation of aggregate has an important influence on the mixture proportions. The material finer than 75 µm turns out to be a more cohesive mixture since the volume of voids is reduced [2].

In many RCC dams the stress level in structure is relatively low. This makes use of lower quality aggregate particularly in the interior of the structure. In this case, long-term durability should be assessed especially if the structure is exposed to cold climate [2].

2.6.4.1 Coarse Aggregates

The selection of the nominal maximum aggregate size aggregate should be based on the need to reduce cementitious material requirements, control segregation and to facilitate compaction. Most RCC projects used a nominal maximum aggregate size aggregate of 37.5 mm to 75 mm. There has not been enough material cost savings from using aggregate sizes larger than 75 mm to offset the added batching cost and cost of controlling the increased segregation problems associated with the larger aggregates [1].

Grading of coarse aggregate usually follows ASTM C 33 size designations. Cost savings can be realized by combining two or more size ranges such as ASTM C 33 size designations 50 to 4.75 mm and 37.5 to 4.75 mm respectively. But, as the size range increases, it becomes more difficult to avoid segregation of the larger particles during stockpiling and handling of this aggregate [1].

It is recommended that the design engineer should evaluate the potential in a reduction in number of stockpiles and separate handling and weighing facilities against the potential for increased variation in aggregate grading and its impact on uniformity of consistency, on bonding, and on permeability of the RCC [1].

2.6.4.2 Fine Aggregates

The grading of fine aggregate strongly influences paste requirements and compactability of RCC. Moreover, it affects water and cementitious material requirement needed to fill the aggregate voids and coat the aggregate particles. ASTM C 33 fine aggregate grading can be used for those mixtures having a sufficient cementitious materials content and paste volume. It can be determined when the mixtures are proportioned [1].

2.6.4.3 Fines

Supplementary fines, materials passing 0.075 mm sieve, are usually required to fill all aggregate voids in low cementitious materials content mixtures. Total volume of the fines can be as much as 10 % of the total aggregate volume depending on the volume of cementitious material and the maximum aggregate size. Most mixtures use approximately 3 to 8 % of supplementary fines. Characteristics of the fines and fines content will affect the relative compactability of the RCC mixture. Moreover, it can influence the number of passes of a vibratory roller required to fully compact a given layer thickness [1].

The fines fill aggregate void space, provide a compactable consistency, help control segregation, and decrease permeability. Including aggregate fines in low cementitious paste mixtures allows reductions in the cementitious materials content. Excessive additions of aggregate fines after the aggregate voids are filled are harmful to the RCC mixture because decreases workability, increases water demand and subsequent strength loss [1].

When adding aggregate fines to a mixture, nature of the fines should also be evaluated. Crusher fines and silty materials are usually acceptable. However, clay fines (plastic fines) can increase water demand and cause strength loss, and produce a sticky mixture that is difficult to mix and compact [1].

2.7 Laboratory Testing of RCC

RCC properties strongly depend on the mixture proportioning and on the quality of compaction. Concrete is consolidated with vibratory rollers in the field. Despite extensive research on this subject, there is as yet no unanimously accepted methodology to simulate the field condition in preparing laboratory samples [2]. Impact compaction required by the dry consistency samples can be achieved by using equipment similar to the modified Proctor test for soils. Selection of the compaction energy is very important. If the compaction energy is too low the sample may develop undesirable layers, where if the compaction energy is too high the aggregates can break resulting in changes in the granulometric curve [2].

For RCC mixtures containing large volume of paste, a Vebe vibrating table can be used for preparation of the test samples [2].

Another method of testing sample preparation is tamping by a vibrating rammer or by a pneumatic pole tamper [2].

2.8 History of RCC

As a result of its economics and successful performance, RCC is accepted worldwide rapidly. During the 1960s and 1970s, some materials that can be considered as RCC were used. These applications led to development of RCC in engineered concrete structures.

In the 1960s, a high production no-slump mixture spread with bulldozers was used in Italy at Alpe Gere Dam and in Canada at Manicougan I. These mixtures were consolidated with large internal vibrators mounted on backhoes or bulldozers.

In 1965, using earthmoving equipment and large rollers for compaction was suggested for fast production of gravity dams as a practical approach to more economical dam construction. However, the real attention was directed to the subject as it was presented by Raphael in 1970 for the “optimum gravity dam”. Optimum gravity dam considers a section similar to but with less volume than the section of an embankment dam.

During the 1970’s, a number of projects ranging from laboratory and design studies to test fills, field demonstrations, non structural uses, and emergency mass uses were accomplished and evaluated using RCC. These efforts formed a basis for the first RCC dams that were constructed in the 1980’s. Notable contributions were made in 1972 and 1974 by Cannon, who reported studies performed by the Tennessee Valley Authority. In 1973 and 1974, the U.S. Army Corps of Engineers performed studies on RCC construction at the Waterways Experiment Station and at Lost Creek Dam. The early work by the U.S. Army Corps of Engineers was in expectation of construction of an optimum gravity dam for Zintel Canyon Dam. However, Zintel Canyon Dam was not funded at the time. Many of its concepts were carried over to the first RCC dam in the U.S., the Willow Creek Dam.

Lowe used what he termed as ‘rollcrete’ for massive rehabilitation efforts at Tarbela Dam in Pakistan in 1974, which was developed initially for the core of Shihmen Dam in 1960. To rehabilitate the auxiliary and service spillways at Tarbela Dam additional large volumes of RCC were used later in the 1970’s.

In England, extensive laboratory studies and field trials were performed by Dunstan in the 1970’s using high-paste RCC. Further studies in the UK were supported by the Construction Industry Research and Information Association and led to developments in laboratory testing of RCC and construction methods.

In the late 1970s in Japan, for Shimajigawa Dam, the design and construction philosophy known as roller compacted dam (RCD) was emerged. Shimajigawa Dam was completed in 1981 with half of its total concrete being RCC. The RCD method uses RCC for the interior of the dam with approximately 1 m thick conventional mass concrete zones at the upstream and downstream faces, the foundation and the crest of the dam. Moreover, in RCD, thick lifts with delays are left after the placement of each lift to allow the RCC to cure. The RCD method gives the dam appearance of a dam with conventional concrete and behavior. However, it requires additional cost and time compared to RCC dams that have a higher percentage of RCC to total volume of concrete.

Willow Creek Dam and Shimajigawa Dam are principal structures that initiated the rapid acceptance of the RCC dams. Willow Creek Dam completed in 1982 and became operational in 1983. The flood control structure was the first major dam designed and constructed to be essentially all RCC. Moreover in Willow Creek Dam precast concrete panels are used to form the upstream face of the dam without transverse contraction joints. In 1984, in Winchester Dam in Kentucky, the precast concrete facing panel concept was improved.

In the 1980s, the U.S. Bureau of Reclamation used Dunstan's high-paste RCC concept for the construction of Upper Stillwater Dam. A steep downstream slope, and high, horizontally slipformed upstream and downstream facing elements as an outer skin of conventional low slump and air entrained concrete are improvements in RCC technology used at this structure.

The high production rates of RCC dam construction was shown in many of the dams in the early 1980s. During the 1980s and 1990s, the use of RCC continued in small and medium size dams in the U.S. Moreover, the use of RCC has expanded to larger projects. In order to meet needs of developing nations, RCC advanced rapidly. In South Africa, the first RCC arch gravity dams were constructed by the Department of Water Affairs and Forestry for Knellport and Wolwedans Dams.

In the mid-1980s, the use of RCC to rehabilitate existing concrete and embankment dams started in the U.S. The main use of RCC to upgrade concrete dams has been to reinforce an existing structure to improve its seismic stability. On the other hand, to upgrade embankment dams RCC has been used as an overlay on the downstream slope to allow safe overtopping during flood [1].

2.9 Steam Curing

It has been recognized from the beginning of concrete production that the ambient temperature, especially the curing temperature, has a major effect on the properties of concrete, including strength [10].

Curing in live steam at atmosphere pressure dramatically increases the rate of strength development of concrete. Maximum curing temperatures may be anywhere in the range 40 ^{o}C to 100^{o}C, although the optimum temperature is in the range 65 ^{o}C to 80^{o}C. The temperature will be a compromise between rate of strength gain and ultimate strength [11].

Mindess et al. also reports that the higher the initial temperature, the lower the ultimate strength. The optimum temperature depends on the application; the use of a lower temperature requires a longer curing period, but gives a better ultimate strength [11].

Moreover, special care must be given to phenomenon called delayed ettringite formation. It has been found that concretes that have been subjected to high-temperature curing up to 100^{o}C may suffer deterioration during later exposure to moisture at ordinary ambient temperatures. This phenomenon known as delayed ettringite formation is characterized by the development gaps around some aggregate particles. These gaps often contain densely compacted ettringite. This problem occurs primarily when cements are used that have a ratio of SO_3 to Al_2O_3 > 0.5 [11].

Neville [12] has reported that since an increase in the curing temperature of concrete increased its rate of development of strength, the gain of strength can be speeded up by curing concrete in steam. When steam is at atmospheric pressure, i.e. the temperature is below 100 ^{o}C, the process can be regarded as a special case of moist curing in which the vapour-saturated atmosphere ensures a supply of water [12].

The primary objective of steam curing is to obtain a sufficiently high early strength so that the concrete products may be handled soon after casting. The moulds can be removed, or prestressing bed vacated, earlier than would be the case with ordinary moist curing, and less curing storage space is required where all these mean an economic advantage. For many applications, the long-term strength of concrete is of lesser importance [12].

Due to the influence of temperature during the early stages of hardening on the later strength, a compromise between the temperatures giving a high-early and a high-late strength has to be made [12].

Neville [12] reports that a probable explanation of the reduction in the long-term strength of steam-cured concrete lies in the presence of very fine cracks caused by the expansion of air bubbles in the cement paste. The thermal expansion of the air is at least two orders of magnitude greater than that of surrounding solid material. The expansion of air bubbles is restrained so that the air is put under pressure. Tensile stresses in the surrounding paste are induced to balance this pressure. These stresses may induce very fine cracks. Therefore strength loss is not in the long-term but at all ages. However, up to the age of 28 days, this loss is masked by the beneficial effect on strength of higher temperature during curing. The disruptive effects of expansion of air bubbles can be reduced by a prolonged delay period prior to steam curing, during which the tensile strength of concrete increases, or by a lower rate of temperature rise as the increase in the air pressure is matched by an increase in the strength of the surrounding cement paste [12].

CHAPTER 3

REVIEW OF RESEARCH ON ROLLER COMPACTED CONCRETE and STEAM CURING

3.1 Previous Research on RCC

Abdel-Halim et al. reports rehabilitation of the spillway of Sama El-Serhan dam using RCC. The foundation of the spillway was damaged by erosion and needed protection work as fast as possible before the coming winter season. The aim of the investigation is defined as evaluation of the RCC used in the rehabilitation work using locally available materials. Maximum aggregate size was 38 mm. Pozzolanic Portland cement was used for mixture. Natural pozzolan was used since natural pozzolan deposits exist in large quantities in the neighboring areas. In order to improve workability and reduce the free water content, plasticizer was used. The required 90 day compressive strength for the RCC section was 10 MPa. First, the mixture proportioning was done in the laboratory. The program started with a fixed aggregate gradation and cement/pozzolan ratio. Then mortar samples were prepared using 100 mm cubes fixed on Vebe apparatus and compacted for full consolidation. Then RCC mixes were prepared by fixing the cementitious content and aggregate proportion while varying the water content of the mix. The Vebe time was determined for each mix by compacting the RCC mix using Vebe apparatus [5].

The relationship between the Vebe time and the water content of the RCC mix was plotted. In the next step, keeping the paste content (cement, pozzolan, water) fixed; the fine aggregate/total aggregate ratio was changed. Different samples were prepared and compacted using Vebe apparatus. The relationship between the Vebe time and the fine aggregate/total aggregate ratio of the RCC mix was plotted. The ratio with minimum Vebe time was determined. A series of Vebe tests were performed on the preliminary design and good workability is obtained as a result. Then the RCC section was constructed to protect the foundation of the spillway. The authors concluded that the rehabilitation work demonstrated the feasibility of using RCC for repair work of existing dams as well as for the construction of new dams in Jordan. The feasibility of the method is attributed to its low cost, ease and rapidity of construction [5].

Koçak E.S. [13] investigated local materials in Kahramanmaraş region that are technically satisfactory and the economical RCC materials to be used in Suçatı Dam in Kahramanmaraş. Two types of ordinary portland cement, one type of fly ash, one type of ground granulated blast furnace slag, various portland cement-fly ash and portland cement-slag combinations, and aggregates are mixed through the study. As a conclusion, using slag-cement mixtures as cementitious materials seem to be a more appropriate material combination as compared to fly ash-cement mixtures or to cement without any finely divided mineral materials. The author suggests in order to make RCC more popular and topical in engineering agenda, the government institutions and organizations, research centers, universities, project consultant companies in connection with this subject should try hard [13].

Qasrawi et al.[14] explains that the use of RCC for pavements is relatively a new technology and is still under development. Roller compacted concrete pavement (RCCP) is defined as a stiff mixture of aggregates, cementitious materials and water which is compacted by vibratory rollers. The concrete should have low consistency and workability for RCCP. Based on the fact that RCCP concrete has low water content and hence may segregate, the nominal maximum aggregate size is selected as 20 mm.

Due to the fact that higher cement content may cause temperature problems in hot weather due to heat of hydration, the amount of cement was used as 12-15% and no pozzolan was used in the mixes. RCCP mixes were proportioned using a soil compaction method where the optimum density was considered the objective of the mix design. The authors explain that there is no standardized method to prepare RCC test specimens. However due to its stiff consistency, conventional concrete specimen fabrication procedures cannot be used to prepare RCCP test specimens. The compaction of the test specimens were done by using California Kneading Compactor. Five different water/cement ratios have been used in the study. Four levels of total aggregate to cement ratio and two levels of coarse aggregate to fine aggregate ratio have been employed during the study. Also three compactive efforts have been used. The main conclusion could be summarized as the cement content was the major factor affecting the fresh and hardened properties of concrete. Moreover, unlike conventional concrete, lowering the water/cement ratio below the optimum would not result in increase in the strength of concrete [14].

Atiş investigated the strength properties of high-volume fly ash roller compacted and superplasticised workable concrete under dry and moist curing conditions. Two different Class F fly ashes are used 0%, 50% and 70% replacement with normal Portland cement. Water/cementitious material ratios changed between 0.28 to 0.43. The author claim that blending cement with fly ash, silica fume, slag or natural pozzolan and using a fly ash in concrete or in RCC for pavement and dam applications are widespread in practice. In addition to that using superplasticizer makes it possible to produce a workable concrete with low water/cement ratio. This results in higher strength and better durability properties. It is given that the use of superplasticizer in concrete gives high early compressive strength and equal long-term strength compared with concrete without superplasticizer. The reason for high early compressive strength is attributed to cement dispersing mechanism of the superplasticizer. Cement dispersing mechanism makes more cement grain surface available for water, thus early hydration is more complete [15].

The author reports that the use of superplasticizer promotes the use of mineral admixture in concrete. The optimum water content concept is followed through designing a zero slump RCC and superplasticised, workable concrete containing high volume fly ash. Atiş concluded that it is possible to convert an RCC concrete to a workable concrete by using a suitable superplasticizer. Moreover, due to its high strength properties, high volume fly ash RCC is a possible alternative to normal Portland cement concrete used for pavement applications and large industrial floors [15].

Sun et al. [16] studied the influence of fly ash on the fatigue performance of roller compacted concrete. The fatigue equations of RCC with and without fly ash that can be used for designing pavement are analyzed through regressive analysis and compared with that of same grade common concrete pavement. The concrete specimen size was 100x100x400 mm, where specimens were cast with pressure about 500 g/cm^2 imposed on the upper surface of the mold while vibrating. Fatigue tests have been performed on four series of specimen, with the fly ash content being 0%, 15%, 30% and 45%. To examine the pore structure of mortars made from concrete specimens after the coarse aggregates were rejected, a mercury intrusion porosimetry was applied. As a result of the study, it was concluded that both fly ash RCC and RCC shows excellent fatigue performance compared with common concrete in pavement if number of fatigue cycles are the same. The mechanism by which fly ash improves the fatigue performance of RCC lies in composite effect of the densification produced by the roller compacted technology and the pozzolanic reactivity and microaggregate effect of fly ash [16].

3.2 Previous Research on Steam Curing

Erdem et al. explains that steam curing is widely used in the production of precast concrete members because it accelerates the rate of strength development. Some precast concrete plants apply steam curing immediately after casting the elements in the formwork in order to speed up the production rate. Although early application of steam curing is a common practice, many researchers have indicated that this is quite detrimental and that some delay period prior to steam exposure is beneficial to concrete properties, such as strength and durability. Some precast concrete plants expose freshly made concrete elements to steam curing immediately after casting. This is detrimental to properties of the product; therefore, some delay prior to the steam curing is beneficial [17].

Liu et al. [18] presents the influence of steam curing on the compressive strength of concrete containing ultrafine fly ash with or without slag. Fly ash has been widely used as a partial replacement of cement in concrete. The benefits include saving cement and lowering the heat of hydration in mass concrete. When ultrafine fly ash is included in concrete, the pozzolanic reaction is accelerated through heat treatment. In the study, ultrafine fly ash and slag were used as a replacement for cement. Moreover, steam curing and chemical activators were used to accelerate hydration of cement and fly ash, and then compared with moist curing. The specimen used for cubic compressive strength had dimensions of 100x100x100 mm. The treatment temperature was $60^{o}C \pm 5^{o}C$ during steam curing. Mixing and specimen preparation was performed at room temperature. After steam curing, the specimens were removed from their molds, and some were used to measure the compressive strength at once. The others were put in the standard curing room, with its 28-day compressive strength. One of the results of the study is that the addition of ultrafine fly ash and ground slag can increase the compressive strengths of concrete containing supplementary cementing materials and can solve the problem of lower strength gaining rate.

According to Türkel and Alabas [19], type of cement as a binder has important role in heat treatment. The behavior of cements under heat treatment is determined by composition and fineness of cements, the type and amount of additives used in blended cements and curing cycle parameters. It is well known that heat treatment at low temperate is economic. Türkel and Alabas [19] investigated the effect of cement type and excessive steam-curing applications on the compressive strength development of concrete. Two types of cement, PC42.5 and PKC/A42.5, were used in the experimental program [19]. Test results indicated that Portland composite cement PKC/A42.5 can be used in place of PC42.5 for steam curing at atmospheric pressure in precast concrete production. On the other hand, in case of early high strength demand for early demolding purposes, curing temperature should be increased to 850C for PKC/A42.5 cement concretes [19].

CHAPTER 4

EXPERIMENTAL STUDY

4.1 Introduction

The objective of this study is to determine early compressive strength of RCC made with natural pozzolan. For each mix group, specimens are steam cured and the results of normal cured and steam cured specimens are compared.

Two types of cement, two types of natural pozzolan, aggregates with varying gradations, and water reducing chemical admixture is used in this study. Before getting started with the tests, the physical and chemical properties of cements, natural pozzolan and aggregates are determined.

In the experimental program 8 RCC mixtures are designed and prepared. Each mix is subjected to Vebe testing, and both steam cured and normal cured specimens are tested for compressive strength on 28th day.

4.2 Materials of RCC

Two types of cement, two types of natural pozzolan, aggregates with varying gradations, and water reducing chemical admixture is used in this study.

4.2.1 Cements

Two cement types were used in the study: Portland Cement of type CEM I 32.5R and type CEM IV/A-P 32.5R. The physical properties and chemical composition of cement types are given in Table 4.1, Table 4.2, and Table 4.3 respectively. The physical and chemical tests on cement samples were performed by Turkish Cement Manufacturers' Association Independent Quality Control Laboratory.

Table 4.1 Physical Properties of Portland Cement

Properties	CEM I 32.5R	CEM IV/A-P 32.5R
Specific Gravity (g/cm^3)	3.02	2.88
Blaine Fineness (cm^2/g)	3315	3705
Initial Setting Time (hr:min)	3:10	3:20
Final Setting Time (hr:min)	4:15	4:30
2day Compressive Strength (MPa)	17.0	11.5
7day Compressive Strength (MPa)	27.9	19.2
28day Compressive Strength (MPa)	41.0	33.5

Table 4.2 Chemical Properties of CEM I 32.5R

Oxide Composition and Properties	CEM I 32.5R
SiO_2 (%)	20.74
Al_2O_3 (%)	4.52
Fe_2O_3 (%)	3.68
CaO (%)	60.4
MgO (%)	3.44
SO_3 (%)	3.41
Loss-on ignition (%)	1.90
Insoluble Residue (%)	0.76

Table 4.3 Chemical Properties of CEM IV/A-P 32.5R

Oxide Composition and Properties	CEM IV/A-P 32.5R
SiO_2 (%)	30.10
Al_2O_3 (%)	7.86
Fe_2O_3 (%)	3.11
CaO (%)	47.92
MgO (%)	1.18
SO_3 (%)	2.10
Na_2O (%)	0.97
K_2O (%)	1.55
Cl (%)	0.0117
Loss-on ignition (%)	4.99
Pozzolanicity	Positive

4.2.2 Natural Pozzolans

Two different natural pozzolans were used in this study. They are brought to the laboratory in ground form. The physical properties of natural pozzolans are determined according to TS 25 and given in Table 4.4. The chemical properties of the natural pozzolans are determined by wet chemical analysis and given in Table 4.5. The physical and chemical tests on natural pozzolans are performed by Turkish Cement Manufacturers' Association Independent Quality Control Laboratory.

Table 4.4 Physical Properties of Natural Pozzolans

Properties	**T1**	**T2**
Specific Gravity (g/cm^3)	2.52	2.74
Blaine Fineness (cm^2/g)	4945	4850
90 µm residue, %	7.4	7.2
7 Day Flexural Strength (MPa)	2.0	1.6
7 Day Compressive Strength (MPa)	11.8	10.4

Table 4.5 Chemical Properties of Natural Pozzolans

Properties	**T1**	**T2**
Loss on ignition (%)	18.11	18.49
SiO_2 (%)	42.28	28.60
Al_2O_3 (%)	11.24	6.80
Fe_2O_3 (%)	4.05	2.83
CaO (%)	18.84	37.68
MgO (%)	2.05	2.00
SO_3 (%)	0.59	1.58
Na_2O	0.88	0.66
K_2O	1.20	0.98
TiO_2	0.62	0.34

4.2.3 Aggregates

Aggregates used in this study are in 0-5 mm, 5-15 mm, 5-25 mm, 15-75 mm, 10-25 mm, 25-75 mm natural river aggregate, 0-10 crushed stone and fine material. The natural river aggregate is sieved through appropriate sizes in order to achieve required gradation. The gradation curves for each size range of aggregates and natural river aggregate are given in Figure 4.1.

Particle Size Analysis of the fine material has been determined by hydrometer analysis and presented in Figure 4.2.

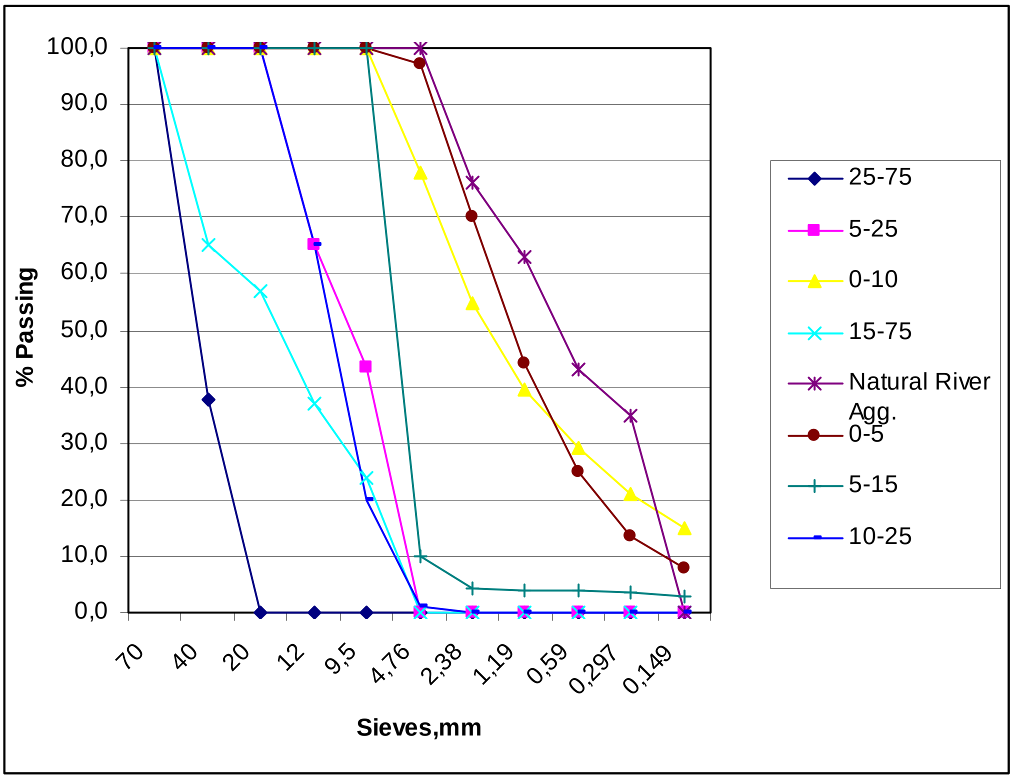

Figure 4.1 Gradation curves for aggregates

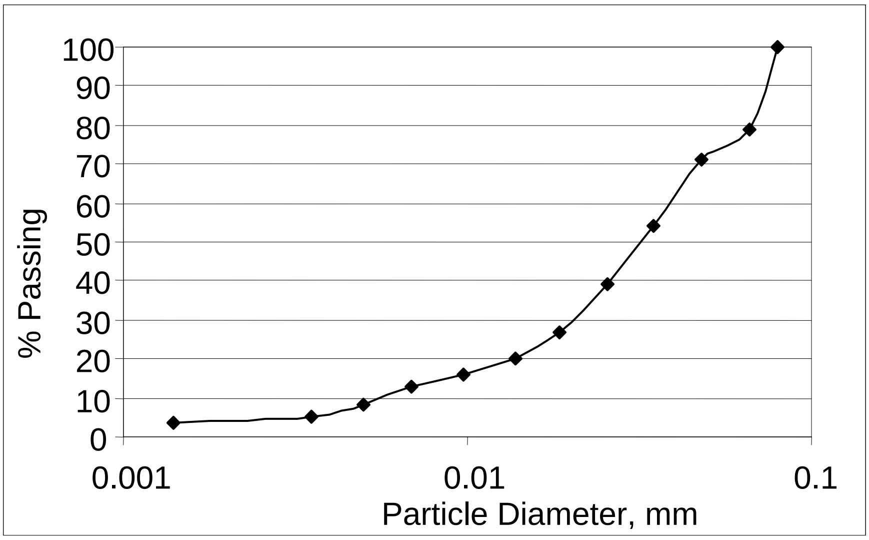

Figure 4.2 Particle Size Distribution of the Fine Material

The physical properties of the aggregate are determined and given in Table 4.6 and Table 4.7.

Table 4.6 Physical Properties of Aggregate Sample-1

Properties	**Fine Material**	**0-5**	**5-15**	**10-25**
Specific Gravity (dry)	2.52	2.52	2.63	2.63
Specific Gravity (SSD:Saturated Surface Dry)	2.58	2.58	2.67	2.66
Water Absorption , %	5.0	2.46	1.62	1.06
Materials finer than 75 µm, %	82	6	-	-
Freezing-thawing resistance, %	-		0.6	
Resistance to abrasion by Los Angeles Test Machine, %	-		23.4	
Organic Material	-		Does not exist	

Table 4.7 Physical Properties of Aggregate Sample-2

Properties	**0-10**	**5-25**	**15-75**	**25-75**
Specific Gravity (dry)	2.56	2.64	2.63	2.63
Specific Gravity (SSD)	2.58	2.66	2.66	2.66
Water Absorption , %	0.6	0.6	0.8	0.8
Materials finer than 75 µm, %	3	-	-	-

Potential alkali reactivity of aggregates is determined by mortar-bar method (ASTM C 1260). The expansion values of the mortar bars at the related test days are given in Table 4.8

Table 4.8 Expansions of mortar bars due to alkali-silica reactivity

Days	Expansion, %
3	0.02
7	0.10
10	0.12
14	0.16

4.2.4 Chemical Admixture

In one mix design of the experimental program, İksa MR25-W water reducing admixture was used for RCC as chemical admixture during mixing of fresh concrete in dosage of 0.1% by weight.

4.3 RCC Mixture Compositions

The mixture contents and proportions are given in detail in the following tables. The following values are calculated by using dry specific gravity of aggregates. The figure after the mixture contents belongs to the mixture's combined aggregate gradation respectively. The upper and lower limits are given by ACI Committee 207.5R-89 [20].

Table 4.9 RCC Mixture 1 Content

Material	**(kg/m^3)**
Cement-CEM I 32.5R	80
Natural Pozzolan-T1	140
Water	118
15-75mm range aggregate	636
5-15 mm range aggregate	573
0-5 mm range aggregate	608
Fine Material	162
Chemical Admixture	2.2
Total	2319.2

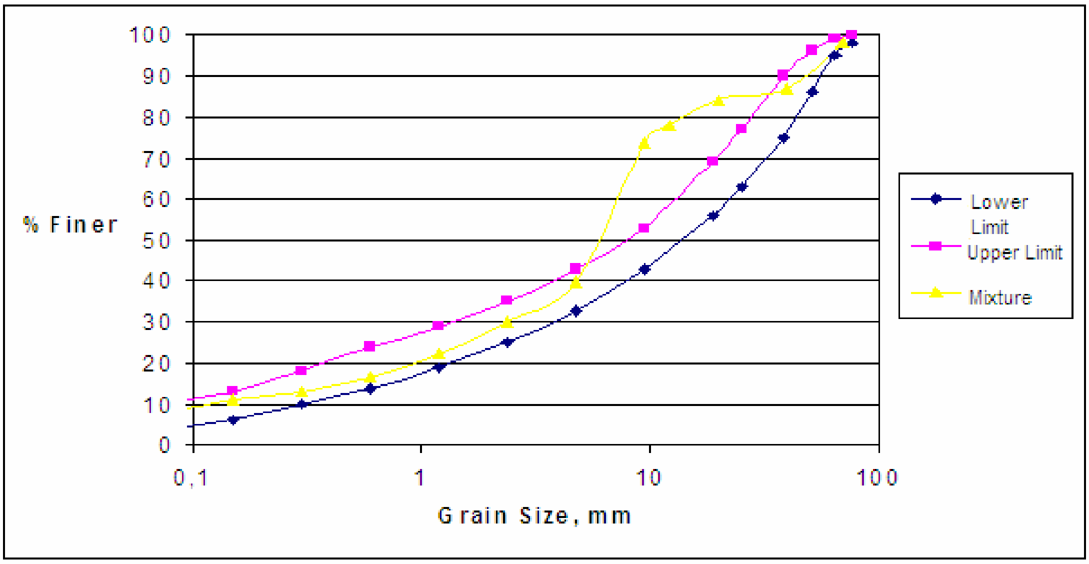

Figure 4.3 Combined Aggregate Gradation in Mixture 1

Table 4.10 RCC Mixture 2 Content

Material	**(kg/m^3)**
Cement-CEM I 32.5R	80
Natural Pozzolan-T1	140
Water	132
15-75mm range aggregate	636
5-15 mm range aggregate	573
0-5 mm range aggregate	608
Fine Material	162
Chemical Admixture	-
Total	2331

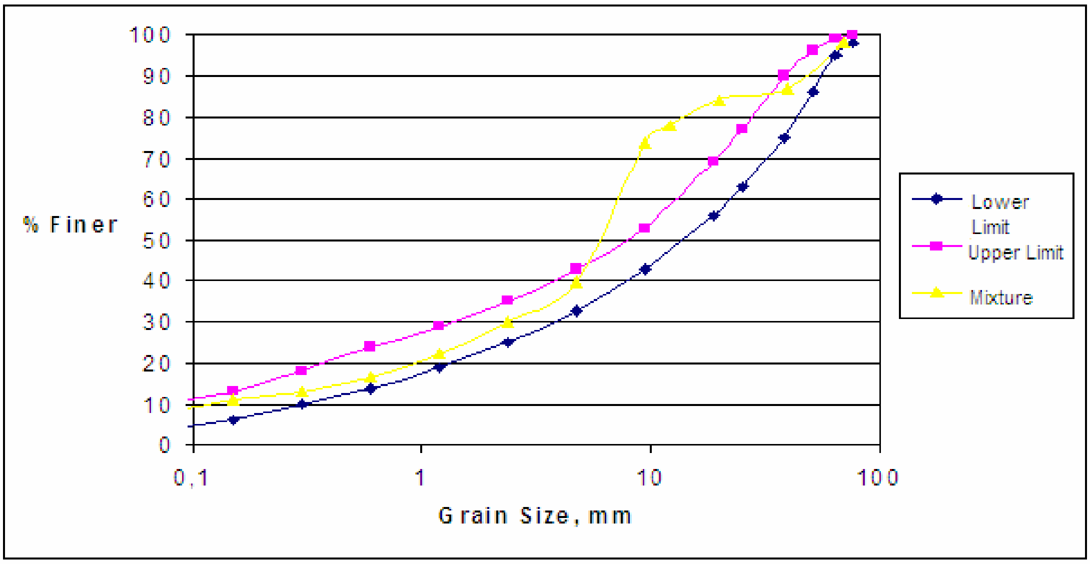

Figure 4.4 Combined Aggregate Gradation in Mixture 2

Table 4.11 RCC Mixture 3 Content

Material	**(kg/m^3)**
Cement- CEM IV/A-P 32.5R	75
Natural Pozzolan-T1	75
Water	93
25-75mm range aggregate	870
5-25 mm range aggregate	230
0-10 mm range aggregate	215
0-5 mm range aggregate	915
Fine Material	-
Chemical Admixture	-
Total	2473

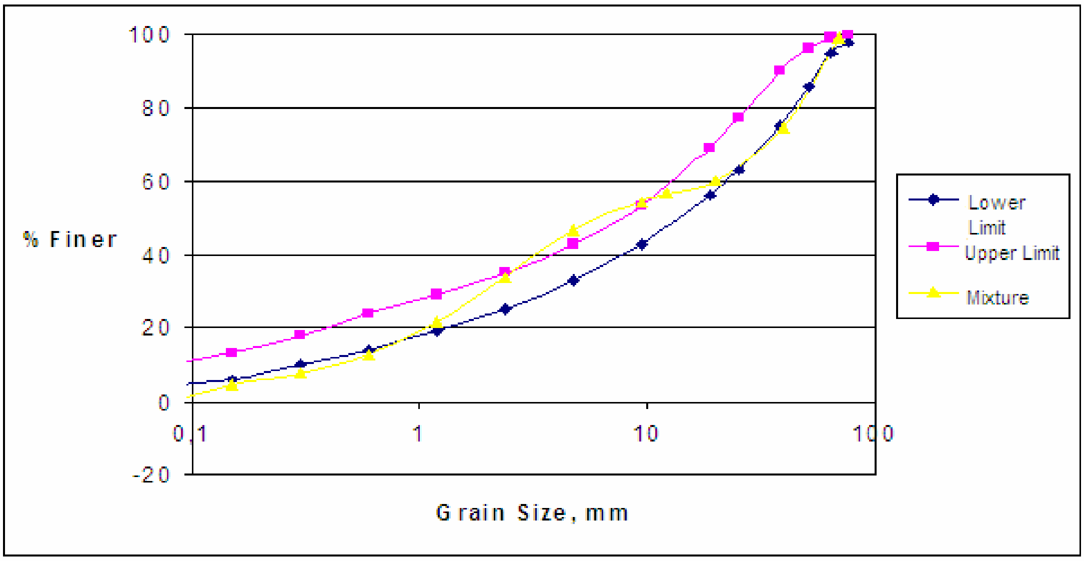

Figure 4.5 Combined Aggregate Gradation in Mixture 3

Table 4.12 RCC Mixture 4 Content

Material	(kg/m^3)
Cement- CEM IV/A-P 32.5R	120
Natural Pozzolan-T1	100
Water	80
25-75mm range aggregate	642
10-25 mm range aggregate	208
0-10 mm range aggregate	808
0-5 mm range aggregate	417
Fine Material	-
Chemical Admixture	-
Total	2375

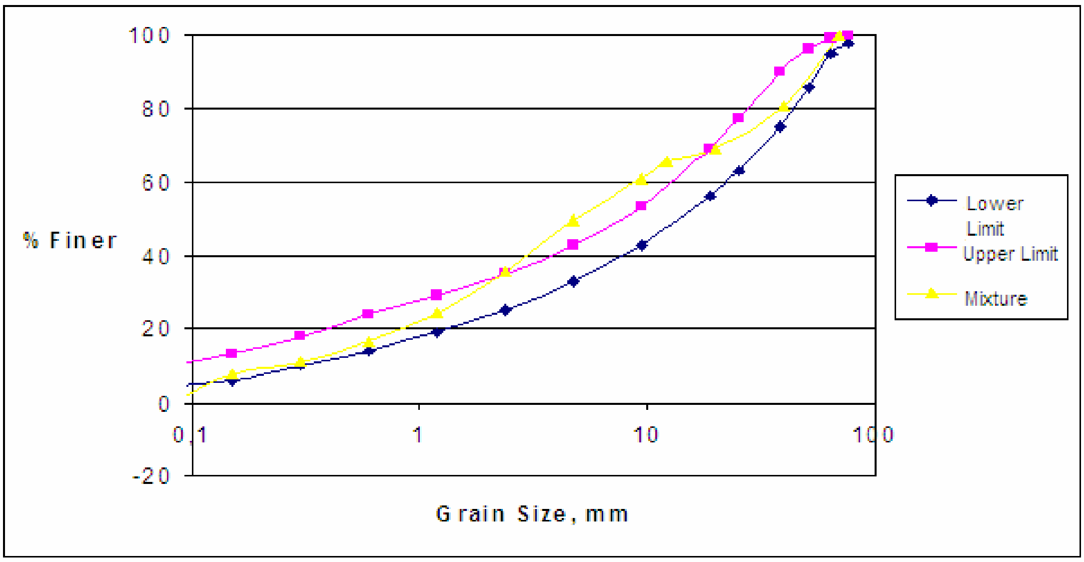

Figure 4.6 Combined Aggregate Gradation in Mixture 4

Table 4.13 RCC Mixture 5 Content

Material	(kg/m^3)
Cement- CEM IV/A-P 32.5R	120
Natural Pozzolan-T1	100
Water	96
25-75mm range aggregate	750
10-25 mm range aggregate	317
0-10 mm range aggregate	-
0-5 mm range aggregate	875
Fine Material	158
Chemical Admixture	-
Total	2416

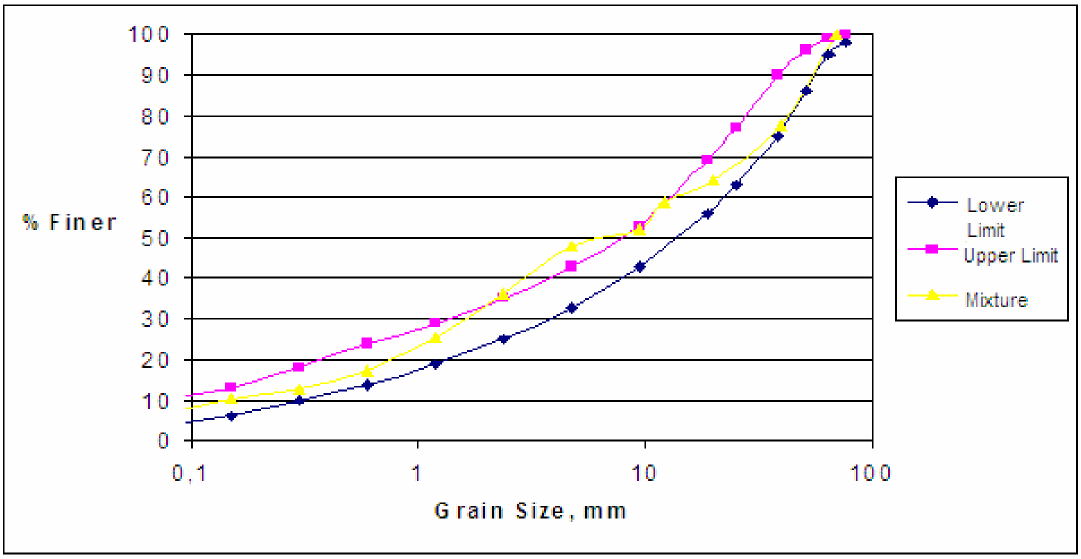

Figure 4.7 Combined Aggregate Gradation in Mixture 5

Table 4.14 RCC Mixture 6 Content

Material	**(kg/m^3)**
Cement- CEM IV/A-P 32.5R	100
Natural Pozzolan-T1	83
Water	89
25-75mm range aggregate	667
10-25 mm range aggregate	217
0-10 mm range aggregate	842
0-5 mm range aggregate	433
Fine Material	-
Chemical Admixture	-
Total	2431

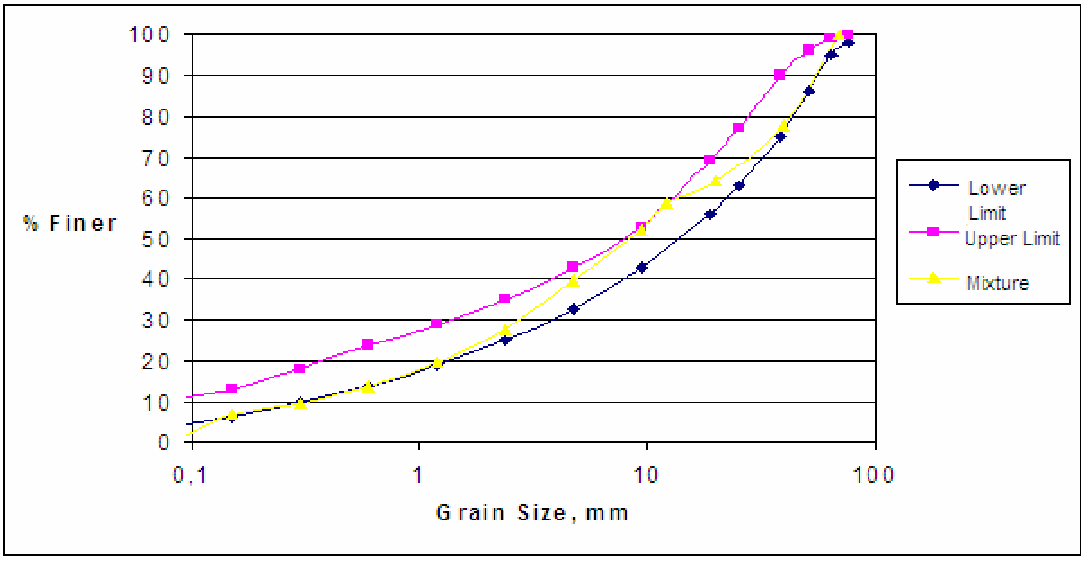

Figure 4.8 Combined Aggregate Gradation in Mixture 6

Table 4.15 RCC Mixture 7 Content

Material	(kg/m^3)
Cement- CEM IV/A-P 32.5R	120
Natural Pozzolan-T2	100
Water	93
25-75mm range aggregate	748
10-25 mm range aggregate	318
0-10 mm range aggregate	696
0-5 mm range aggregate	314
Fine Material	-
Chemical Admixture	-
Total	2389

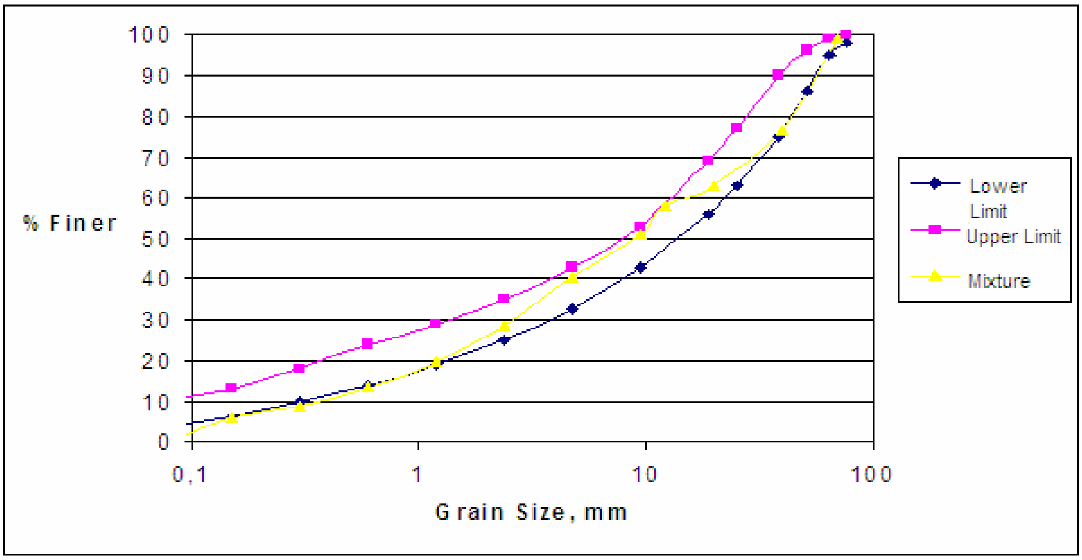

Figure 4.9 Combined Aggregate Gradation in Mixture 7

Table 4.16 RCC Mixture 8 Content

Material	**(kg/m³)**
Cement- CEM IV/A-P 32.5R	90
Natural Pozzolan-T2	80
Water	80
25-75mm range aggregate	786
10-25 mm range aggregate	334
0-10 mm range aggregate	732
0-5 mm range aggregate	330
Fine Material	-
Chemical Admixture	-
Total	2432

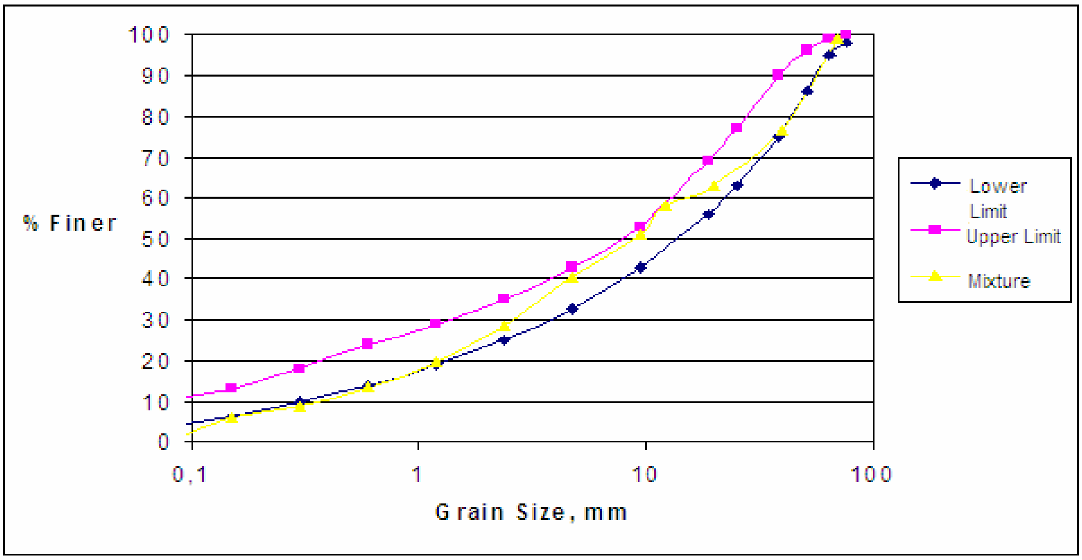

Figure 4.10 Combined Aggregate Gradation in Mixture 8

Table 4.17 Percentages of Cementitious Constituents of RCC Mixtures

RCC Mixtures	Cementitious Materials	w/cm	Cement %	Natural Pozzolan %
RCC Mixture 1	CEM I 32.5R + T1	0.54	36	64
RCC Mixture 2		0.60	36	64
RCC Mixture 3	CEM IV/A-P 32.5R + T1	0.62	50	50
RCC Mixture 4		0.36	55	45
RCC Mixture 5		0.44	55	45
RCC Mixture 6		0.49	55	45
RCC Mixture 7	CEM IV/A-P 32.5R + T2	0.42	55	45
RCC Mixture 8		0.47	53	47

4.4 RCC Test Specimen Preparation

The RCC mix design is performed by following the “suggested gradation of aggregates for RCC with minus No.200 nonplastic fines included” in ACI 207.5R-89 [20]. Then by using dry specific gravities of the aggregates, the quantities other materials are determined.

The ingredients are mixed in the mixer. The water is added to the mixer in parts, so that when the mixture is wet enough the addition of the water is stopped. After that, the mixture is poured on the clean floor and by shovels, the mixture is homogenized as shown in Figure 4.11. Then Vebe test is performed for the RCC mix as shown in Figure 4.12.

Figure 4.11 Homogenization of the mixture on the floor

Figure 4.12 Vebe test equipment during experiment

Then the mixture is placed in 20x20x20 cm cubic molds. The molds are filled in 3 layers, each layer being compacted 15 times by the big mallet as shown in Figure 4.13. Each mold consequently has been compacted 45 times.

After the third layer compaction the surface of the specimens were finished (Figure 4.14) and they were kept wet for 12±4 hours at room temperature.

Figure 4.13 Compaction of the layers

Figure 4.14 Finishing of the specimens

4.5 Curing of Test Specimens

For one batch, half of the test specimens were cured in laboratory conditions. The other half were kept wet in molds for 12±4 hours. Then the specimens were exposed to steam curing at $55^{o}C \pm 5^{0}C$ in the steam cabinet (Figure 4.15) for 8 hours in molds. After termination of 8 hour steam curing the specimens were taken off the molds and kept wet for 24 hours. Then the specimens were again exposed to steam curing at $55^{o}C \pm 5^{0}C$ for 5 hours (Figure 4.16). Then the specimens were kept wet under cloth in laboratory conditions until day of testing (Figure 4.17).

Figure 4.15 Steam Cabinet

Figure 4.16 Specimens in the steam cabinet

Figure 4.17 Specimens cured at room temperature

CHAPTER 5

TEST RESULTS AND DISCUSSIONS

5.1 Vebe Test Results

The Vebe times were determined for all of 8 mixtures and given in Table 5.1.

Table 5.1 Vebe Test Results of RCC Mixtures

	Vebe Time (sec)
RCC Mixture 1	12
RCC Mixture 2	12
RCC Mixture 3	12
RCC Mixture 4	11
RCC Mixture 5	11
RCC Mixture 6	12
RCC Mixture 7	13
RCC Mixture 8	11

As mentioned before, RCC mixtures with the degree of workability necessary for ease of compaction and production of uniform density from top to bottom of the lift, for bonding with previously placed lifts, and for support of compaction equipment, generally have a Vebe time of 10 sec to 45 sec. All mixtures are workable according to ASTM C 1170.

5.2 Compressive Strength Test Results

The 28-day compressive strength results of both steam cured and normal cured specimens for each mix of RCC were given in the following table. For each curing type 3 specimens were subjected to compressive load and average of 3 specimens was given in the table.

Table 5.2 Compressive Strength Test Results of RCC Mixtures

	28 Day Compressive Strength (MPa)	
	Steam Cured	Normal Cured
RCC Mixture 1	12.6	7.5
RCC Mixture 2	8.2	4.3
RCC Mixture 3	1.7	1.8
RCC Mixture 4	12.5	12.0
RCC Mixture 5	4.9	4.8
RCC Mixture 6	2.8	4.0
RCC Mixture 7	6.6	6.0
RCC Mixture 8	3.6	4.0

5.3 Discussion of the Results

Mixture 1 incorporates CEM I 32.5R type of cement, natural pozzolan, fine material and water reducing chemical admixture remarkably. The compressive strength results of Mixture 1 show relatively good results among all. Especially steam curing improves 28 day compressive strength when compared to normal curing.

Mixture 2 has the same type and amount of cement, natural pozzolan and fine material. The only difference from Mixture 1 is that Mixture 2 does not contain water reducing chemical admixture.

In the analysis of compressive strength results of Mixture 2, again it is clearly seen that steam curing improves 28 day compressive strength when compared to normal curing. In addition to that, Mixture 2 shows lower compressive strength in both steam curing and normal curing samples when compared to Mixture 1 respectively. When the mixture constituents of Mixture 1 and Mixture 2 are analyzed, it can be clearly seen that using a water reducing admixture improves RCC compressive strength property. The main reason of improvement in compressive strength of RCC in Mixture 1 by using a water reducing admixture can be attributed to reduced water content with the same cementitious constituent.

When compressive strength results of Mixture 3 are analyzed, it can be seen that the values decrease significantly. This can be explained by using CEM IV/A-P 32.5R type of blended cement instead of CEM I 32.5R (Type I) cement. Even though the percentage of cement in the cementitious constituents increased from 36% to 50%, blended type of cement incorporates less hydration inputs, thus decreases strength significantly. In addition to that the inadequate and non-homogenous distribution of aggregate grading contributes to decreased compressive strength. The size range distribution of the aggregate changed after Mixture 1 and Mixture 2. The remarkable difference is that fine material is not used in Mixture 3. Since the aggregate mix does not contain enough fine aggregate, in addition to lack of fine material, the contribution of fine material to the compressive strength cannot be achieved in this mixture. Moreover, it can be seen from the Figure 4.1 that aggregate grading does not cover a sufficient range of nominal sizes. Also the difference between the compressive strength results of steam cured and normal cured specimens disappears.

Mixture 4 shows compressive strength results close to Mixture 1. This can be attributed to having a homogenous aggregate content by increasing 0-10 mm range of aggregate thus increasing fine material. Moreover, this mixture incorporate higher cement constituent than Mixture 3, which has same type of cement CEM IV/A-P 32.5R. This can be explained by (assuming fully compacted concrete) decreased w/cm ratio. In addition to that the discrepancy between the compressive strength results of steam cured and normal cured specimens disappears.

Mixture 5 incorporates CEM IV/A-P 32.5R type of cement, natural pozzolan and fine material. Comparing the mixture content of Mixture 4 and Mixture 5, the cementitious constituents are exactly the same. The main difference between these mixtures is that Mixture 4 incorporates more homogeneous aggregate size distribution than Mixture 5. In Mixture 5, the increase in 0-5 mm aggregate range could not compensate the homogeneity created by 0-10 mm aggregate range. Even though fine material is used, Mixture 5 could not reach compressive strength of Mixture 4. Moreover, the use of fine material increased the water requirement of the mix, thus reduced the compressive strength. Also the difference between the compressive strength results of steam cured and normal cured specimens disappears.

Mixture 6 shows higher compressive strength values in normal cured specimens than steam cured specimens. The cement constituent (CEM IV/A-P 32.5R type) is equal in percentages in Mixture 5 and Mixture 6. However, the compressive strength results indicate that increasing w/cm ratio decrease the compressive strength, comparing compressive strength results of Mixture 5 and Mixture 6.

The natural pozzolan type is changed from T1 to T2 in Mixture 7 and Mixture 8. The aggregate proportioning is close in these two mixtures. The higher cementitious material content in Mixture 7 results in higher compressive strength than Mixture 8. This can be attributed to higher w/cm ratio of Mixture 8.

Table 4.4 gives that T1 shows higher pozzolanic activity than T2. Comparing Mixture 4 and Mixture 7, the cementitious material percentages are equal and the aggregate size ranges can be accepted close. The reason behind the great difference in compressive strengths can be listed as using a less active natural pozzolan and using higher w/cm ratio in Mixture 7.

Among 8 mixtures used in the study, Mixture 1 and Mixture 4 give highest compressive strength values. Considering the availability of cement type, aggregate and natural pozzolan type the user can choose the most economic mixture.

In the project site natural pozzolan is generously available. On the other hand, fine material is not available at the project site. Since continuous supply of CEM I 32.5R type portland cement could not be achieved, and in order to decrease internal temperature rise of the RCC, the project is directed to use CEM IV/A-P 32.5R. Mixture 1 and Mixture 2, since they contain CEM I 32.5R, confirm the efficient use of steam curing in order to determine the compressive strength of RCC at the early age. However, other 6 mixtures which include CEM IV/A-P 32.5R type of blended cement do not show satisfactory differing compressive strength results between steam cured and normal cured specimens.

Another important result is that when fine material is used as a constituent, the compressive strength increases remarkably as seen in Mixture 1 and Mixture 2. This can be attributed to filling of voids with fine material, thus increasing compressive strength. However, due to lack of fine material near the project site, the intention was to compensate the filler effect of fine material with other applications such as mentioning the importance of aggregate gradation, as seen in Mixture 4.

Steam curing becomes efficient in ordinary portland cement constituents rather than blended cement. The reason may be since the amount of cement is already low in RCC, when blended cement type is used there is not enough CH to react with natural pozzolan after accelerated reaction by steam curing. Thus, the compressive strength gaining ability of RCC decreases significantly, normal cured specimens reach and even gain higher compressive strength.

As mentioned before compressive strength is generally regarded as the most convenient indicator of the quality and uniformity of the concrete. Therefore, the design compressive strength is usually selected based on the level of strength necessary to satisfy compressive tensile and shear stresses plus durability under all loading conditions**.** Moreover, **c**ompressive strength is an indicator of other properties such as durability [2]. The aim of the project is to obtain the optimum RCC mixture to generate compressive strength of 7 MPa at project site. So the firm can satisfactorily use Mixture 1, Mixture 2 and Mixture 4 according to availability of materials on the project site. In addition to that, Mixture 7 has also performed close to 7 MPa. This can be another alternative for the project.

In Mixture 4 and Mixture 7, since CEM IV/A-P 32.5R low heat portland cement is used, heat of hydration, internal temperature rise problem is eliminated. By using high volume of natural pozzolan the alkali-silica reaction is lowered. Thus, Mixture 4 and Mixture 7 are suggested to be used in the project under the specified conditions.

CHAPTER 6

CONCLUSIONS

Various procedures for mixture proportioning have developed to accommodate wide range of material processing and cementitious material contents for RCC. However, there is no one best solution for all situations. Material selection and proportioning of RCC mixtures is controlled by design requirements, availability of materials and planned placement procedures.

The designer should always be aware of the potential for variability of hardened strength properties of RCC due to potential for greater variations due to differences in materials.

The most important step in RCC to provide economy, time and cost efficiency is the selection of materials. The results of the study show that an economic and satisfactorily performing RCC mixture can be designed with available materials rather than the best performing constituents. Since fine material and ordinary portland cement is not available for the project, the design has to be made by other available materials.

In this study, the results indicate that chemical admixture usage improves properties of RCC. The main reason of improvement in compressive strength of RCC mixture incorporating water reducing admixture can be attributed to reduced water content with the same cementitious constituent. However, it should be kept in mind that, one must make a comparison between cost of admixture and benefits supplied by it.

Moreover, it is revealed that usage of fine material is essential to obtain desired results since the amount of cementitious materials is considerably low in RCC. However, aggregate gradation should be well designed to support fillers. Again availability of fine materials should be considered in order to provide economy.

Steam curing is known as its property of providing long term compressive strength at early ages. It was observed that application of steam curing in CEM I type cement used RCC mixtures generated expected results. However, in CEM IV type cement used RCC mixtures compressive strength results did not behave in the same manner. In that case, the difference between compressive strengths of steam cured and normal cures specimens disappears. Thus, it can be concluded that steam curing is effective in ordinary portland cement mixtures and is not effective in blended types of cement mixtures.

In conclusion, 8 mixtures are designed and compressive strength tests are performed on these specimens. 4 of these mixtures have performed close to the design compressive strength. Among these 4 mixtures, Mixture 1 and Mixture 2 incorporates CEM I 32.5R and also fine material, which are both not available at the project site. Thus, Mixture 4 and Mixture 7 are suggested to be used in the project under the specified conditions.

CHAPTER 7

RECOMMENDATIONS

RCC is becoming popular worldwide in the recent years. However, Turkey has not yet used RCC practically up to date. One of the reasons for this may be lack of information in this area.

To make RCC popular in Turkey to have advantages, research laboratories, universities, special firms and consultant should follow up the developments on the subject in the world and promote usage of it as well.

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