

**REPUBLIC OF TURKEY
YILDIZ TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

**THE EFFECTS OF VERY FINE AGGREGATE
CHARACTERISTICS ON DURABILITY PERFORMANCE OF
CONCRETE**



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LIST OF ABBREVIATIONS

BET	Brunauer-Emmett-Teller
CPL	Concrete produced with limestone
CPS	Concrete produced with sandstone
CS	Crushed sand
EC	Electrical conductivity
HRWR	High range water ratio
LSF	Limestone sand fines
MBV	Methylene blue value
PSD	Particle size distribution
SP	Superplasticizer
TOC	Total organic carbon
VFCA	Very fine crushed aggregate
XRD	X-ray diffraction

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ABSTRACT

THE EFFECTS OF VERY FINE AGGREGATE CHARACTERISTICS ON DURABILITY PERFORMANCE OF CONCRETE

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Department of Civil Engineering

MSc. Thesis

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The effects of two different crushed aggregates in different geological characteristics on fresh and hardened state concrete properties has been researched. These crushed aggregates obtained from limestone and sandstone quarries generating very fines aggregate fraction below 63 μm . Fresh and hardened concrete tests were performed to understand the effects of these aggregates on the performance of concrete with various fines content (particle sizes below 63 μm). The experimental studies showed that increment of fines content from 0% to 15% had different results for concretes produced with limestone or sandstone crushed sands. According to test results, using limestone in concrete performs better than concrete produced with sandstone in terms of fresh and hardened state properties. Durability properties of concrete produce with limestone superior than concrete produce with sandstone. These positive effects of limestone crushed sands on durability and fresh concrete properties are linked to its geological origin and morphological characteristics. The methods of very fine aggregates characteristics of limestone and sandstone aggregates were investigated through several instrumental techniques. A strong correlation has been established between aggregate characteristics and concrete performance. The test results revealed that the characteristics of limestone and sandstone fine aggregates play an important role in controlling durability performance of concrete.

Key words: Sandstone, limestone, fines content, durability of concrete, characterization of aggregates



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İNCE AGREGA KARAKTERİSTİĞİNİN BETONUN DURABİLİTE PERFORMANSI ÜZERİNE ETKİLERİ

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Farklı jeolojik karakterdeki iki farklı kırma agreganın, betonun taze ve sertleşmiş haldeki özelliklerine etkileri araştırıldı. Kireçtaşı ve kumtaşı taş ocaklarından elde edilen bu kırma agregalardan 63 µm altı çok ince malzeme fraksiyonu elde edilmektedir. Bu agregaların çeşitli ince malzeme oranlarında betonun performansına etkisini anlamak için taze ve sertleşmiş beton deneyleri yapıldı. Deney sonuçları gösteriyor ki; ince malzeme oranının %0'dan %15'e kadar artışı kireçtaşı ve kumtaşı ile üretilen betonlarda farklı sonuçlar doğurmaktadır. Deney sonuçlarına göre taze ve sertleşmiş beton özellikleri göz önüne alındığında kireçtaşı ile üretilen betonlar kumtaşı ile üretilen betonlara kıyasla daha iyi performans göstermektedir. Kireçtaşı ile üretilen betonların durabilite performansları kumtaşı ile üretilen betonlardan daha iyidir. Kireçtaşı kırma kumunun betonun durabilite ve taze beton özelliklerine olumlu etkisi kireçtaşının jeolojik kökeni ve morfolojik karakterizasyonu ile ilgilidir. Kireçtaşı ve kumtaşının çok ince agrega karakteristiği bir çok deneysel metotlarla incelendi. Agreganın karakteristiği ile beton performansı arasında güçlü bir ilişki kuruldu. Test sonuçları, kireçtaşı ve kumtaşı ince agrega karakteristiğinin betonun durabilite performansı üzerinde önemli bir rol oynadığını göstermektedir.

Anahtar Kelimeler: Kumtaşı, kireçtaşı, incelik oranı, betonun durabilitesi, agrega karakterizasyonu

INTRODUCTION

1.1 Review of Literature

Cement, sand and aggregate are essential needs for construction industry. With the development of economic construction, the amount of natural sand has been unable to meet the growing demand of concrete [1]. Using crushed sand (CS) instead of natural sand is become universal to overcome difficulties of obtaining natural sand and to save money.

Recently, researchers tend to study on very fine crushed aggregates (VFCA) effects on concrete properties. Despite the fact that there are lots of researches on VFCA effects on concrete, a significant part of this studies are on mechanical properties of concrete. However, limited researches contain durability performance of concrete and investigation of very fine aggregate characteristics effects on concrete performance.

This chapter comprises recent literature studies on the effects of very fine aggregates characteristics on concrete properties. These properties are given as follows:

- Fresh concrete properties of concrete,
- Mechanical behavior of hardened specimens,
- Durability performance of concrete incorporating with various fine content.

These properties were assessed under the light of findings obtained from comprehensive characterization of the very fine aggregates investigated.

1.1.1 Requirement of Researches on Very Fine Crushed Aggregates

Concrete is the construction material which most widely used in the world. It is produced by cement as a binder material, water and aggregates in required proportions. Aggregates cover the largest volume of concrete have a significant influence on both rheological and mechanical properties of mortars and concrete [2]. The percent of fine aggregate nearly makes about one third of the total amount of concrete aggregates, where the fine aggregate occupies the voids among coarse aggregates [3]. Also their specific gravity, particle size distribution (PSD), shape and surface texture influence markedly the properties of mortars and concrete in the fresh and hardened state.

The production of CS also generates high percentages of microfines, particles that pass the 75 μm sieve, ranging from 5% to 20% [4]. The content of fines (particles smaller than 0,075 mm) in aggregates used for the production of concrete is generally limited by most standards worldwide [5]. For instance ASTM C 33[6] limits the amount of aggregate smaller than 75 μm (No. 200 sieve) to be used in concrete. Recently, explanation of very fine aggregate characteristics effects on concrete performance is a major topic.

These very fine aggregates have historically been viewed as undesirable for many reasons. Primarily they are seen to reduce workability due to their high surface area, which necessitates an increase in the amount of water, which in turn reduces strength and durability [7]. Menadi [8] introduced that CS does not have a significant demand due to its high fines content that exceeds the standard allowable limit of 5%.

The effect of inclusion of limestone sand fines (LSF) in CS on fresh and hardened concrete has been another important topic for many years [9]. Many previous researches on the effect of inclusion of LSF as either sand or cement replacements on fresh and hardened mortar and concrete have been developed [10]. They concluded that, the inclusion of 12 to 18% of fines could be allowed in sand without harmful effects on the physical and mechanical properties of mortar and concrete [10]. Beixing [9] et al. stated that it has been established that 10–15% of LSF could be allowed in CS without harmful effects on the physical and mechanical properties of concrete.

1.1.2 Sandstone as Fine Aggregate

Due to depletion of river sand in the use of concrete and environmental pressure on solid waste disposal, the use of crushed stone sand, commonly known as quarry dust (solid waste) is considered a viable alternative to river sand in concrete [11]. Kumar [11] described crushed sandstone is a fine material formed during the process of conversion of rock into aggregate and has particle size ranging from 4 mm to dust size (<0.075 mm) and the fine particles of CS stone as a fine aggregate has irregular shape. Such morphological characteristics of aggregate would have harsh effects on fresh concrete properties. For this reason, there is a poor reputation in construction industry. However, recent studies [5, 12 and 13] have shown that this crushed sandstone can be used in concrete. CS is manufactured by crushing larger stones of quarry to particular size of sand and its chemical & physical properties such as color, size & shape, surface texture up particles depend upon types of stone & its source [12]. One of the type of rock source is sandstone.

Sandstone is a widespread aggregate resource and is increasingly being used in concrete construction around the world [14]. Kumar [11] stated that sandstone is a sedimentary rock composed of sand-sized grains of mineral rock or organic material and also contains a cementing material that binds the sand grains together and may contain a matrix of silt-or clay-size particles that occupy the spaces between the sand grains. The geological properties of this sedimentary rock are fairly diverse such as quartzite, arkose, subarkose and greywacke aggregate that may produce a wide range of hardened concrete properties [15].

Some sandstones are reactive materials, which may have detrimental effect on concrete durability [11]. Prezzi [16] et al. carried out a research to explain one of the major concerns with such aggregate. This concern is the alkali-silica reactions, that is a deleterious chemical reaction between hydroxyl ions associated with alkalis present in cement or other sources and certain reactive siliceous components that may present in aggregates, producing the gel, which in presence of moisture expands and eventually produces cracks in aggregate particles as well as in the cement paste in concrete.

1.1.3 Limestone as Fine Aggregate

Use of CS has become a good substitute for natural sand and it has become essential keeping in view of technical, commercial & environmental requirements and proper quality control while using CS can result in better results [17].

Limestones are sedimentary rocks primarily of calcium carbonate and they are generally obtained from the calcareous remains of marine or fresh water organisms embedded in calcareous mud [18]. They change from the soft chalks to hard crystalline rocks [18]. The use of limestone in the construction industry has been increasing due to benefits as aggregate. Some of these benefits include good strength, low possibility of alkali-silica reaction and the decrease in drying shrinkage in concrete [19].

Crushed limestone fine sand is a by-product of the quarry process and typically does not have a significant demand due to its high fines content that exceeds the standard allowable limit of 5% and the fines are particles whose diameters are less than 80 μm [8]. Historically, the reason for this limit is that most deleterious clay or silt that may be present in an aggregate will be removed along with this size fraction [20]. Chen [21] et al. stated that LSF can be also used as fine aggregate replacement and the addition of LSF has no or little adverse effect on the concrete properties.

Schimdt [22] et al. stated limestone, when ground for optimum fineness, can lower the water demand, reduce bleeding, improve workability, and increase strength because it improves overall particle gradation of cement.

CS is very abundant in limestone quarries and its use could significantly decrease the materials cost of concrete, eliminate the dust disposal cost, reduces environmental pollutions and dilapidation of natural resources [8].

1.1.4 The Role of Fine Aggregate Characteristics on Concrete Properties

Physical as well as chemical properties of fine aggregate affect the durability, workability and also strength of concrete, so fine aggregate is a most important constituent of concrete and cement mortar [23].

The shape of the fine aggregate has a more significant impact on water demand than the shape of the coarse aggregate and the PSD of the fine aggregate was found to have a greater influence in the properties of concrete [2]. The impact of the physical

characteristics of the sand used in the concrete mix is even greater than that of the coarse aggregate fractions, both in the concrete's plastic and hardened states [24].

Neville [25] stated that aggregates specific gravity, PSD, shape and surface texture influence markedly the properties of concrete in the fresh state. On the other hand, the mineralogical composition, toughness, elastic modulus and degree of alteration of aggregates are generally found to affect the properties of mortars and concrete in the hardened state.

Natural sand, which may be weathered, differs from most fine crushed aggregates in its grading, particle shape and surface texture and compared to natural sand, crushed fine aggregates incorporate significantly more fine particles (fillers), have different PSD, and tend to be more angular with rougher surfaces [26]. The main characteristics of aggregates that affect the performance of fresh and hardened concrete are:

- Shape and texture
- Grading
- Adsorption
- Mineralogy and coatings
- Strength and stiffness
- Maximum size
- Specific gravity or relative density
- Soundness
- Toughness [27]

Particle shape includes two properties: sphericity and roundness. Sphericity is a measure of whether the particle is compact in shape and the roundness refers to the relative sharpness or angularity of the particle edges and corners whereas surface texture refers to the degree of roughness or irregularity of the aggregate particle surface [28]. The influence of fine aggregate shape and texture on the strength of hardened concrete is almost entirely related to its influence on the resulting water-cementitious material ratio of the concrete if the fine aggregate has a grading within the normally accepted limits and its grading is taken into account in selecting concrete proportions [28].

Galloway [29] concluded that shape is related to three different characteristics: Sphericity, form and roundness. Sphericity is a measure of how nearly equal are the three principal axes or dimensions of a particle and form is a measure of the relation between the three dimensions of a particle based on ratios between the proportions of the long, medium, and short axes of the particle [27].

The surface texture, also called surface roughness, of particles is the sum of their minute surface features [27].

Shape and texture of fine and very fine aggregates affect workability of fresh concrete and have an effect on strength and durability of hardened concrete. Shilstone [30] stated that for a given workability flaky and elongated particles increase the demand for water thus affecting strength of hardened concrete and spherical or cubical particles lead also to better pumpability and finishability as well as produce higher strengths and lower shrinkage than flaky and elongated.

CS has rough surface, more angularities, large fineness modulus and other characteristics which are not conducive to the workability of concrete [1].

The PSD of the aggregate in concrete has great effects on the performance of the concrete mix produced [31]. First, the PSD would affect the packing density of the aggregate, which in turn would determine the volume of voids to be filled with paste [31].

The effect of shape and surface texture of fine aggregates on mechanical properties is often not a factor in conventional concretes (30–40 MPa), although these properties may cause an increase in the water demand [13].

The particle shape, angularity, surface texture, and grading of fine aggregate used in Portland cement concrete, may significantly affect the properties of the concrete that are important to its behavior in service [32].

The shape and PSD of aggregate particles used in concrete (sand, gravel; 0.2 mm to 15 mm) can affect various properties in the fresh and hardened states, particularly rheological and mechanical properties [33]. Moreover the mechanical properties of CS depend on the source of its raw material. Hence selection of quarry is very important for obtaining quality fine aggregate [34]. Figure 1.1 presents crushed stone type's percentage in United State of America and Figure 1.2 shows aggregate obtaining percentage in Japan.

The gradation of the aggregate, or distribution of particle sizes, should meet the specifications outlined in ASTM C33 [6], "Standard Specification for Concrete Aggregates." ASTM C33 suggests that the gradation curves shall be smooth, with neither a deficiency nor excess of material of any one size.

Chen [1] et al. stated the addition of LSF to fill into the voids between aggregate particles can reduce the volume of voids. Grading refers to the distribution of particle sizes present in an aggregate [28]. Besides particle shape, crushing processes also influence grading of the crushed fine aggregates, and the proportion of microfines (minus 75 μm material), particularly when compared to natural fine aggregates [35].

Particles of this size may lead to reduced workability due to the large surface area that must be wetted. This leads in turn to an increase in the amount of water required to maintain proper workability, to an increase in cement content required to maintain strength, and, as a result, to higher shrinkage values and greater sensitivity to cracking [5].

Kim and Park [36] experimentally investigated that the fracture characteristics of crushed limestone. They also investigated strength of crushed limestone sand concrete. They observed that the fracture energy of concrete was little influenced by the type of fine aggregate. In addition, the fracture energy of CS concrete was slightly higher than that of river sand concrete. They say that it seemed to be due to very fine sand included in CS, which tends to improve the cohesion between cement paste and aggregate. Also, the fracture energy was not proportionally increased with an increase of concrete strength. The characteristic strength of crushed limestone sand concrete was almost the same as that of river sand concrete.

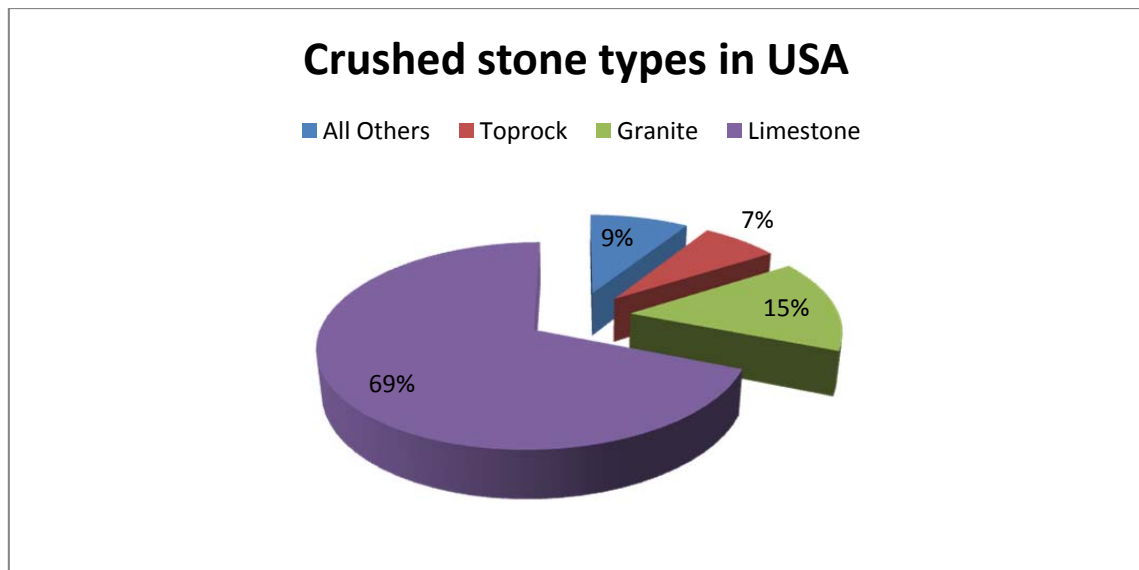


Figure 1.1 Crushed stone types in United States [19]

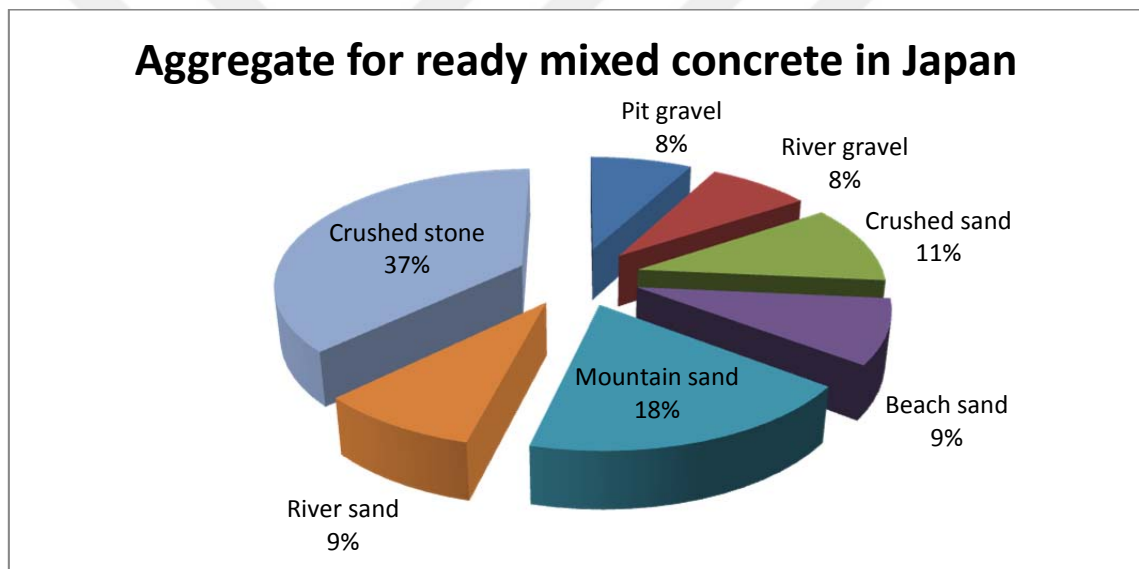


Figure 1.2 Aggregate for ready mixed concrete in Japan [19]

A number of studies have dealt with the influence of both grading and particle shape of the fine aggregate in mortars and concrete. At a given water/cement ratio, it has been found that concrete made with crushed fine aggregates achieved compressive strength equal to or higher than concrete made with natural sand, reducing the void content of the aggregate, thereby lubricating the aggregate system without increasing the water requirement of the mixture [35].

1.1.5 Impact of Fines Content on Concrete Properties

The characteristics of aggregate play the substantial role in the fresh and hardened properties of concrete as it occupies about 50% to 80% total concrete volume [11]. Aggregate content is a factor which has direct and far-reaching effects on both the quality and cost of concrete. Unlike water and cement, which do not alter in any particular characteristic except in the quantity in which they are used, the aggregate component is infinitely variable in terms of shape and grading [24]. Moreover, the fines content (particles finer than 75 μm) in aggregate has substantial effects on the performance of concrete [31].

The type and gradation of aggregates have significant effects on concrete properties and performance [7]. Even the smallest particles, those smaller than 75 μm , often referred to as “microfines,” can significantly impact properties from workability to strength and durability [7].

1.1.5.1 Fresh State Concrete Properties

Correct and economical proportioning for the fresh state properties is the first step in manufacturing concrete structures with desired hardened, durability, and sustainability properties [26]. Fresh concrete is the concrete phase from time of mixing to the time when concrete surface is finished and it is placed in its final location in the structure [37]. It is the stage in which concrete can be moulded and it is in plastic state, it is also described as consistence, which is the ease with which concrete will flow and the significance of fresh concrete stands in there that the first 48 hours are very important for the performance of the concrete structure, it controls the long term behavior, influences ultimate strength, elastic modulus, creep, and durability [35].

Fine aggregates (smaller than 4.75 mm, No. 4 mesh) play a very important role in controlling the properties of fresh concrete [5]. They help to improve the cohesiveness of fresh concrete, improve its workability, and prevent segregation and bleeding [5].

Chen [21] et al. aimed to evaluate workability performance of concrete with variable limestone fines content.

Bederina [38] et al. focused on effect of limestone fillers on fresh concrete properties of concrete. This investigation showed that adding limestone fillers improves the workability of concrete.

Donza [13] et al. concluded the effect of CS on fresh concrete presents some disadvantages compared with natural sand. CS require a higher dosage of admixture to overcome the adverse shape and texture of particles.

1.1.5.2 Hardened State Concrete Properties

Durability is a very important parameter to develop concrete technologies and construct reinforced concrete structures with long service life due to some economical and environmental reasons [39].

Corrosion of steel reinforcement in concrete is the most common problem affecting the durability of reinforced concrete structures [17]. The durability of steel-reinforced concrete structures being in contact with either marine environment or deicing solutions is determined mainly by their resistance to chloride-induced corrosion [40].

Kumar [11] has been carried out an investigation into the potential use of crushed sandstone aggregates in high performance concrete. The engineering properties of both fresh and hardened properties have been obtained. Moreover the durability performance of hardened concrete has been conducted by doing the sorptivity, absorption and permeable pore voids and rapid chloride penetration test. Combination of silica fume and fly ash as partial replacement of cement with crushed sandstone aggregates found to positive effect on hardened properties of concrete such as strength and durability.

Chen [21] et al. carried out a research on fine content effect on durability performance of concrete. These durability performances were mechanical strength, water permeability, sorptivity and porosity. For the mechanical strength, there were no or little adverse effect were taken from the test results. Furthermore, LSF would significantly reduce drying shrinkage and water permeability. Because the addition of LSF to fill into the voids between aggregate particles can reduce the volume of voids to be filled [21].

Gonçalves [2] et al. stated a number of studies have dealt with the influence of both grading and particle shape of the fine aggregate in mortars and concrete. It has been found that concrete made with crushed fine aggregate (with up to 7% microfines) achieved compressive strength equal to or higher than concrete made with natural sand.

Kenai [10] et al. performed some tests to explain effect of crushed LSF on strength and durability of concrete. Experimental results of the effect of LSF as sand replacement on compressive strength showed that an increment compared to concrete without fines. By

contrast, higher content of LSF decreased the strength at all ages because of dilution effect.

A similar study performed by Beixing [9]. This study comprised the effect of LSF content in CS on compressive strength, chloride ion permeability and abrasion resistance of both low- and high-strength concretes. The result showed that the incorporation of up to 15% LSF as a partial replacement for fine aggregate in low-strength CS concrete or 10% LSF for in high-strength CS concrete improved compressive strength. For low-strength CS concretes, the resistance to chlorine ion permeability increased but LSF has little influence on the chloride ion permeation for high strength CS concrete. The abrasion resistance of CS concretes showed an improvement at 10%.

Another investigation was carried out by Beixing [4] et al.. Their study included influence of CS characteristics on strength and abrasion resistance of concrete. They concluded that The increment of microfines in CS from 4.3 to 20% do not adversely affect the strengths and abrasion resistance of CS concretes, when the microfines content is 10%, the pavement performances of the CS concrete achieve the best.

Stewart [20] et al. stated that microfine aggregates can be incorporated into concrete at levels of 15% by volume of the sand without detrimentally affecting hardened concrete properties of compressive and flexural strength, chloride ion penetrability, and abrasion resistance. However, the use of microfines does increase water or water-reducer demand somewhat. The extent of the influence of a particular microfine on water demand can be estimated using its methylene blue value (MBV).

Balapgol and Kulkarni [41] investigated the hardened properties of concrete with use of crushed basalt stone fine aggregate as a replacement of natural sand. The results showed that there was significant increase in compressive strength with CS.

Kumar and Singh [42] investigated the suitability of crushed stone dust waste as fine aggregate for concrete. Test results indicated that crushed stone dust waste can be used effectively to replace natural sand in concrete. Concrete made with this replacement can attain the same compressive strength.

Baum and Katz [5] studied the effects of microfines below 63 μm on concrete performance. They concluded that the addition of fine has a positive impact on the

properties of the concrete. They also noted that compressive strength improved, chlorides permeability and the shrinkage reduced.

Ravina [43] investigated the use of CS as fine aggregates. Results showed that the particle shape of CS is more angular with a rougher surface texture, and usually flakier and more elongated than of natural sand. Moreover the CS, unless suitably treated, contains much more fines. As a result the workability of the fresh concrete is impaired with the corresponding need for higher water requirement which in turn makes for lower concrete strength and higher drying shrinkage.

1.2 Objective of the Thesis

CS may contain high percentage of very fine material below 63 μm . Furthermore, CS is different in shape, grading and geological origin compared with natural sand. Limestone and sandstone were investigated in experimental study. Limestone and sandstone obtained from different geological source. Because of this, aggregate characteristics of both aggregates are expected to be different. Due to limestone and sandstone have different geological origin, would have different effect on fresh and hardened concrete properties. Especially durability properties of concrete would change in relation to aggregate origin. There are limited researches conducted to determine the crushed fine aggregate characterization effects on durability performance of concrete.

This study explains the role of crushed fine aggregates characterization on concrete performance and establishes a connection between aggregate characterization and durability properties.

1.3 Hypothesis

Two different CS having different geological origins are used in mix designs. The first one is limestone obtained from Çerkesli quarry and other one is sandstone from Cendere quarry.

It is hypothesized that increases of fines ($< 63 \mu\text{m}$) content in CS with a range of fines content up to 15% with the same water/cement ratio have different effects on durability performance of concrete. These differences are related with related with characterization of very fine aggregates. The reasons of different effects on concrete

properties of both CS aggregates need to be explained with regard to their geological origin.



CHARACTERIZATION OF THE CRUSHED AGGREGATES

2.1 Origin of the Crushed Aggregates

Characterization of sandstone and limestone were investigated in this part of the study. These aggregates obtained from Cendere and Çerkeşli quarries respectively. Impact crushers of various types have been employed in crushed fine aggregate production, in particular vertical shaft impactors and comminution in this type of crusher is the result of propelling particles with a rotor moving at high speeds, against an anvil or a curtain of falling particles [2]. Particle fracture and particle shape are influenced by crusher type [32]. In case the management in Crushing & Screening Plants is not fulfilled in compliance with the related techniques, this means fine material below 63 μm quantity in the crushed increases [44].

Figure 2.1 shows processes flow chart for crushed limestone aggregate. Figure 2.2 presents a flow chart of crushing process for sandstone aggregate. The first step of processing begins after the extraction from quarry. Scalping is used to divert fines at a jaw primary crusher in order to improve crusher efficiency. In this way the very coarse portion is crushed and then recombined with the portion of crusher-run material before further processing. After primary crushing the resulting aggregate generally is placed in a large stock area where the aggregate may be fed into the secondary operation whenever convenient. Secondary and tertiary crushing are the final steps in reducing the material to a desired product size.

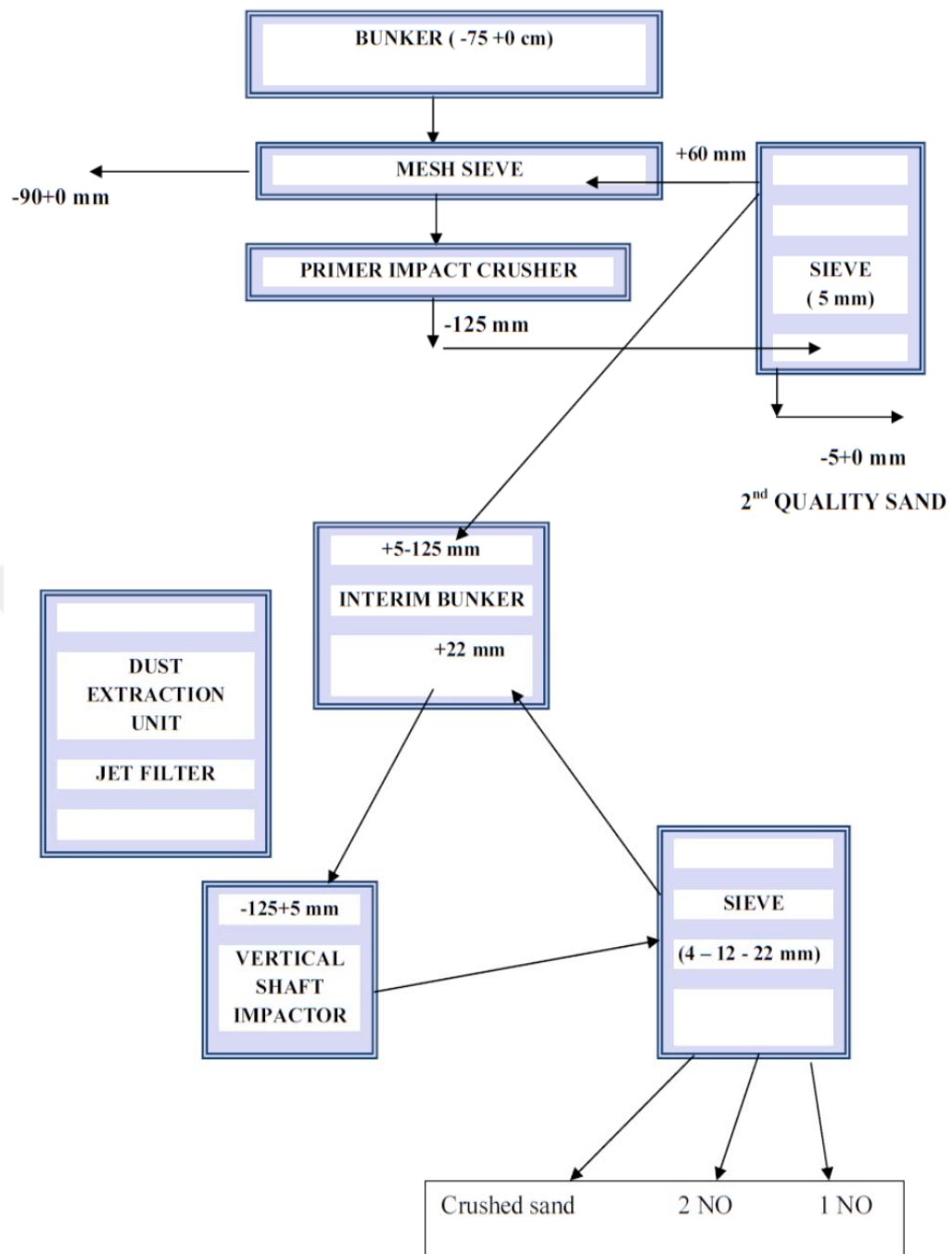


Figure 2.1 Flow chart for crushing processes of limestone aggregate

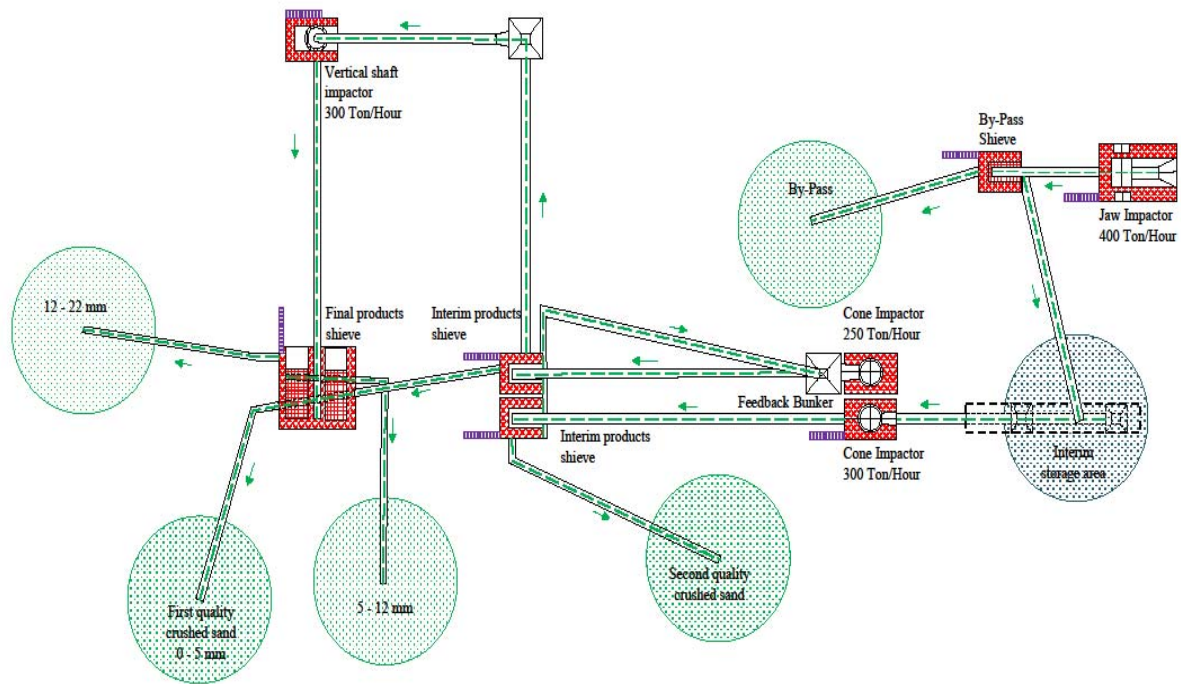




Figure 2.3 X-Ray diffractometer

After X-Ray analysis was completed, the scans were analyzed by using software. Using software, peak intensities at different angles were compared to a database of different minerals and compounds. Compounds with peak intensities matching those of the scans were identified and determined to be compounds present in the microfines.

Petrographic examination provides excellent information very rapidly. Besides shape and texture petrography could be used for following items:

- Determine physical and chemical characteristics of aggregates,
- Describe and classify constituents of a sample,
- Determine weathering and porous characteristics of aggregates, as they can affect freezing and thawing resistance of aggregates,
- Verify weather aggregates have alkali-silica or alkali-carbonate reactive constituents and determine the contaminants. [27]

2.2.2 BET Surface Area Analysis

The Brunauer-Emmett-Teller (BET) method is the most widely used procedure for the determination of the specific surface area of solid materials by means of the BET theory is based on the physical adsorption of gases on the total surface of a porous material, which means outside as well as inside surfaces. The surface area is obtained from following equation (Brunhauer 1938):

$$\frac{P}{v(P - P_0)} = \frac{c - 1}{v_m c} \frac{P}{P_0} + \frac{1}{v_m c}$$

v : the adsorbed volume of nitrogen at a given pressure P ,

P_0 : the saturation pressure,

v_m : the volume corresponding to a monolayer of N_2 on the surface,

c : the heat of adsorption in the first and subsequent adsorbed layers.

When equaling these quantities to the experimental slope and intercept of the straight line, one obtains two equations that may be solved for v_m . From this value and knowing the cross-sectional area of the adsorbed molecule, the specific surface area of the absorbent may be calculated directly with following equation:

$$S_{S,BET} = \sigma \frac{v_m \cdot N}{V}$$

BET analysis provides precise specific surface area evaluation of materials by nitrogen multilayer adsorption measured as a function of relative pressure using a fully automated analyzer. The technique usually adopts non-corrosive gases (nitrogen, CO_2 etc.) as adsorbents to determine the surface area [45].

Figure 2.4 shows that the QUADRASORB SI manufactured by Quantachrome instruments was used for the test.



Figure 2.4 Quadrasob apparatus used for BET Analysis

2.2.3 Particle Size Distribution (Master Sizer)

PSD of fine aggregate plays an important role on workability, segregation and pumpability of fresh concrete. Laser size distribution was more accurate than hydrometer sizing, sizing through image analysis, sieving, and electrical zone sensing [46]. Samples of each of the microfines used in all performance tests were sent to YTU Central Laboratory for laser particle size analysis. The Mastersizer 2000 laser diffraction particle size analyzer was employed to measure the size of the particles for both limestone and sandstone samples. The Mastersizer 2000 uses the technique of laser diffraction to measure the size of particles. It does this by measuring the intensity of light scattered as a laser beam passes through a dispersed particular sample. This data is analyzed to calculate the size of the particles that created the scattering pattern. This technique is based on Fraunhofer and The Mie theories, the key fact about these theories is that if you know the size of the particle and other details about its structure, you can accurately predict the way it will scatter light, each size of particle will have its own characteristic scattering pattern.

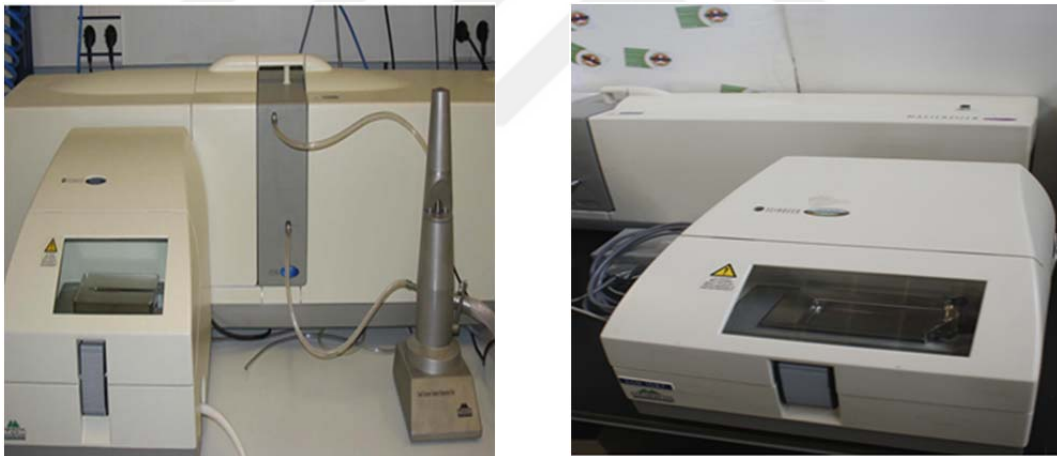


Figure 2.5 The Mastersizer 2000 apparatus

2.2.4 Methylene Blue Test

The methylene blue test was performed in accordance with AASHTO TP57 [47] for the determination of deleterious component in aggregate such as clays and other organic materials. This test is a measure of the capacity of aggregates to adsorb methylene blue dye and can be used to indicate the presence or absence of clay in an aggregate sample [7]. As methylene blue dye was added to a fine aggregate and water-based slurry, the aggregate absorbs the blue dye until an endpoint was reached when the aggregate stops

absorbing additional blue dye. The method is based on the ability of these clays to exchange cations and therefore adsorb methylene blue dye. The MBV may depend on some aggregate characteristics such as mineralogy, PSD and porosity. In general high MBV could potentially generate problems such as high water demand or high range water reducer (HRWR) [27].



Figure 2.6 Methylene blue test

2.2.5 Morphology Analysis

Limestone and sandstone's samples with particle sizes ranging between 0-63 μm and 0,125-1 mm were analyzed by using Morphology G3 particle characterization system. The instrument measures size and shape of a sample of particles. Shape of fine aggregate's particle effects concrete in one major way through its influence on the workability of fresh concrete. The influence of fine aggregate shape on the strength of hardened concrete is almost entirely related to its influence on the resulting water/cement ratio of the concrete. This means the shape of fine particles has a significant effect on water demand [48].



Figure 2.7 Morphology G3 apparatus and software

The shape has four most important factors employed in characterization process are as follows;

- **Circularity**; is the ratio of the perimeter of a circle with same area as the particle divided by the perimeter of the actual particle image , it is calculated with following equation;

$$\text{Circularity} = \frac{2 \times \sqrt{\pi \times \text{Area}}}{\text{Perimeter}}$$

Circularity has values in the range of 0-1 , while a perfect circle has a circularity of 1 an irregular object has a circularity close to 0 based on this circularity might also be described as “derivation from a perfect circle ”.

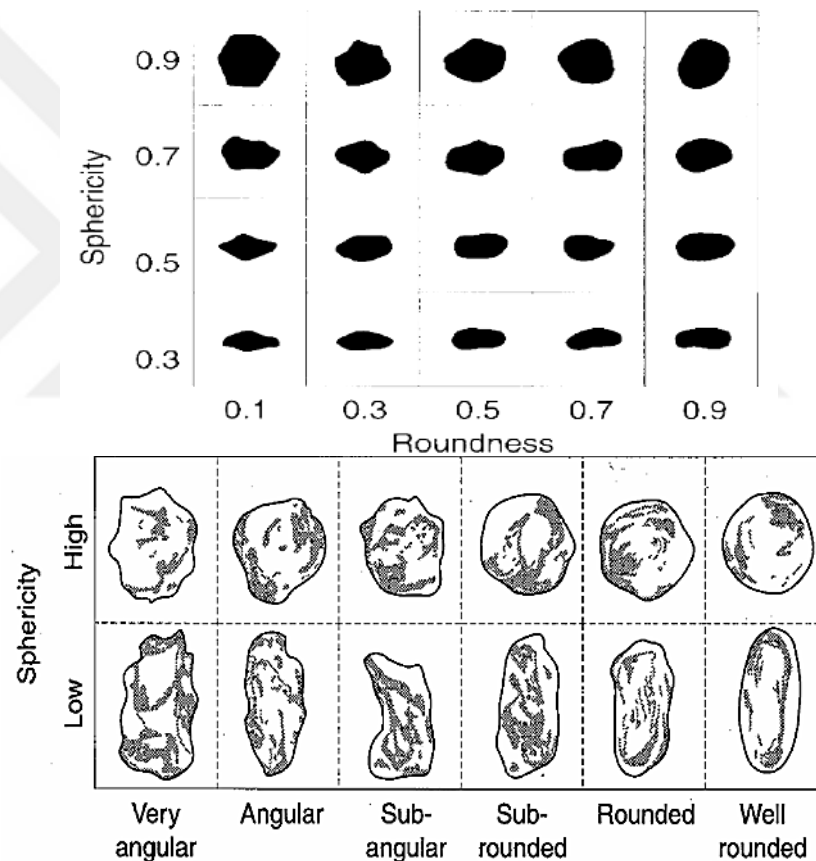


Figure 2.8 Visual assessment of particle shape [Powers,1953 ; Krumbein ,1963]

- **Convexity**; is a measurement of the edge roughness of a particle. It is calculated by dividing the convex hull perimeter by the actual particle perimeter. Convexity also has values between 0-1 similar to circularity. A smooth shape's convexity value is 1 while an irregular object has a convexity closer to 0.

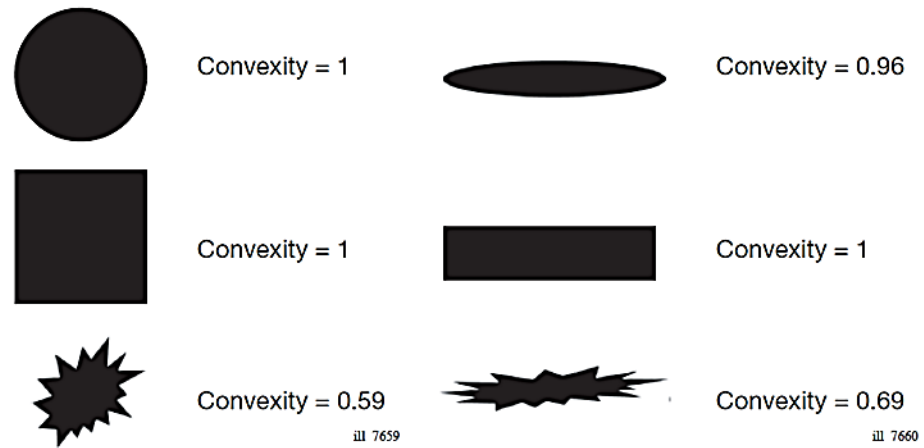


Figure 2.9 Values of convexity for different shapes of particles

- **Elongation**; is defined as width/length ratio and as the name suggest it is a measure of elongation. Elongation values change between 0 - 1.

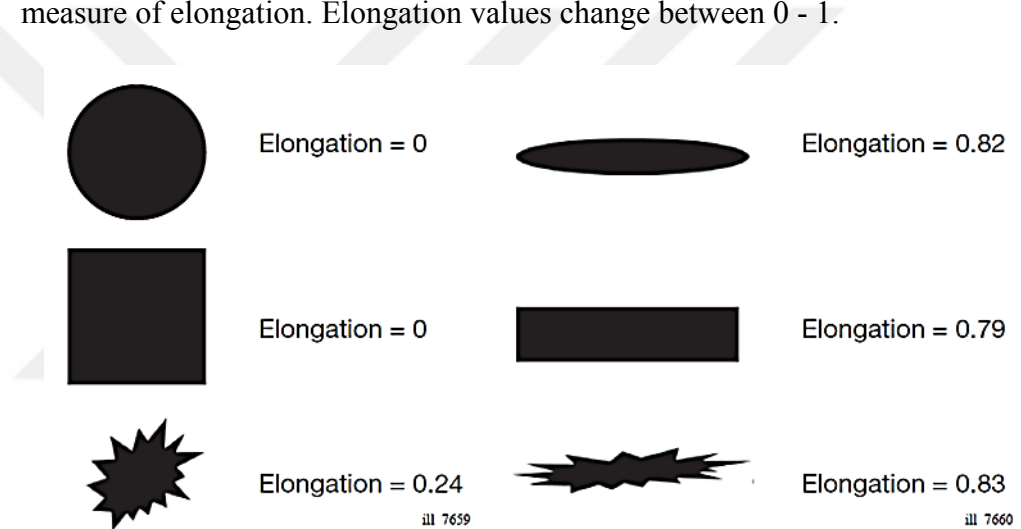


Figure 2.10 Values of elongation for different shapes of particles

- **Intensity Mean**; is the average of the pixel greyscale levels in the objects and it is calculated as follows:

$$Intensity\ mean = \frac{\sum_{i=1}^{i=N} I_i}{N}$$

For grayscale images, Intensity Mean ranges from 0 (black) to 255 (white).

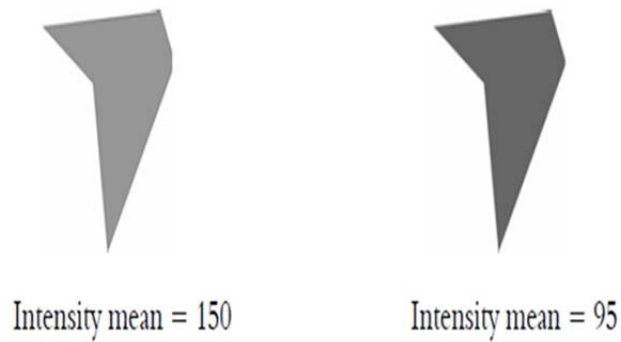


Figure 2.11 Visual representation of intensity mean value.

2.2.6 Total Organic Carbon Content

The total organic carbon (TOC) content, as the name implies, is a measure of the amount organic carbon compounds present in the aggregates. These arise naturally from soils and sediments in aggregate quarries or during formation of aggregate in geologic processes. The TOC is determined either by subtracting the inorganic carbon content from the total carbon content, or by determining the carbon content on a sample that has had the inorganic carbon content removed by acidification.



Figure 2.12 Apparatus used for determination of TOC content

2.2.7 Electrical Conductivity

Electrical conductivity (EC) is the measure of a material's ability to accommodate the transport of an electric charge. Conductivity can be measured by using a number of techniques, but the most widespread involve placing a sample between two electrodes. The electrodes may contact the sample directly or through electrical contact. The test determines the total electrical charge passed through a sample placed between conductive solutions of sodium chloride (NaCl) and sodium hydroxide (NaOH). The test measures the electrical conduction of all ions. [49]

2.2.8 pH

pH is an approximate measure of acidity or alkalinity of a solution and is defined as the negative logarithm of the hydrogen ion concentration. As the pH of a solution increases, the number of free hydrogen ions decreases, and a change in pH of one reflects a tenfold change in the hydrogen ion concentration. Concrete is known to be a highly alkaline material. Depending on the concentration levels Na^+ , K^+ and OH^- ions. Because pH is a measure of a solution measuring the pH of concrete as a solid substance is generally regarded to be a challenging task.

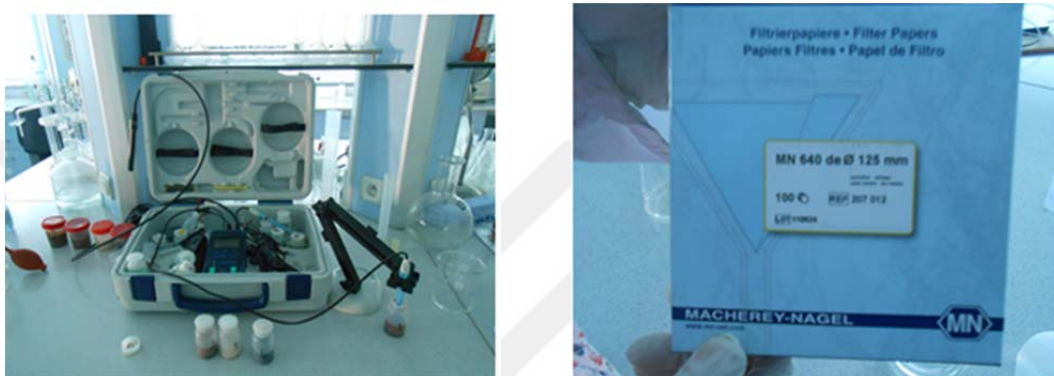


Figure 2.13 Apparatus used to measure pH value of the samples

2.3 Result and Discussion

2.3.1 Petrography Results

Petrographic analyses of sandstone and limestone samples were performed in İstanbul University Minerology and Petrography Laboratory for the analysis. Thin slices were prepared from each sample. These were photographed with a digital imaging system after petrographic examination under a polarizing microscope.

Sandstone sample is mainly composed of fine grained quartz and quartz-rich sandstone grains. Quartz and quartz sandstone crumbs constitute about 75-80% of the sandstone and roundness is not good enough. Grading and sorting was not monitored. Also small percentage (5%) of feldspar minerals was determined. There is a binding which contains organic material (graphite), opaque minerals (magnetite, hematite), chlorite (chamosite), muscovite and calcite. Generally binder includes clay and carbonate. It was influenced sandstone from low grade metamorphism, so chlorite minerals were developed from clay portions. Chlorides generally are characterized by pale green. The sample has 10-

12% chlorite. In addition, 5% of muscovite mica was observed in the sandstone. Secondary sparitic calcite fillings have slightly occurred in rock cracks.

Figure 2.14 presents the details of sandstone sample as follow;

A: Small-grained quartz is dominated which is greywacke and cutting sparitic calcite line of rock,

B: green chlorite with black graphite and opaque minerals between particles,

C: quartz which composing the rock and muscovite mica between them,

D: general view of the sample,

Ku: quartz,

Ka: calcite,

Kl: chlorite,

Fd: feldspar,

Ms: muscovite.

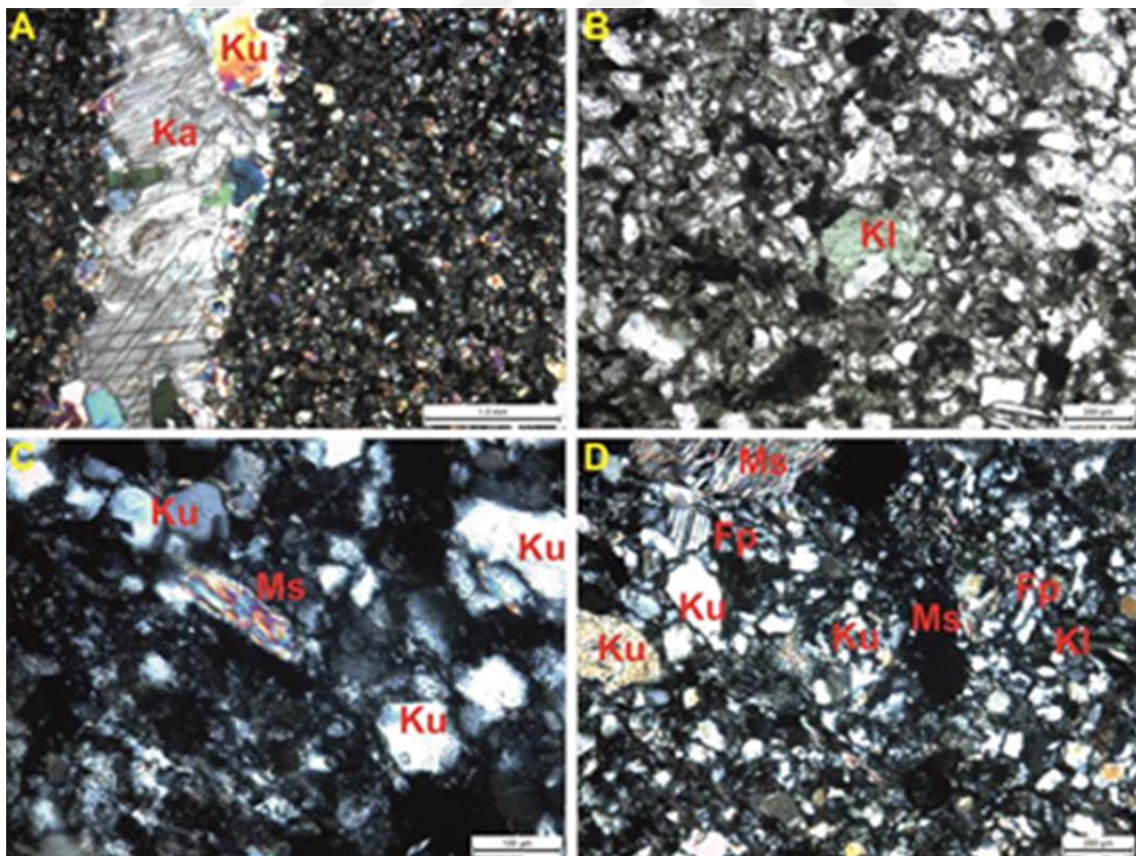


Figure 2.14 Sample of sandstone under polarizing microscope

Figure 2.15 shows the sample of limestone under polarizing microscope. Secondary sparitic calcite is filled to broken parts of the particles. X-ray diffraction (XRD) test presents that the sample is entirely composed from calcite and not include dolomite and quartz.

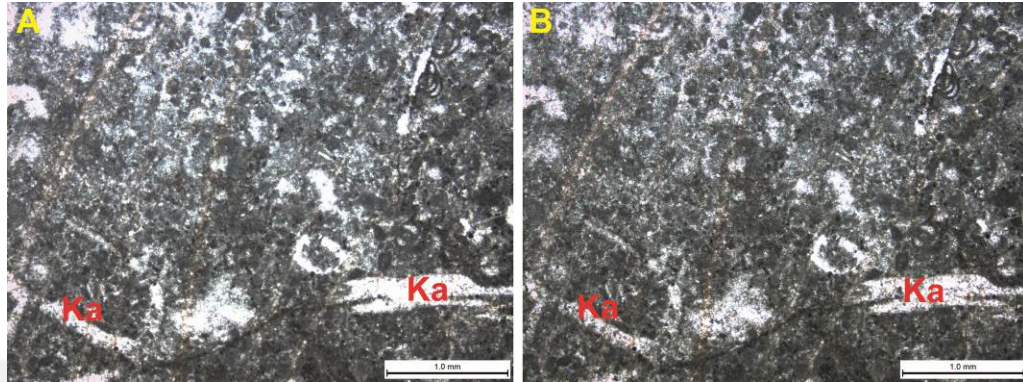


Figure 2.15 General layout of limestone

2.3.2 BET Analysis Results

Based on BET analysis results, it is indicated that the sandstone sample had much larger pore surface area than the limestone sample as shown in Table 2.1. The surface area result indicates how aggregates interact with their surroundings, such as how they dissolve, burn and react with other materials. Besides pore volume is the average volume (size) of the pores present in the sample. Typically smaller particle size results in larger surface area and vice versa. Greater surface area requires more water for lubricating the mix to give the desired workability.

Table 2.1 Comparison of pore surface area of the samples

Pore Surf. Area (m ² /g)	
<u>Limestone</u>	<u>Sandstone</u>
2,159	7,348

2.3.3 Particle Size Distribution (Mastersizer)

The PSD analysis of sandstone and limestone samples was measured by means of Mastersizer 2000 laser. This laser diffraction particle size analyzer is designed for measuring particle size in the 0,02 to 2000 μm range and the test performed between the range. Figure 2.16 and Figure 2.17 present a comparison of PSD results of sandstone and limestone samples.

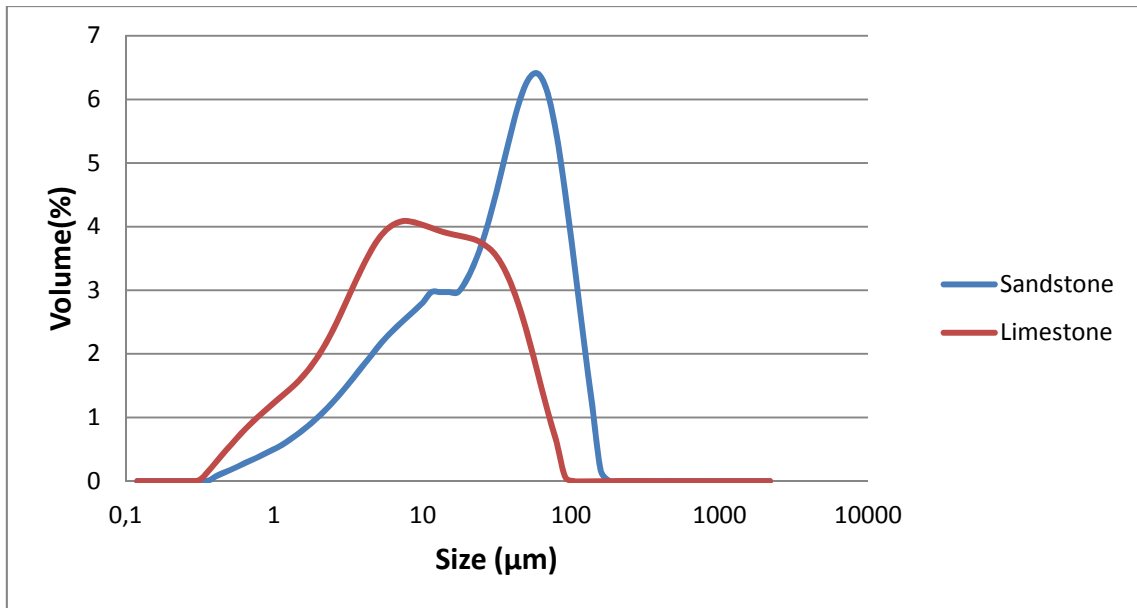


Figure 2.16 Comparison of PSD of sandstone and limestone samples

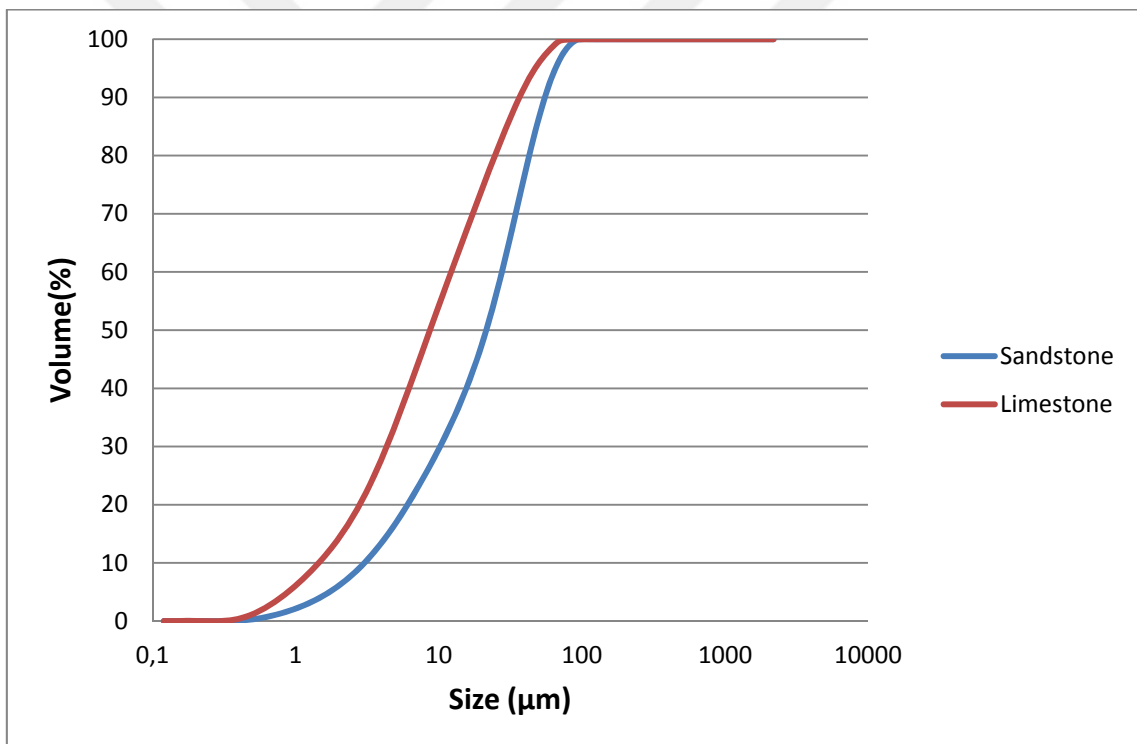


Figure 2.17 Comparison of PSD of sandstone and limestone samples

Comparison of the results of sandstone and limestone samples initially indicated that both of the samples have most of their particles ranged within 0,5-100 μm . They include no particles with size larger than 1000 μm . However, as the frequency polygon graph shows while limestone sample have no particles with size larger than 100 μm , sandstone sample has a considerable percentage. According to these results, it is possible to reach

the conclusion that in general limestone sample has finer particles than sandstone sample.

2.3.4 Methylene Blue Test

Methylene blue test was performed to determine deleterious component such as clay in aggregates ingredients. Test samples (sandstone and limestone) included various percent of fine content up to 15%. MBV are given in Figure 2.18.

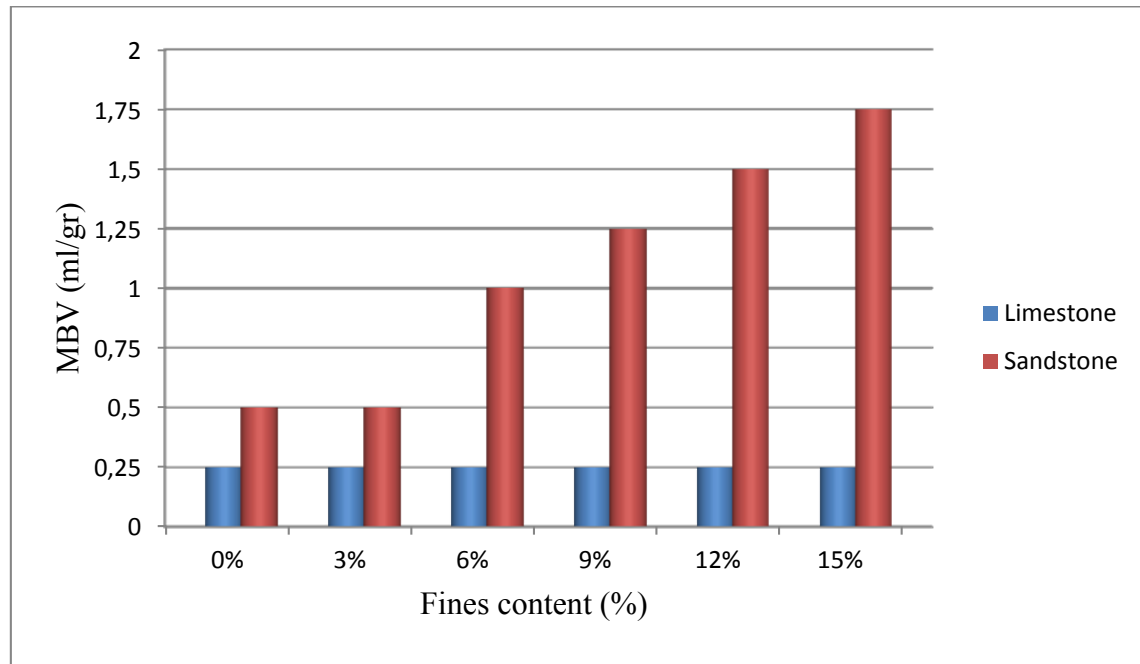


Figure 2.18 MBV for sandstone and limestone crushed aggregates samples with different fines content

According to the results methylene blue values are constant for limestone up to 15% fine content percent. However, the results showed that MBV increases with increment of fines content for sandstone. This increment may be effect of fresh concrete properties of concrete produced with sandstone (CPS).

2.3.5 Morphology Results

Limestone and sandstone fines with particle sizes ranging between 0-2 μm , 0-63 μm , 2-63 μm and 0,125-1mm were analyzed by using Morphology G3 device. Circularity, convexity, elongation and intensity mean are the most important shape factor to analyze each type of aggregates. After analyzing the results were evaluated and compared.

2.3.5.1 Circularity

Circularity as a shape factor is given in Figure 2.19 to Figure 2.22 for sandstone and limestone. Also Figure 2.23 and Figure 2.24 present frequency polygon for respectively sandstone and limestone.

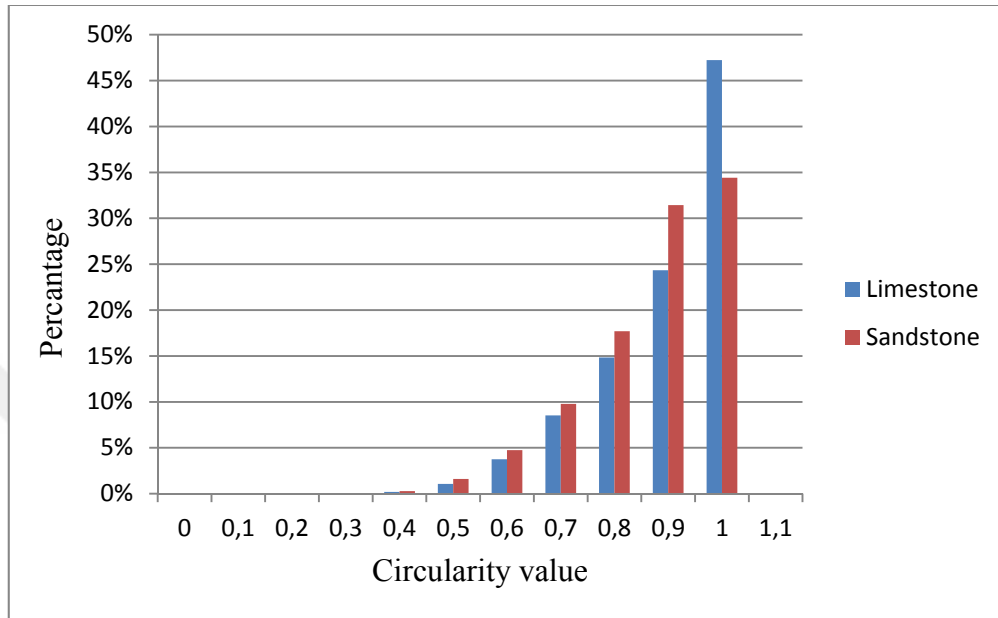


Figure 2.19 Circularity histogram of 0-63 μm of sandstone and limestone

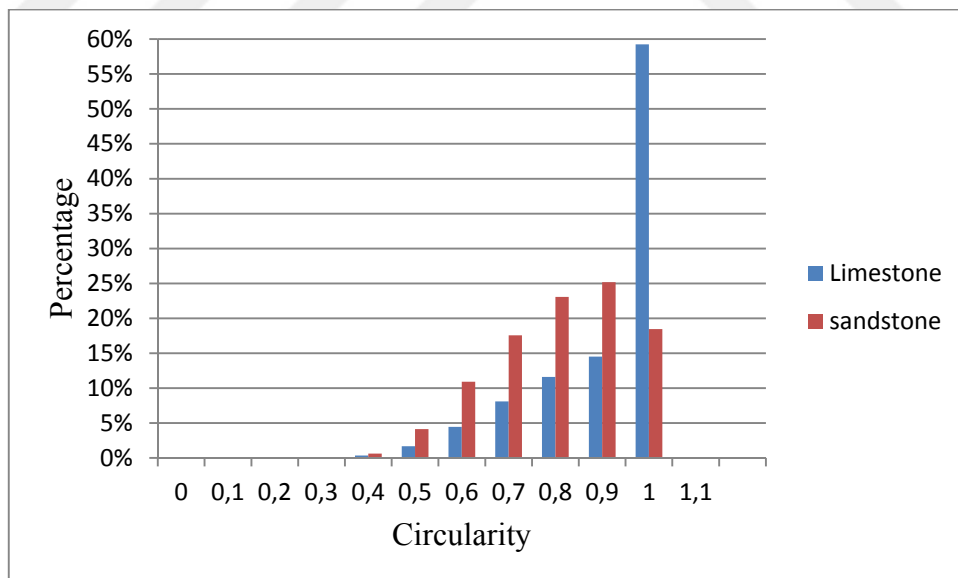


Figure 2.20 Circularity histogram of 0-2 μm of sandstone and limestone

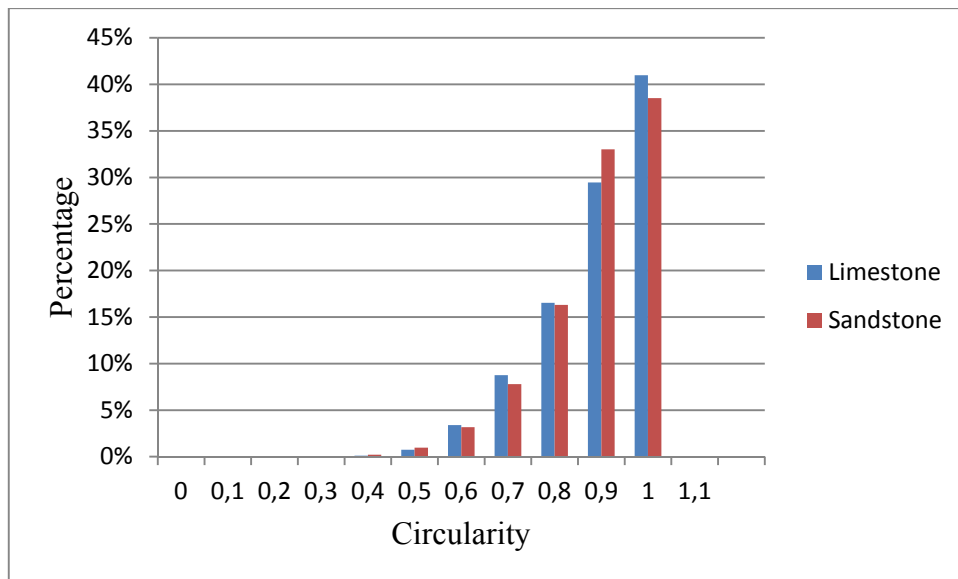


Figure 2.21 Circularity histogram of 2-63 μm of sandstone and limestone

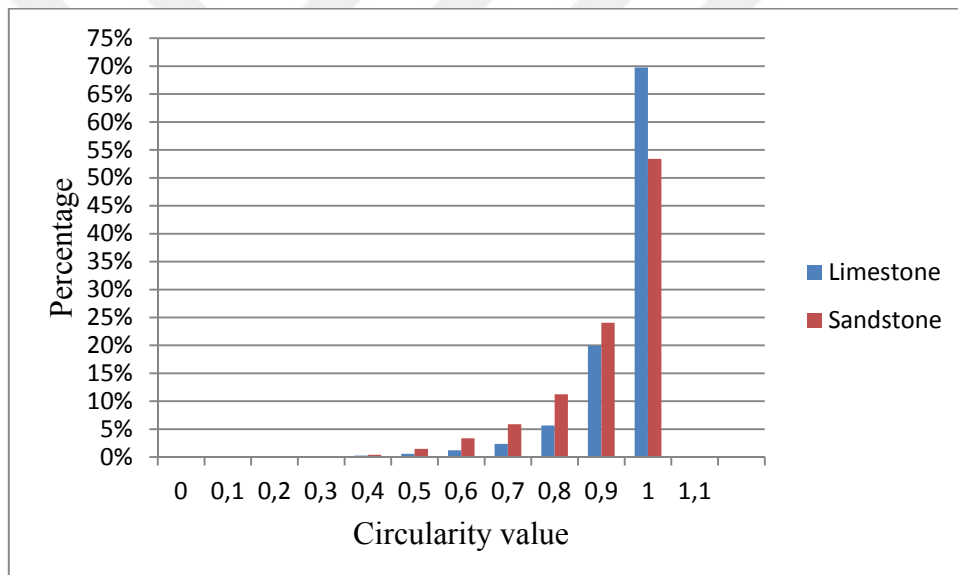


Figure 2.22 Circularity histogram of 0,125-1 mm of sandstone and limestone

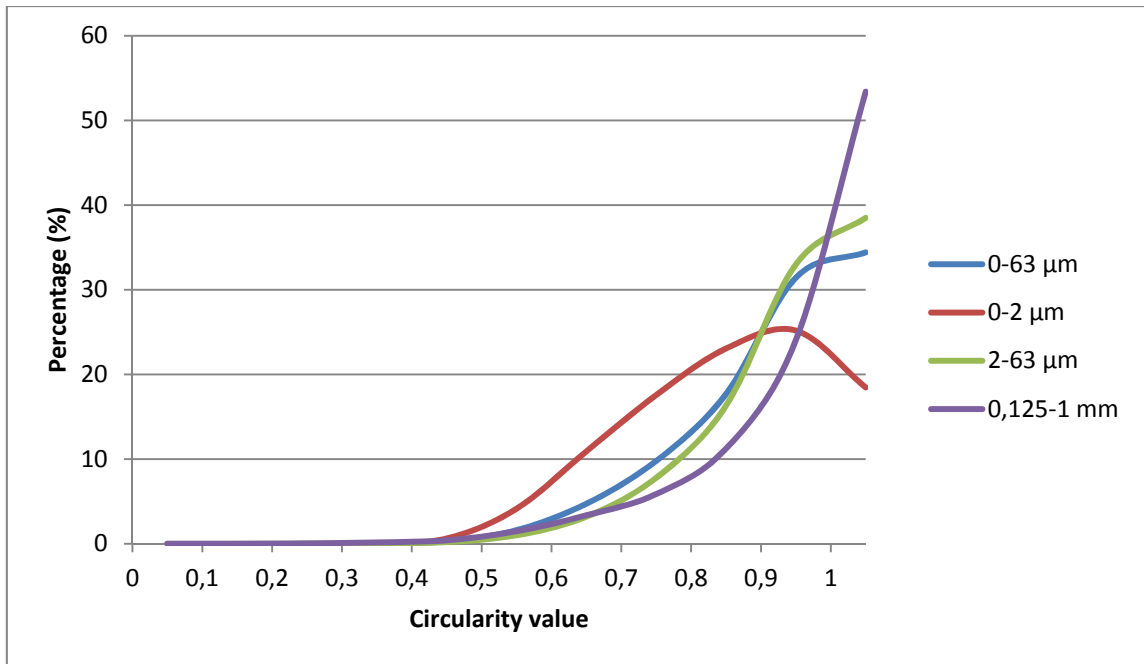


Figure 2.23 Frequency polygon of sandstone for each sizes

As the frequency polygon chart indicates sandstone sample in Figure 2.23 with particle size of 0,125-1 mm has the highest percentage of particles (53.4%) with circularity values of 1, while particles within the range of 0-2 μ have the lowest percentage (18.47%) of circularity values of 1.

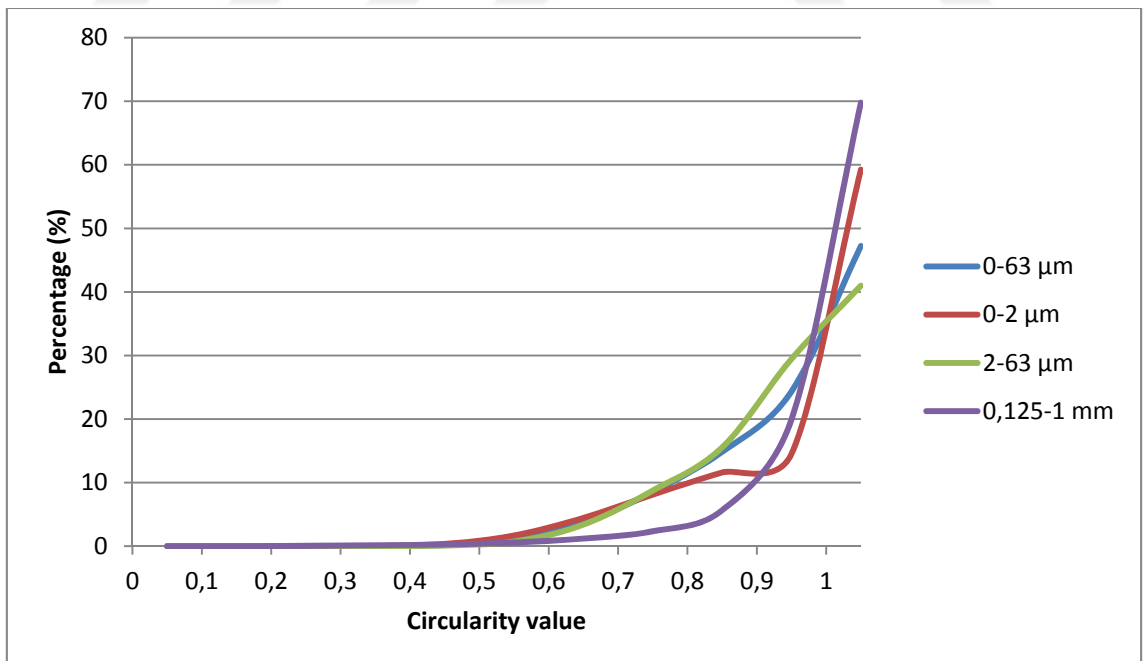


Figure 2.24 Frequency polygon of limestone for each sizes

Circularity value of 1 for the limestone sample as shown in Figure 2.24 reaches its highest values within the particle size range of 0-2 μ and 0,125-1 mm with 59,24% and 69,77% respectively. The lowest value is found in the range of 2-63 μ with 40,98% .

The frequency polygon graph clearly shows that within the particle size range of 0-63 μ limestone sample has a higher percentage of particles with circularity value of 1 exactly 47,23% of particles have the value of 1 for this parameter what makes their shape be the shape of a perfect circle. On the other hand 34,42% of particles of sandstone sample have the circularity value of 1.

It seems from the graphs two samples are distinguished from each other when it comes to circularity values for particle size range of 0-2 μ , while limestone sample has 59,24% of its particles with the circularity value of 1 this percentage drops significantly for sandstone sample only 18,47% of particles have circularity of 1, owing to this as well as to the fact that particles of sandstone sample have higher percentage of low circularity values than those of limestone it can be concluded that particles constituting limestone sample are more well-rounded than those of sandstone sample.

According to the graphical representation of circularity parameter for the particle size range of 2-63 μ both aggregate's samples have very close percentage of particles with the same values of circularity. For both samples percentage of particles with circularity equal to that of a circle (1) is high (38,5% for sandstone and 40,98% for limestone sample) as well as the percentage of particles with circularity close to 1 is very high. Low values of circularity are almost absent for both samples. Thus makes both of the samples in this size range well rounded.

The conclusion that can be yielded from the frequency polygon graphs of the two different aggregate's samples is that in general limestone sample contains a higher percentage of particles (69,77%) with circularity of 1 than the particles of sandstone sample (53,40%). However the percentage of particles which possess circularity between 0,3 - 0,9 is higher for sandstone sample, since most of the particles for both samples have high values of circularity it can be concluded that in the range of 0,125mm-1mm particles are well rounded.

2.3.5.2 Convexity

Figure 2.25 presents convexity histogram of sandstone for ranging 0-63 μ m, 0-2 μ , 2-63 μ m and 0,125-1mm. Limestone convexity histogram is given in Figure 2.26 with the same ranging.

For 0-63 μ m samples convexity analysis, it is easy to see both limestone and sandstone have the convexity value of 1 (85,22% for sandstone and 89,11% for limestone). It means that particle 0-63 μ m range for both samples is smooth. Irregular particles are almost absent for both of them. However limestone samples are smoother than sandstone.

According to the same graphs convexity parameter for sandstone and limestone samples seem to differ in that that while 90,13% of particles of limestone sample have convexity value of 1, nevertheless 77,88% of particles of sandstone sample have convexity values of 0,9. It shows that both samples smooth and of regular shaped for the range of 0-2 μ . However limestone particles seem to be smoother than sandstone particles.

Convexity figures of the two samples almost completely overlap with each other with a very high percentage of particles (87,13% and 88,57% for sandstone and limestone respectively) with convexity value of 1. A clear indication is that particles of both samples are of regular shape and very smooth.

Convexity figures of two samples almost overlap with each other, nearly all of the particles for both samples have convexity value of 1 (94,61% for sandstone and 97.85% for limestone sample) which means that almost all of the particles for both samples have regular shapes with almost no particles with convexity values in low ranges.

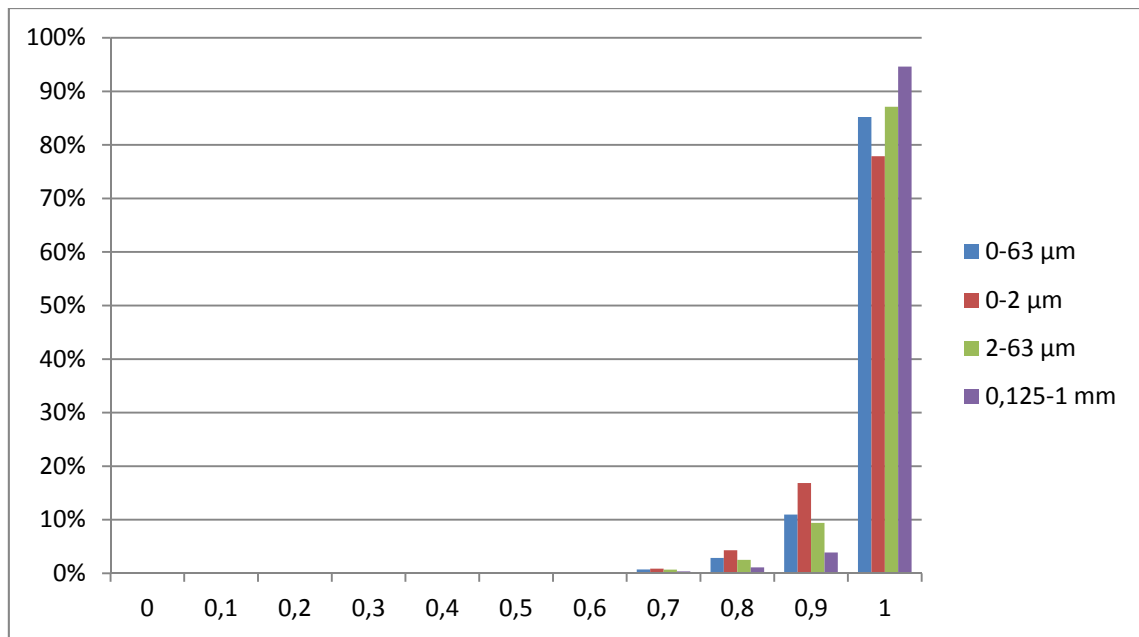


Figure 2.25 Convexity histogram of sandstone

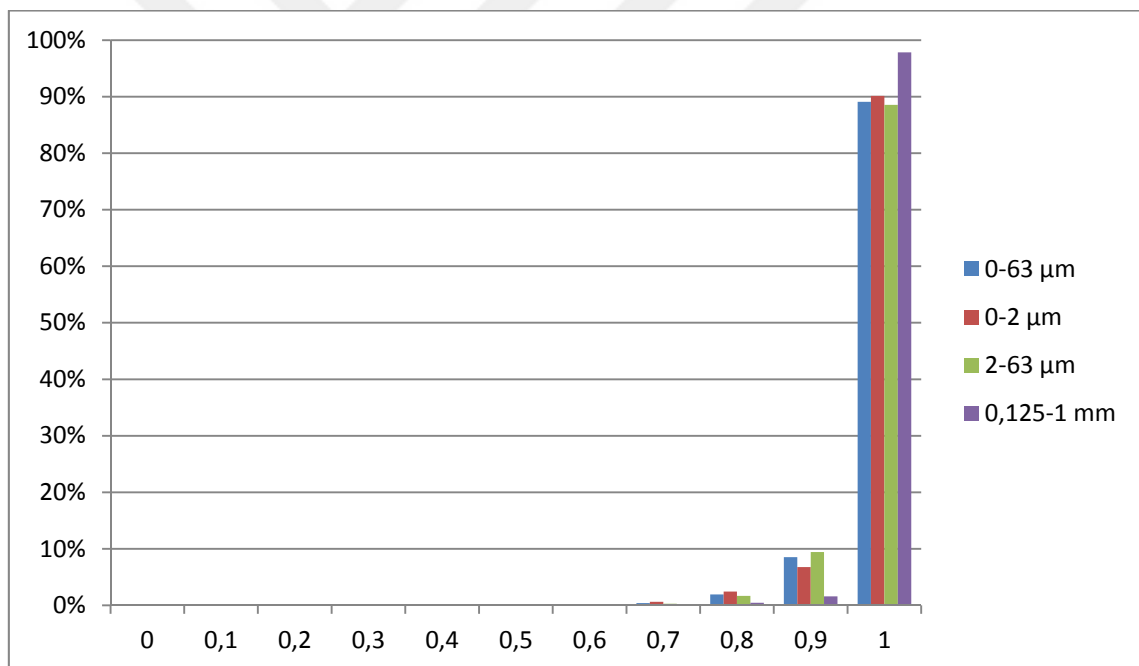


Figure 2.26 Convexity histogram of limestone

2.3.5.3 Elongation

The results from Figure 2.27 and Figure 2.28 tell that particles of both samples have similar values of elongation. For the range 0-63 μm the highest percentage of particles (21,9% for sandstone and 20,42% for limestone) having the value 0,4.

Similar results with 0-63 μ m observed for 0-2 μ m range. Limestone sample has a considerably high percentage of particles with elongation between 0,2 - 0,3. It can be said that particles of limestone sample are somewhat symmetric, as for sandstone sample it is also seen that a great deal of particles have low elongation values.

For both of the samples it can be told from the figures for 2-63 μ m that a very high percentage of particles have elongation values between 0,3 – 0,5. That both samples contain particles that are mostly regular shaped and have small aspect ratios.

Elongation parameter for the two samples within the particle size range of 0,125-1mm does not show very significant differences, for both samples highest percentage of particles (21,21% for sandstone and 25,14% for limestone) possess elongation value of 0,3. Also there is a considerable percentage for both samples is under 0,3. Even though particles with large elongation values are also present in both of the samples it is possible to conclude that in general particles constituting the two samples are of regular shape and have low aspect ratios.

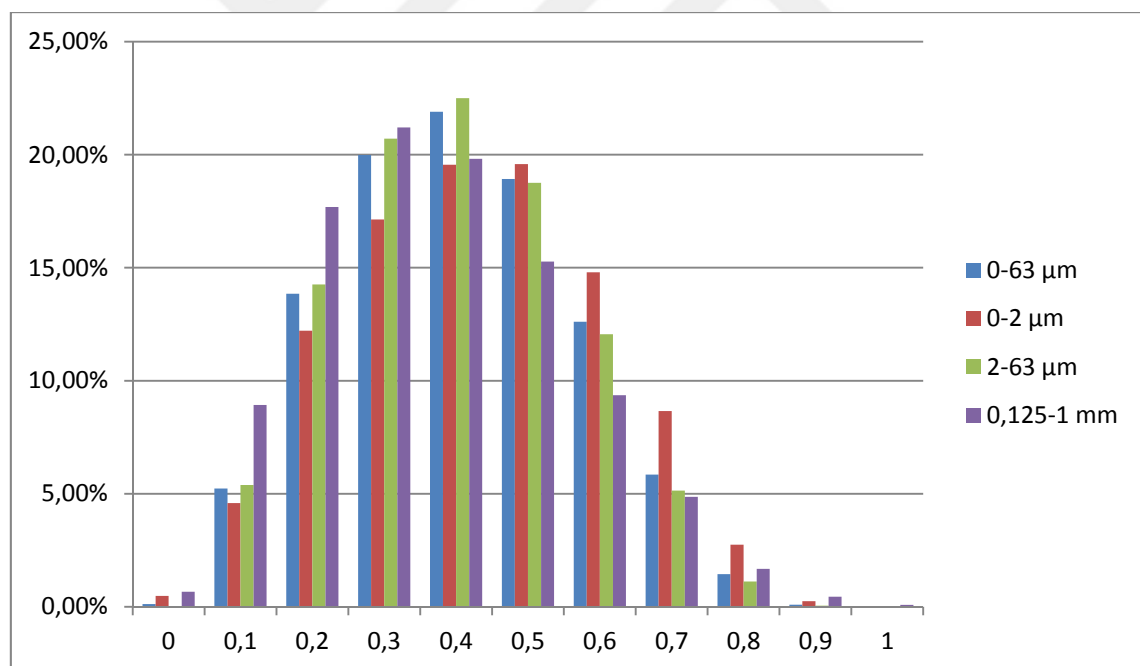


Figure 2.27 Elongation histogram of sandstone

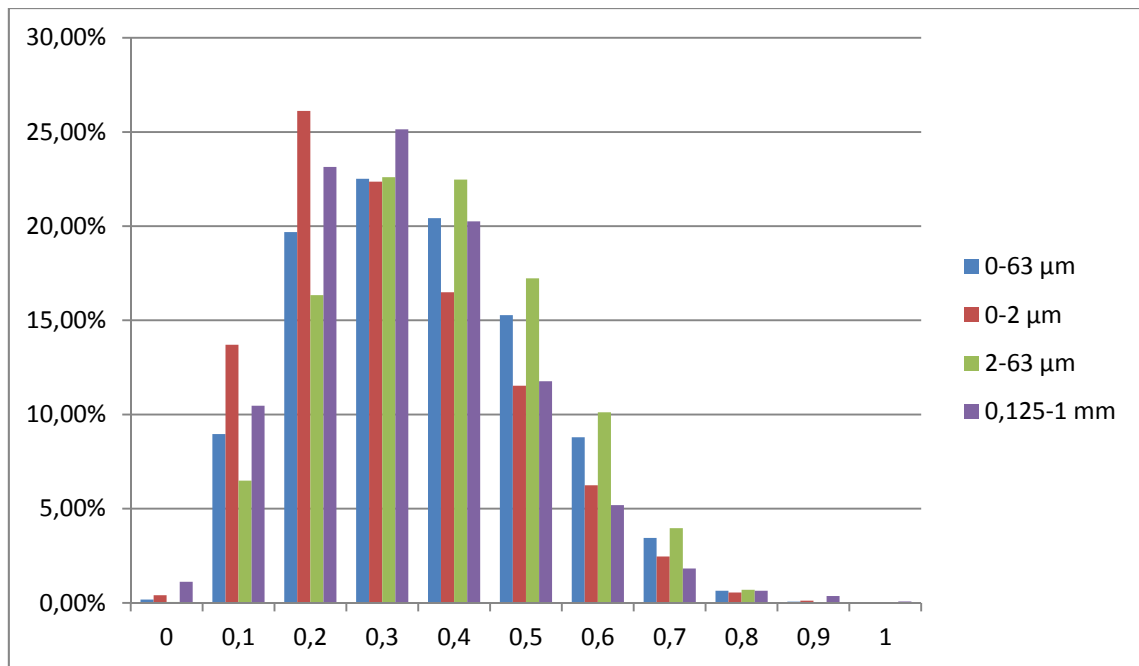


Figure 2.28 Elongation histogram of limestone

2.3.5.4 Intensity Mean

Comparison of intensity mean frequency polygon for sandstone and limestone with ranging 0-63μm, 0-2μ, 2-63μm and 0,125-1mm are given in Figure 2.29, Figure 2.30, Figure 2.31 and Figure 2.32.

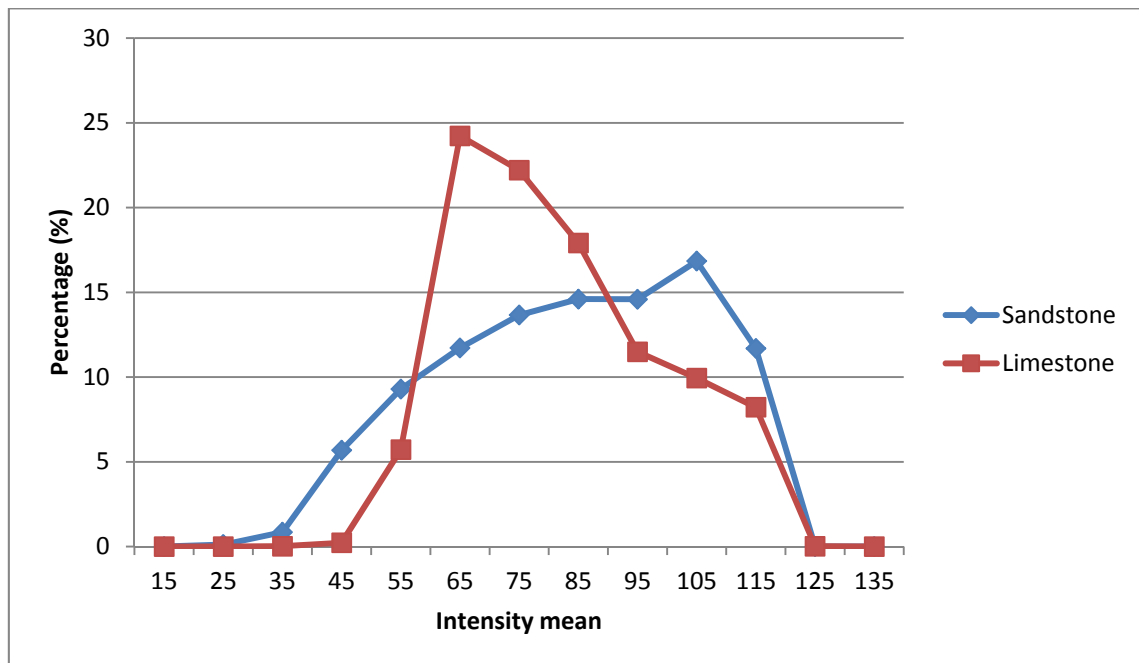


Figure 2.29 Intensity mean values for 0-63μm range

For range of 0-63 μ m, almost half of particles of limestone sample have values of intensity mean in the range of 60-70 whereas sandstone sample is different due to the fact that a high percentage of particles have values standing between 80 - 120. It can be concluded that the presence of black (dark) particles is high for limestone sample on the other hand white (bright) particles are found in sandstone sample.

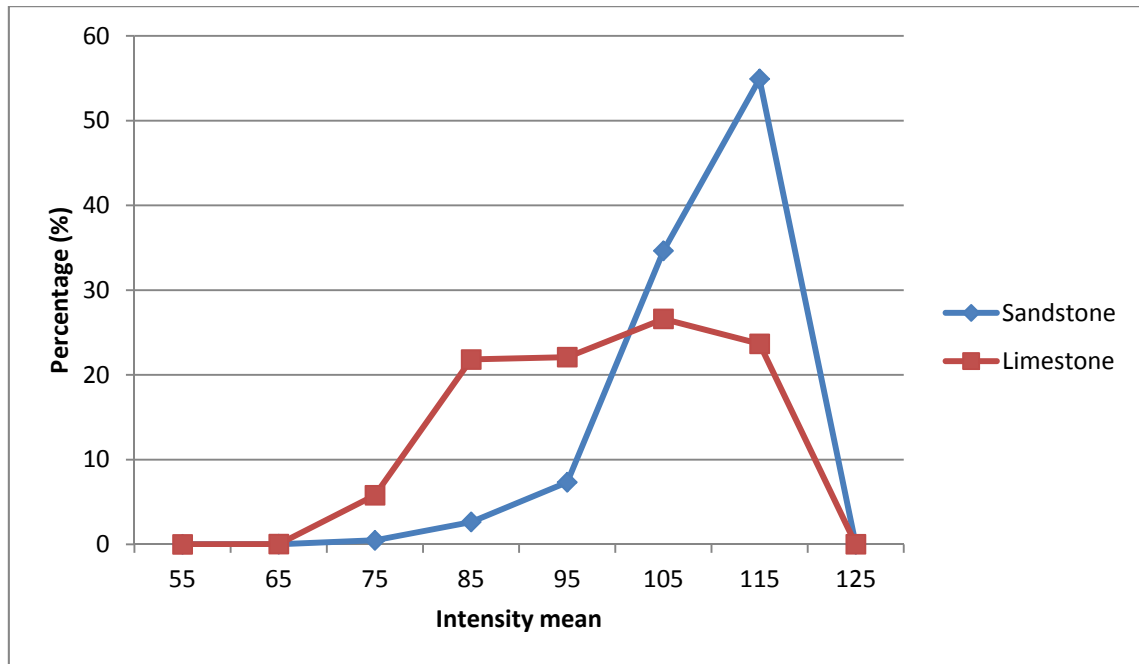


Figure 2.30 Intensity mean values for 0-2 μ m range

In the range of 0-2 μ m, 54,91% of the particles of sandstone sample possess intensity mean value of 110 which compared to the limestone particles which have lower intensity mean values makes them be brighter particles.

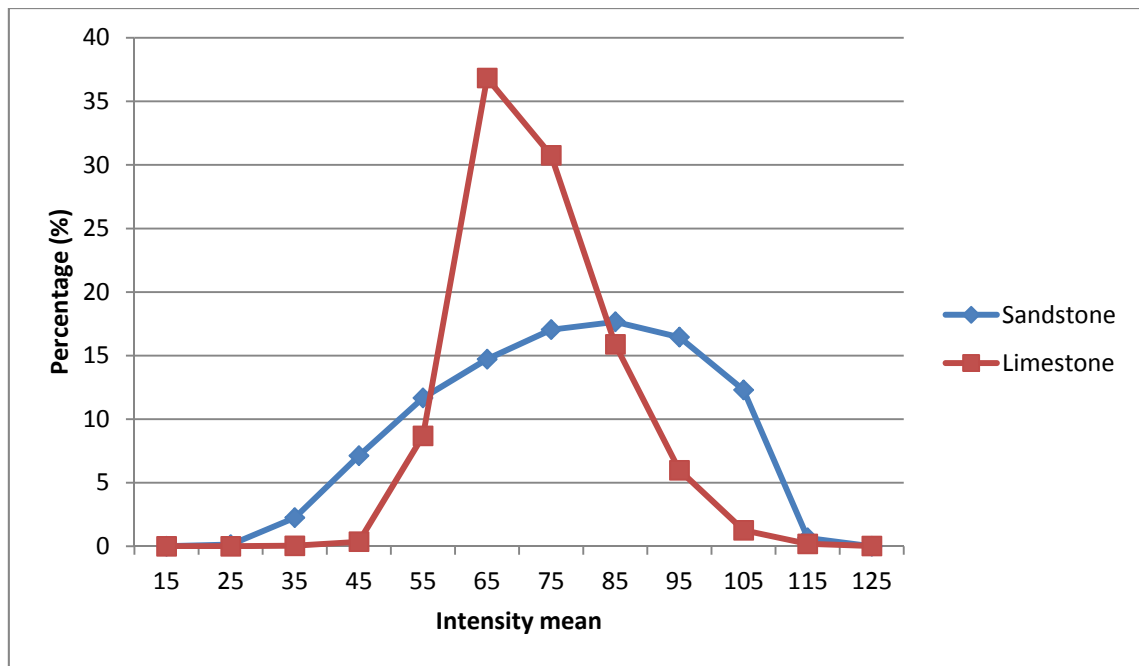


Figure 2.31 Intensity mean values for 2-63μm range

In the particle size range of 2-63μm the first difference is that while a great majority of particles for limestone sample have the intensity mean value changing between 60-70. Particles of sandstone sample in general have higher values of this parameter such as 17,66% with intensity mean value of 80. It can be concluded that in general sandstone particles are brighter than those of limestone sample.

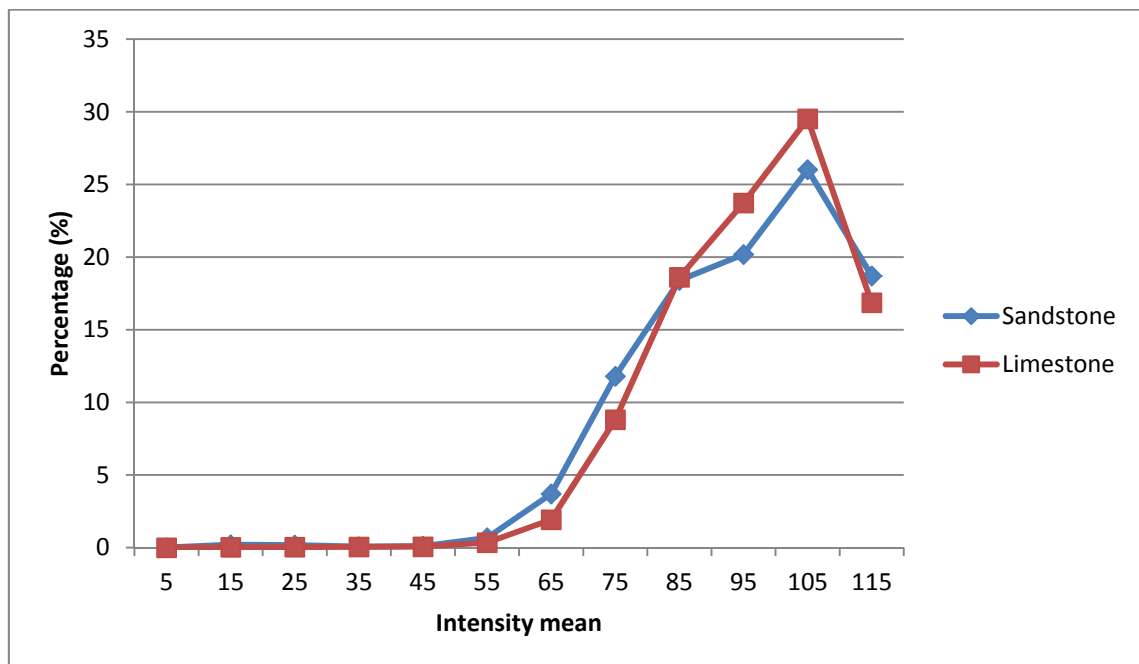


Figure 2.32 Intensity mean values for 0,125-1mm range

In contrast to other particle size ranges in which the parameter of intensity mean showed significant differences in the case of particles within the range of 0,125-1mm. For both samples the highest percentage of particles (26,02% for sandstone and 29,52% for limestone) have the intensity mean value of 100. It can be concluded than in general particles of both samples are black (dark) particles.

2.3.6 Total Organic Carbon Content

Table 2.2 presents TOC content of test samples. Organic carbon content affects fresh concrete properties especially setting time. It also effects compressive strength development. In addition to these effects, it may also impact frost performance by reducing the air-entrainment ability of certain admixtures. It can be easily observed from results both limestone and sandstone have almost similar carbon content. So this test results do not help to determine fresh and hardened properties of concrete in this study.

Table 2.2 TOC content for aggregate samples

Sample type	TOC content (%)
Sandstone	0,4
Limestone	0,5

2.3.7 pH and Electrical Conductivity Results

The results for pH and EC are given in Table 2.3. The results from the experiments related that limestone sample had a greater value of pH than the sandstone sample with 9.4 for limestone and 8.87 for sandstone. As for EC values the results related that sandstone sample had a greater value of EC than limestone sample.

Table 2.3 pH and EC results for limestone and sandstone aggregate's sample

Parameter	Method	Unit of measure	Limestone value	Sandstone value
Saturation with water	TS 8333:1990	%	23	30
EC/Salt	TS ISO 11265:1996	24,2 C- μmhos/cm/%	71/0,02	118/0,04

Table 2.3 (cont'd)

pH	TS 8332 ISO 10390:1995	24,5 C/pH	9,4	8,87
Lime content	TS 8332 ISO 10390:1996	%	50,66	4,21
Organic matter	TS 8336:1990	%	0,06	0,06



FINES CONTENT EFFECTS ON DURABILITY PERFORMANCE OF CONCRETE PRODUCED WITH SANDSTONE OR LIMESTONE

Increase the amount of fines material in the CS affects the durability properties of concrete. This effect is related to the origin of aggregate. According to the geological characteristics of the aggregates, increment of fines content below 63 μm may have positive effects on concrete properties. Even using fines content without any harmful effect on concrete, there are some limits in international standards. For example British standards 882 [50] allow up to 15% of fines content below 63 μm in sand whereas the current ASTM C 33 specification limits the amount of aggregates smaller than sieve 75 μm that can be included in concrete mixes to 3–7%. On the other hand some researches [9, 20 and 51] provide more fine content.

This chapter includes an experimental study on fine aggregates effects on concrete properties for each type of CS. Other purpose of this chapter is to establish relations between very fine aggregate characteristics and concrete performance. This part of the study was carried out focusing on the items as follows:

- Compressive strength,
- Chloride-ion migration,
- Pressured water permeability,
- Wenner prober resistivity,
- Evaluation of chloride resistance in comparison with electrical resistivity.

3.1 Experimental Studies

3.1.1 Materials

Cement used was blast furnace slag cement (type CEM III-B 32,5N) produced by Bolu Cement Corp., complying with the European Standard (EN 196-2), with density of 2,94 g/cm³ and the Blaine value of 5210 cm²/g. Chemical properties of cement are given in Table 3.1 and PSD of cement presents in Figure 3.1.

Table 3.1 Chemical composition and physical characteristics of slag cement

Compound or Test	Unit	Measurement Results
Corrected loss of ignition	%	1,27
SiO₂	%	32,59
Al₂O₃	%	8,68
Fe₂O₃	%	1,97
CaO	%	48,18
MgO	%	3,58
SO₃	%	1,76
Na₂O	%	0,35
K₂O	%	0,81
Na₂O equivalent total alkali	%	0,88
Cl⁻	%	0,0209
7 – Day heat of hydration	cal/g	52
28 – Day heat of hydration	cal/g	61,3
2 – Day compressive strength	MPa	11,4
7 – Day compressive strength	MPa	20
28 – Day compressive strength	MPa	34,9

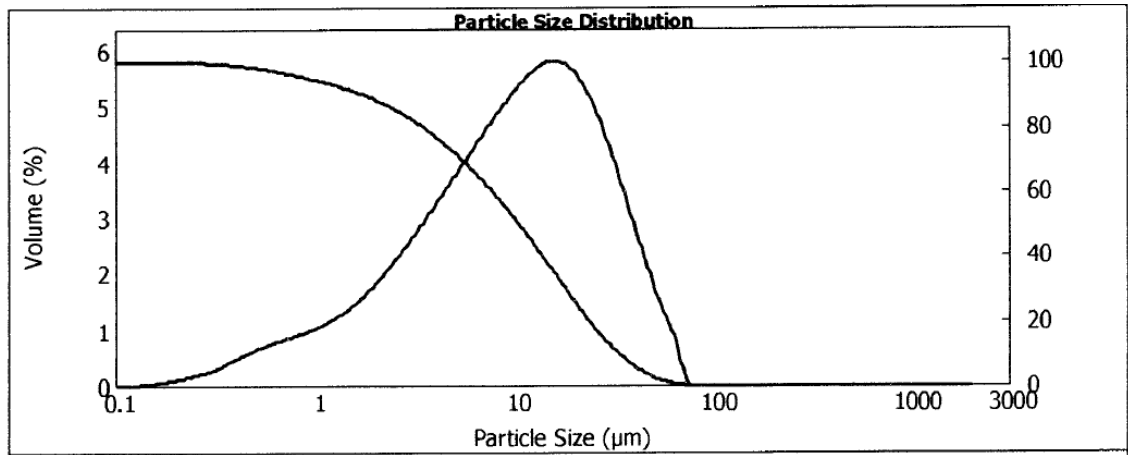


Figure 3.1 PSD of slag cement

Coarse aggregates used were crushed stone from Çerkesli and Cendere with a grain size between 4 mm and 22 mm. Two different crushed fine aggregates which have different mineralogical properties were used in concrete mix proportions. Fine aggregates were obtained from Çerkesli limestone quarry and Cendere sandstone quarry. The properties of limestone and sandstone aggregates are presented in Table 3.2 and Table 3.3 presents the properties of sandstone.

Table 3.2 Properties of the limestone aggregates

Property / Item	Manufactured Sand	Test Result (4-12)	Test Result (12-22)
Specific gravity	2,69	2,71	2,72
Water absorbtion (%)	0,9	0,4	0,3
Fines Content (%)	9	1	0,4
Los Angeles Coefficient (%)	-	29	29
Water soluble chloride content (%)	<0,01	<0,001	<0,001
Water soluble alkali content (%)	<0,01	<0,01	<0,01
Acid soluble sulfate content (%)	0,06	0,06	0,06
MBV	0,25	-	-

Table 3.3 Properties of the sandstone aggregates

Property / Item	Manufactured Sand	Test Result (4-12)	Test Result (12-22)
Specific gravity	2,69	2,70	2,71
Water absorbtion (%)	1,2	0,8	0,5
Fines Content (%)	14	1	0,4
Los Angeles Coefficient (%)	-	17	17
Water soluble chloride content (%)	< 0,001	<0,001	<0,001
Water soluble alkali content (%)	< 0,01	<0,01	<0,01
Acid soluble sulfate content (%)	0,06	0,06	0,06
MBV	1,75	-	-

Sieve analysis with washing was performed to prepare controlled fine aggregate gradations having fines below 63 μm at 0%, 3%, 6%, 9%, 12%, 15%. Controlled gradations of CS are given in Table 3.4. Sieve analysis graph for each fine content design is shown in Figure 3.2. The admixture used was a high performance water reducer (phosphonate polycarboxylate formaldehyde). The properties of HRWR are given in Table 3.5.

Table 3.4 Controlled gradations of manufactured sand

Sieve Size (mm)	Controlled gradations adjusted according to target fines contents (percent <0.063 mm)					
	Limestone					
4	100	100	100	100	100	100
2	60	60	60	60	60	60
1	29	29	29	29	29	29
0,5	21	21	21	21	21	21
0,25	6	8	11	13	16	18

Table 3.4 (cont'd)

0,125	1	4	8	11	14	18
0,063	0	3	6	9	12	15
	Sandstone					
4	100	100	100	100	100	100
2	59	59	59	59	59	59
1	30	30	30	30	30	30
0,5	22	22	22	22	22	22
0,25	7	9	12	15	18	20
0,125	1	5	8	12	16	20
0,063	1	3	6	9	12	15

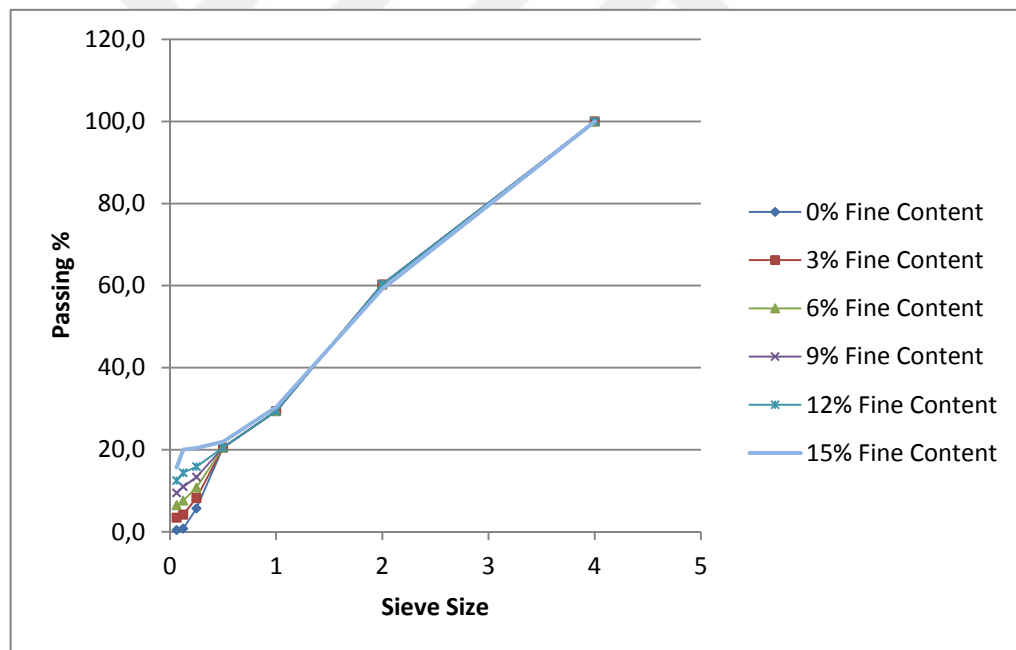


Figure 3.2 Sieve analysis graphs for each fine content design

Table 3.5 Properties of HRWR

Properties	Test Result
Appearance	Homogeneous
Colour	Yellow
Density	1.060
pH	4,32
Water soluble chloride	0,026
Solid content	29,90
Effective component	Acceptable
Alkali content	<%2

3.1.2 Design and Production of the Concrete Mixtures

Twelve different mix proportions, made for concrete with limestone fine and concrete with sandstone fine with 0,38 w/c ratio. Two different fine aggregates from different mineralogical origin were used in concrete mix design. The microfines were used as part of the fine aggregate, the rate of fines is adjusted to 0%, 3%, 6%, 9%, 12% and 15%, by weight of fine aggregate. Table 3.6 shows the mix proportions of the concrete series.

In production of the concrete series, the solid constituent materials were poured into a mixer and firstly mixed at dry state for 1 minute. Then water and HRWR were added gradually 2 minutes. After demoulding, 24 hours after casting, the specimens are kept in water at a temperature of 20 ± 5 ° C for 28 days.

Table 3.6 Concrete mix proportion

Mixture		Fine Content (%)	Water Cement Ratio	Materials (kg/m³)					
No	Code			Water	Cement	Aggregates			HRWR
						0-4	4-12	12-22	
1	LS-L-00	0	0,38	142	380	915	495	492	3,57
2	LS-L-03	3	0,38	142	380	915	495	492	3,57
3	LS-L-06	6	0,38	142	380	915	495	492	3,57
4	LS-L-09	9	0,38	142	380	915	495	492	3,57
5	LS-L-12	12	0,38	141	380	915	495	492	5,32
6	LS-L-15	15	0,38	141	380	915	495	492	5,32
7	SS-L-00	0	0,38	141	380	925	642	345	4,74
8	SS-L-03	3	0,38	140	380	925	642	345	5,8
9	SS-L-06	6	0,38	140	380	925	642	345	6,8
10	SS-L-09	9	0,38	139	380	925	642	345	7,6
11	SS-L-12	12	0,38	139	380	925	642	345	8,6
12	SS-L-15	15	0,38	138	380	925	642	345	9,8



Figure 3.3 Concrete mixing in concrete mixing machine

3.1.3 Methods

3.1.3.1 Fresh Concrete Properties

The slump and flow results actually achieved of the each concrete mixes for its workability.

A digital thermometer was used to determine the temperature of the fresh concrete.

3.1.3.2 Compressive Strength

The compressive strengths were determined on three 150x150x150 mm cubes from the concrete for each casting. Moulds were removed 1 day after casting. Then water curing was applied at a temperature of 20 ± 2 C° and testing of the cubes at the age of 28 days, in accordance with BS EN 12390-3. Specimens are loaded to failure in compression testing machine conforming to EN 12390-4. The maximum load sustained by the specimen is recorded and the compressive strength of the concrete is calculated.



Figure 3.4 Compressive strength device

3.1.3.3 Wenner Probe Resistivity

Resistivity test was performed. Cylinder (100x200 mm) specimens were cut with the specified diameter used for the test at the age of 28 days. The electrical resistivity measurements were taken three times for each specimen. Average of the three readings was used for each specimen as the result.



Figure 3.5 Device of resistivity test



Figure 3.6 Resistivity test for cylinder specimen

3.1.3.4 Chloride Migration

Chloride ion migration test was performed according to the Nordic Test Method Build 492, Chloride Migration Coefficient from Non-Steady-State Migration Experiments. This procedure is for determination of the chloride migration coefficient in concrete, mortar or cement-based repair materials from non-steady-state migration experiments. The method requires cylindrical specimens with a diameter of 100 mm and a thickness of 50 mm, sliced from cast cylinders or drilled cores with a minimum length of 100

mm. The cylinders and cores should meet the requirements described in NT BUILD 201 and NT BUILD 202 respectively.

The rapid chloride migration test is based on the forced ionic migration induced by the external electrical voltage applied across the Ca(OH)₂ saturated concrete specimen. Due to the potential difference between the electrodes, chloride ions migrate from the upstream NaCl solution, through the concrete specimen, towards the downstream NaOH solution, for a certain time. Afterwards, the specimen is split open and sprayed with AgNO₃ an indicator for chlorides. Chloride penetration depth is measured from three specimens and based on this value the D_{nssm} is calculated as follow:

$$D_{nssm} = \frac{RT}{zFE} \cdot \frac{x_d - \alpha\sqrt{x_d}}{t}$$

where:

$$E = \frac{U - 2}{L}$$

$$\alpha = 2 \sqrt{\frac{RT}{zFE}} \cdot \text{erf}^{-1} \left(1 - \frac{2c_d}{c_0} \right)$$

D_{nssm} : non-steady-state migration coefficient, m²/s;

z : absolute value of ion valence, for chloride, $z = 1$;

F : Faraday constant, $F = 9.648 \times 10^4$ J/(V·mol);

U : absolute value of the applied voltage, V;

R : gas constant, $R = 8.314$ J/(K·mol);

T : average value of the initial and final temperatures in the anolyte solution, K;

L : thickness of the specimen, m;

x_d : average value of the penetration depths, m;

t : test duration, seconds;

erf^{-1} : inverse of error function;

c_d : chloride concentration at which the colour changes, $c_d \approx 0.07 \text{ N}$

c_0 : chloride concentration in the catholyte solution, $c_0 \approx 2 \text{ N}$.

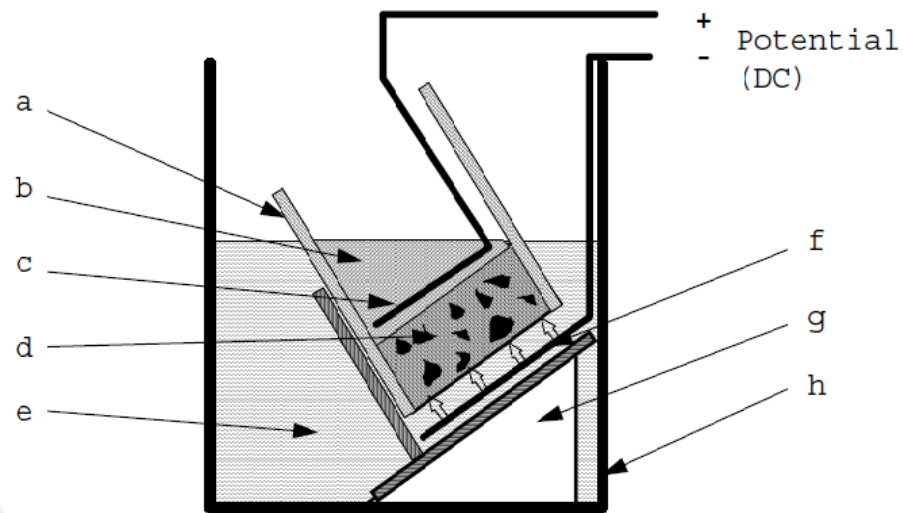


Figure 3.7 One arrangement of the migration set-up

a. Rubber sleeve

b. Anolyte

c. Anode

d. Specimen

e. Catholyte

f. Cathode

g. Plastic Support

h. Plastic box



Figure 3.8 Preparation of specimens for the test



Figure 3.9 Preparation for giving a start to the test



Figure 3.10 Temperature of water on the specimen



Figure 3.11 Test devices



Figure 3.12 Half slice of specimen after completion of the test and red line shows penetration depth of chloride-ions

3.1.3.5 Water Penetration Depth under Pressure

The water penetration test was performed in accordance with BS EN-12390-8. This European Standard specifies a method for determining the depth of penetration of water under pressure in hardened concrete which has been water cured. In this test, 150x150x150 mm concrete cubes, after 28 days of water curing, were dried under laboratory conditions for 24 h. Water was applied on one face of the specimen under a pressure of 0.5 MPa. This pressure was maintained constant for a period of 72 h. After the completion of the test, the specimens were taken out and split open into two halves.

The water penetration profile on the concrete surface was then marked and the maximum depth of water penetration in three specimens was recorded and considered as an indicator of the water penetration.



Figure 3.13 Pressured water permeability test device

3.2 Results and Discussion

3.2.1 Fresh Concrete Properties

Slump values for each type of source are given in Figure 3.14. According to the results slump values of limestone concrete are higher than the sandstone concretes. It may be related with characterization of aggregate especially mineralogical properties of aggregates. Furthermore, increase in fines content has negative effect on slump value for sandstone concrete. Katz [5] stated increasing the fines content increased the amount of HRWR needed to maintain a constant slump. Workability of concrete produced with limestone (CPL) can be controlled with the increment of superplasticizer (SP) dosage. However increases of SP dosage in high percentage for CPS do not meet targeted workability.

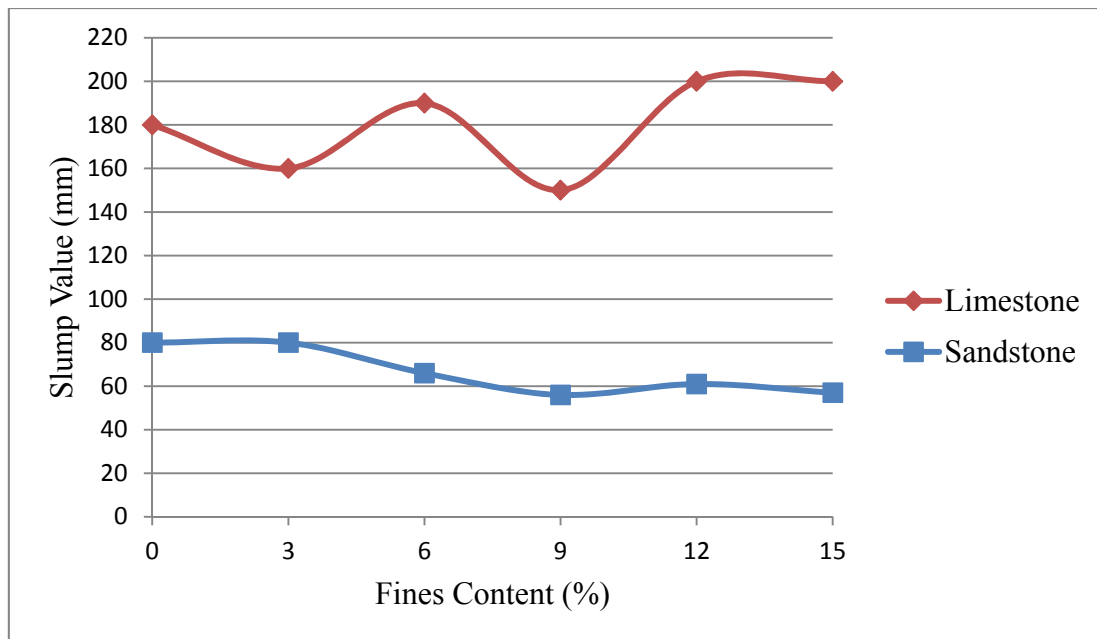


Figure 3.14 Fines content effects on slump values for limestone and sandstone

Comprehensive aggregate characterization tests were performed to explain differences of fresh concrete properties of CPL and CPS. Figure 3.15 shows the differences on fresh state for both CPL and CPS with regard to slump value and SP demand.

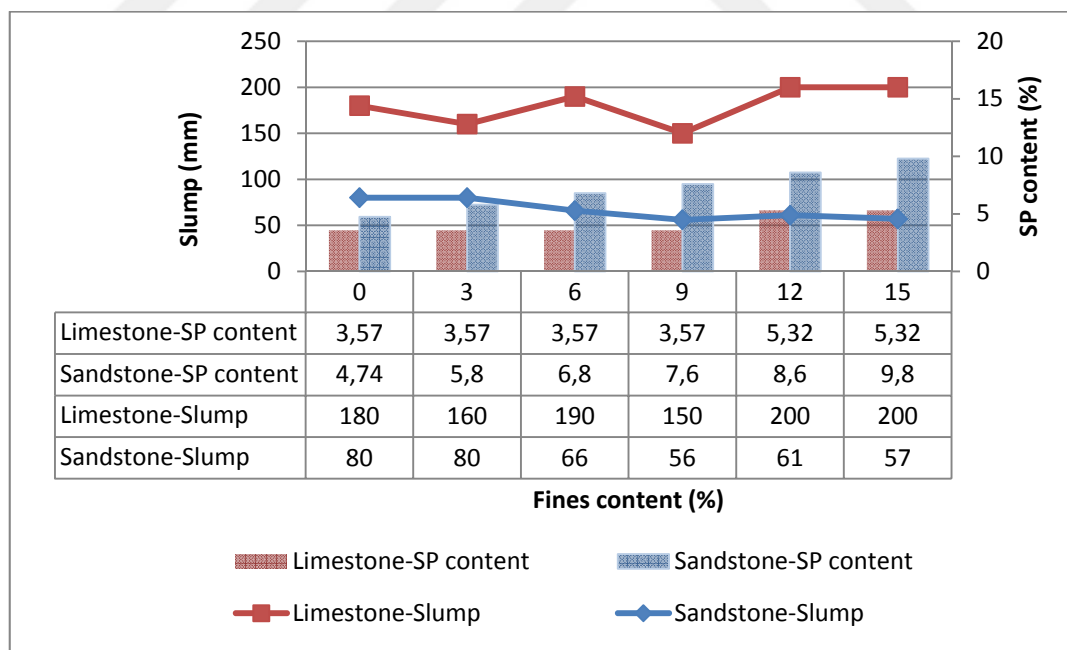


Figure 3.15 Slump value and SP content for various fines content

SP was used in concrete mix design to keep constant slump value. As shown in Figure 3.15, increases of fines content do not affect workability of CPL up to 9%. However,

finer content from 9% to 15% requires more SP content to keep same workability. Even though by adding more SP for the CPS, slump values are less than CPS for all finer content series. Moreover, increment of finer content from 0% to 15% requires more SP content. These huge discrepancies for using SP content are related with petrography, morphology, PSD and MBV.

Table 3.7 gives minerals contents of each types of aggregates base on petrography analysis. Sandstone aggregates includes huge amount of quartz and quartz-rich sandstone. Also roundness of quartz and quartz-rich sandstone are not good enough. This effects workability of CPS negatively. Moreover, sandstone contains considerable amount of chlorite. Chlorite minerals were developed in the clay fraction of the sandstone. Clay portions are playing an important role on fresh concrete properties. However, according to the petrography analysis, limestone contains 100% calcite and free form clay minerals.

Table 3.7 Minerals content of aggregates

Aggregates	Minerals				
	Quartz	Feldspar	Chlorite	Muscovite	Calcite
Limestone	-	-	-	-	100%
Sandstone	75%-80%	5%	10%-12%	5%	-

Besides petrography analysis, fresh concrete properties are assessed based on morphology. Circularity, convexity, elongation and intensity mean are the most important shape factors to affecting workability of concrete.

Table 3.8 presents circularity percentages for very fine aggregate fractions of sandstone and limestone. According to the analysis performed for four different fractions, limestone is more circular than sandstone. In addition to this, the fraction of the fines below 2 μm shows a substantial decrease in circularity value of sandstone. Because of this reason, concrete mixtures such very fine aggregate showed poor workability even at increased SP dosages. However, for the range between 0-2 μm and 2-63 μm , increases of finer content increase circularity value of limestone. This affects workability of concrete positively.

Table 3.8 Circularity value of 1 percentage of both aggregates

Test Range	Sandstone	Limestone
0-2 μm	18,47%	59,24%
0-63 μm	34,42%	47,23%
2-63 μm	38,50%	40,98%
0,125-1 mm	53,40%	69,77%

Table 3.9 shows the convexity percentage of limestone and sandstone for the fractions of 0-63 μm , 0-2 μm , 2-63 μm and 0,125-1mm. According to Table 4.3 particles of both samples are very smooth and have regular shape. However, for all range limestone sample have convexity value of 1 more than sandstone sample. It means limestone particles seem to be smoother than sandstone particles and limestone shape is more regular than sandstone. This result explains that workability and compactability of CPL is better than CPS. It directly affects SP content of design.

Table 3.9 Convexity value of 1 percentage of both aggregates

Test Range	Sandstone	Limestone
0-2 μm	77,88%	90,13%
0-63 μm	85,22%	89,11%
2-63 μm	87,13%	88,57%
0,125-1 mm	94,61%	97,85%

Table 3.10 gives the elongation value of sandstone and limestone for all range. Elongation parameters for both samples within specified range do not show very important differences. However, elongation parameter of limestone is lower than sandstone for each range. It means limestone particles have more regular shape and low aspects ratios than sandstone particles. Furthermore, increment of fines content below 63 μm decrease elongation value of aggregates for limestone particles in contrast to sandstone. These results clearly show that workability, pumpability and compactability of CPL is better than CPS. Moreover, increases of fines content have positive effect on fresh concrete properties of CPL in contrast to CPS.

Intensity mean value of sandstone and limestone with specified range in below table is given in Table 3.11. According to the results intensity mean value for sandstone is higher than limestone. The reason of these results is that sandstone comprises chlorite. Chlorite generally occurs as the alteration products of other minerals especially as green

schist. Consequently sandstone which has higher intensity mean, requires more water and SP content.

Table 3.10 Elongation value 1 percentage of both aggregates

Test Range	Sandstone	Elongation Value	Limestone	Elongation Value
0-2 μm	19,59%	0,5	26,12%	0,2
0-63 μm	21,90%	0,4	22,52%	0,3
2-63 μm	22,50%	0,4	22,60	0,3
0,125-1 mm	21,21%	0,3	25,14	0,3

Table 3.11 Intensity mean value of both aggregates

Test Range	Sandstone	Intensity Mean Value	Limestone	Intensity Mean Value
0-2 μm	54,91%	110	26,60%	100
0-63 μm	16,84%	100	24,23%	60
2-63 μm	17,66%	80	36,83%	60
0,125-1 mm	26,02%	100	29,52%	100

Figure 3.16 shows the deleterious content of sandstone and limestone with various fines content by MBV. Increment of fines content for CPL does not have any harmful effect of fresh concrete properties. However, MBV increases by increment of fines content for CPS. It directly affects fresh state properties of concrete. Increment of MBV requires more water and SP content to keep target slump value and workability. It means higher sandstone fines content negatively affects workability of concrete even it was substantially increased SP dosages.

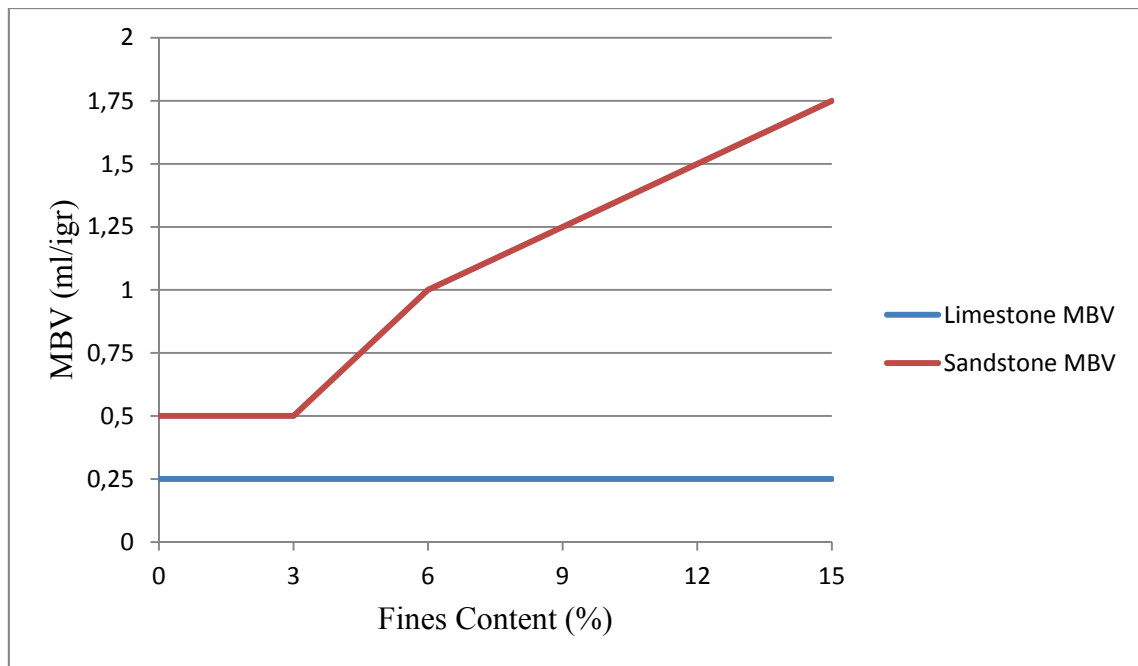


Figure 3.16 MBV for various fines content

According to BET analysis result in chapter 2, sandstone has much larger pore surface area and pore volume than the limestone sample. CPS requires more water or SP content to reach close workability condition with CLP due to sandstone's larger surface area.

3.2.2 Compressive Strength

Figure 3.17 presents the mechanical strength results of CPL and CPS incorporating fines content increment. According to the results low water-cement ratio slag cement concrete tends to suppress the positive effect of the fines on compressive strength observed in that of high water-cement ratio. Compressive strength CPS slightly decreases with the addition of fines.

The compressive strength differences between CPL and sandstone are meaningful. Even w/c is constant some reduction was observed for the sandstone concrete. As it can be seen in Figure 3.17 compressive strength results of CPS are lower. Aggregate characterizations may cause this result.

The results show that fine content increment does not have significant effect on concrete strength. Ramezaniapour [51] stated that up to 10% limestone replacement is not significant in this reduction.

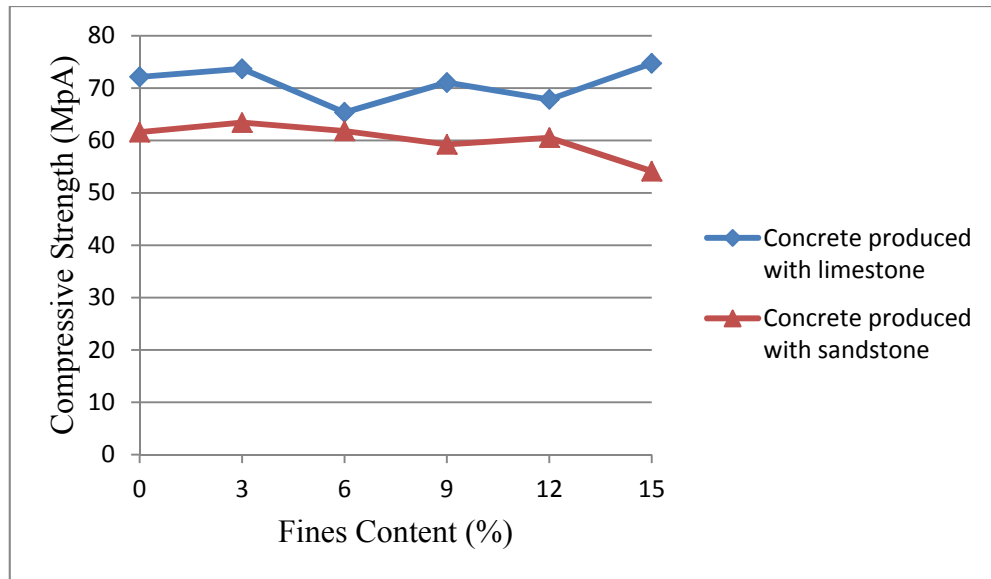


Figure 3.17 Compressive strength results for CPL and CPS with various fines content increments

3.2.3 Wenner Probe Resistivity

The resistivity only appraises the available porosity which is equivalent to the effective diffusion coefficient. The concrete resistivity is a parameter that is related to the reinforcement corrosion and seems also very appropriate to represent concrete resistance against chloride ingress. However, it has to be taken into account that resistivity only informs on the available space in the solid material. The results obtained from resistivity measurements are illustrated in Figure 3.18. A significant change was not observed in measured values for relatively low fines contents. However, same differences with compressive strength results were observed. Wenner probe resistivity for limestone concrete is higher. Because, CPL has lower pore structure than CPS.

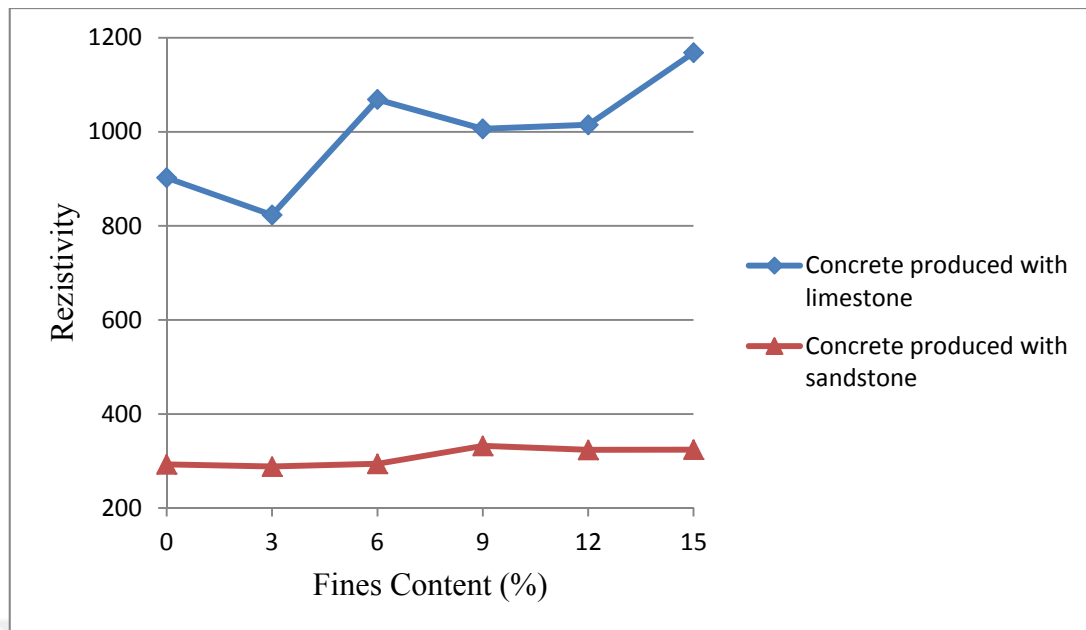


Figure 3.18 Electrical resistivity results for limestone and sandstone increment

3.2.4 Chloride Migration Resistance

Figure 3.19 shows the chloride migration coefficient for each type of concrete with different fines content. For the CPL, significant decreases were observed with the addition of fines content. Chloride migration coefficient is 2.29 for 0% fines content whereas it decreased 1.27 for 15% fines content addition.

For the CPS an important decrease shown in results up to 9% fines content. However more fines content effects chloride migration coefficient negatively for CPS.

Furthermore chloride migration coefficient for CPL much lower than CPS with the same fines content. This result is linked to EC values of sandstone and limestone aggregates. EC value of limestone aggregate is 71 whereas 118 for sandstone aggregate. Because of lower EC value chloride migration coefficient of CPL is lower than CPS.

According to the comparison of results for each type of aggregate, chloride migration resistance is definitely different. This difference is related with electrical resistance and aggregate characteristic. Limestone concrete shows significant resistance to chloride-ion ingress.

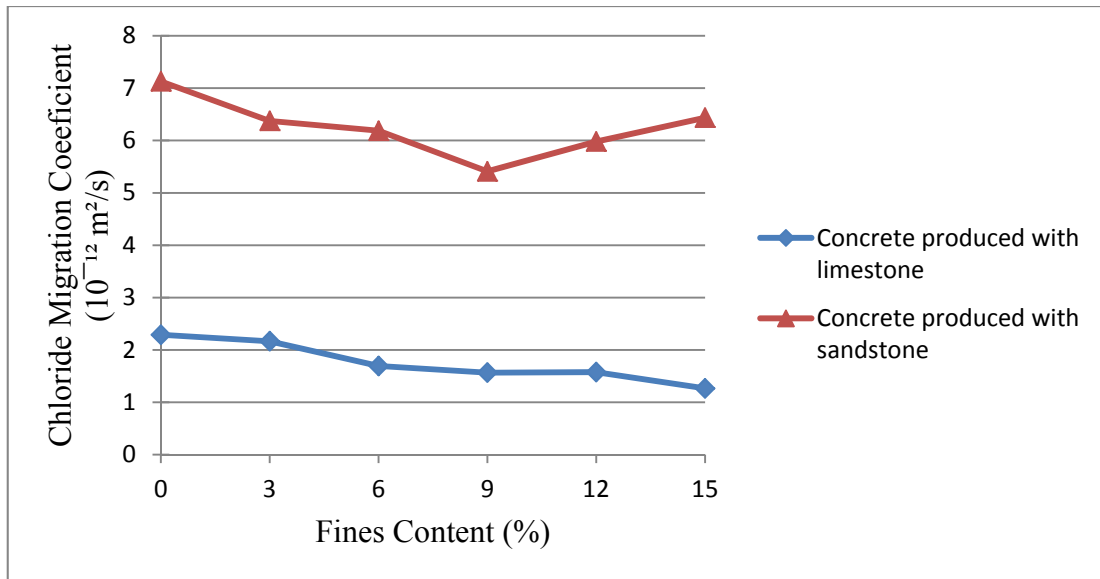


Figure 3.19 Chloride migration co-efficient for limestone and sandstone with various fines content increment

Figure 3.20 shows the relationship between chloride migration coefficient and Wenner probe resistivity values. It is easily observed that the determinant parameter in both performance criteria is the origin of aggregate. However, it is also an indicated situation there is a meaningful transition between CPL and CPS by the effects of fines content. Chloride migration coefficient for CPL significantly decreases relevant with resistivity values. Also there is a slightly decreases observed for CPS by the increment of fines content and resistivity value. This reduction has a significant sense of correlation between chloride migration coefficient and resistivity value. This finding strongly implies that high amount of fines (137 kg) in manufactured sand functions as a decent pore filling powder material phase that significantly close the gap in performance [52].

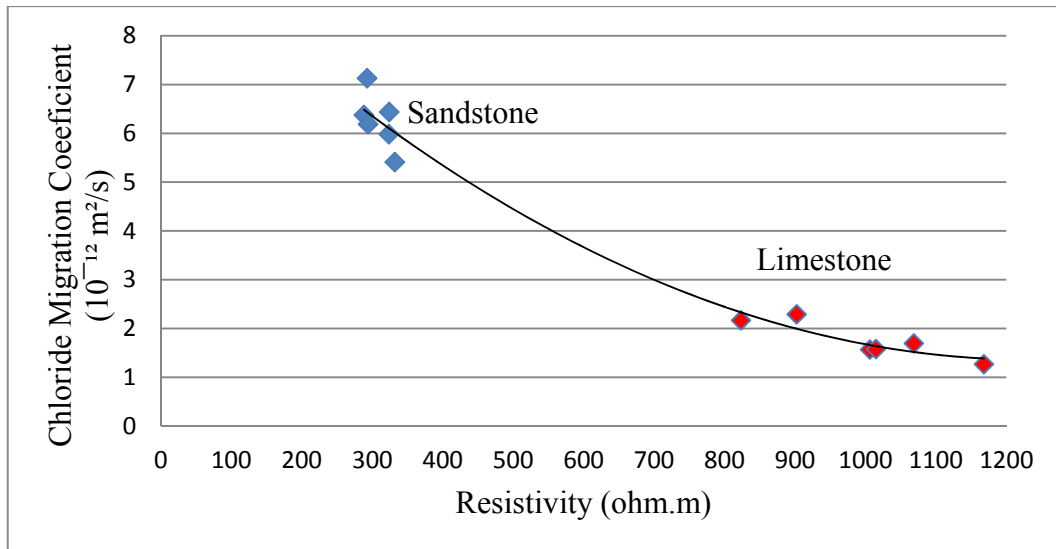


Figure 3.20 Compilation of data demonstrating the correlation between chloride migration coefficient and Wenner probe resistivity measurements

3.2.5 Water Penetration Depth under Pressure

Figure 3.21 explains the comparison of water penetration depth between the concretes produced with limestone (CPL) and sandstone (CPS). Depth of water slightly decreases with the addition of fines content up to 15% for limestone. Similar decreases were observed for the sandstone concrete up to 7% fines content. However, after 7% fines content a significant increase was observed. It can be concluded that sandstone fines does not have adversely effect on concrete up to 7% fines content. Limestone fines content improved concrete properties against water ingress under pressure.

On the other hand, as shown in Figure 3.21 CPL is superior to the CPS. These results are in similar with the other test result. All these results prove that very fine aggregate characteristics have a big impact on concrete durability performance. Even cement content and w/c ratio kept in constant, durability performance is different for limestone and sandstone. The most important proof is about the impact of aggregate characteristics.

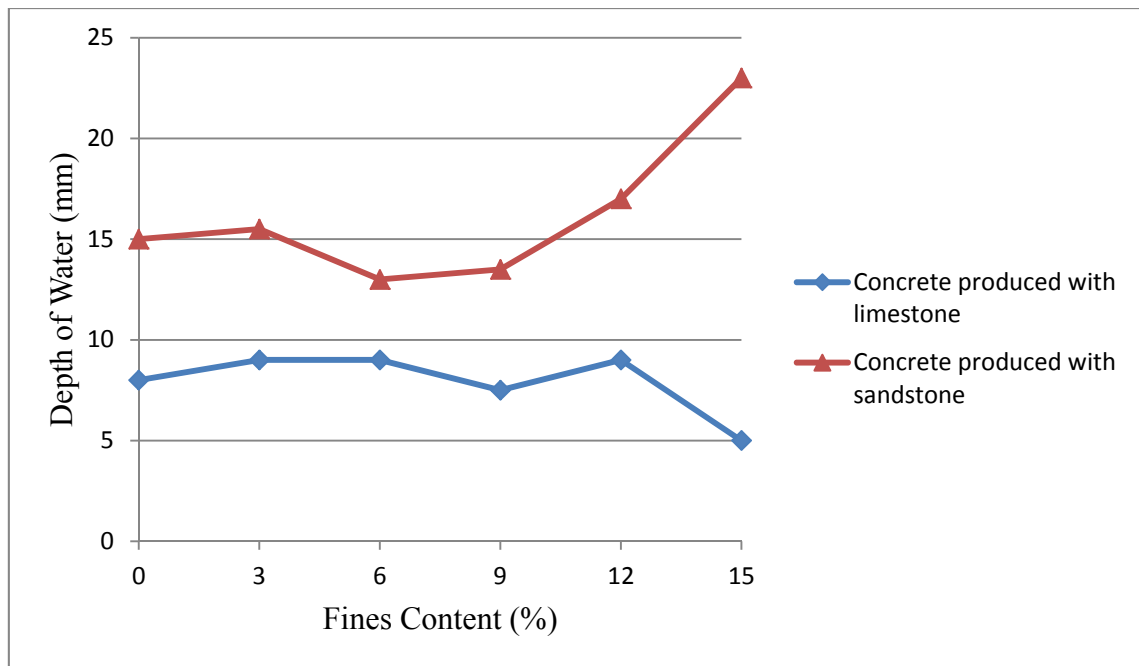


Figure 3.21 Depth of water penetration for CPL and CPS with various fines content increment

CONCLUSION

This experimental study was carried out in order to better understand the influence of aggregate characteristics on fresh state properties and durability performance of slag cement concrete produced with limestone sand or sandstone sand. According to the results, the following conclusions have been highlighted;

- Fines content between 9% to 15% did not affect fresh state properties of the concrete produced with limestone sand. In contrast to this implication, fines content increases for concrete produced with sandstone sand absolutely increase water demand and affect fresh state properties negatively. Because of this, concrete mix design required more SP dosage. Aggregate characterization section supports this inference. Limestone samples were better shaped, smooth and rounded than sandstone samples. This situation will positively contribute to the SP dosage of concrete as it lowers the water demand. In addition to this, sandstone samples had more elongated particles, higher rate of harmful materials content and higher pore surface area.
- Fines content up to 15% for limestone sand can be used in concrete without adversely affecting on compressive strength. However, slightly reduction was observed with the increment of fines content from 6% to 15% percentage for concrete produced with sandstone. As a result the compressive strength was not apparently dependent on fines content of crushed sand. On the other hand, concrete containing crushed sand taken from limestone quarry will result a higher compressive strength than that containing sandstone. Increase of well-shaped particles, thereby reducing the voids in the concrete and as a result its compressive strength will rise.

- Chloride-ion ingress has a reduction trend with the increment of fines content for concrete produced with limestone. Similar reduction was observed for concrete produced with sandstone sands up to 9% fines content. More fines content has an adverse effect on chloride migration resistance for CPS. Another inference is chloride-ion ingress performance of CPL is better than CPS. Chloride migration coefficients of concretes are linked to EC values of aggregates. Chloride migration coefficient of CPL is lower due to limestone sand has lower EC value than sandstone sand.
- Similar results with the chloride migration tests were observed for depth of water penetration under pressure test.
- Resistivity values are in good correlation with the chloride migration coefficient. Wenner probe resistivity values increases with the reduction of chloride migration coefficient. There is meaningful relation EC value, electrical resistivity value and chloride migration coefficient.
- Clay content, as indicated by the methylene blue value test, affects the concrete properties, but the microfines material percentage does not relate to the clay content.

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