THE CORRELATION BETWEEN AGGREGATE SHAPE AND COMPRRESSIVE STRENGTH OF CONCRETE: DIGITAL IMAGE PROCESSING APPROACH

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INTRODUCTION

Since up to approximately 80% of the total volume of concrete consists of aggregate, aggregate characteristics significantly affect the performance of fresh and hardened concrete and have an impact on the cost of concrete (Hudson, 1999). The aggregates not only make concrete economical by occupying more volume, but also impart volume stability and increase durability. Also, the particle shape characteristics of the aggregate used can significantly affect the workability, strength, and durability of the concrete produced (Ozol, 1978; Kwan et al., 1999; Erdogan, 2005; Erdogan et al., 2006). The shape of aggregate particles can significantly influence certain properties of concrete, both in its fresh and hardened states (Jamkar and Rao, 2004). Also, the shape of aggregates used in concrete is an important parameter that helps determine many concrete properties, especially the rheology of fresh concrete and...
early-age mechanical properties (Erdogan, 2005; Erdogan et al., 2006).

Aggregates shape, texture and grading have a significant effect on the performance of fresh concrete. Aggregate mixture with well-shaped, rounded, and smooth particles require less paste for a given slump than mix with flat, elongated, angular, and rough particles. At the same time, uniform grading with proper amounts of each size result in aggregate mixture with high packing and in concrete with low water demand. Optimized aggregate mixtures have high packing, requiring low amounts of paste. As a result, they are less expensive and will have less durability problems caused by the paste such as heat generation, porosity, and drying shrinkage (Quiroga and Fowler, 2004).

Shape and texture of coarse aggregates apparently are not as important as shape and texture of fine aggregate, but they play a role on the behavior of fresh and hardened concrete. Shape and texture affect the demand for sand. Flaky, elongated, angular, and rough particles have high voids and require more sand to fill voids and to provide workable concrete, thus increasing the demand for water (Shergold, 1953; Kaplan, 1958; Murdock, 1960). Poorly shaped aggregates may also increase segregation (Quiroga and Fowler, 2004). Flaky and elongated particles tend to produce harsh mixtures and affect finishability. According to Shilstone (1990), flaky and elongated particles, particularly those of intermediate sizes (between 3/8 in. (9.5 mm), and No. 8 (2.36 mm)), can affect the mobility of mixtures and contribute to harshness. Additionally, research shows that there is a clear relationship between shape, texture, and grading of aggregates and the voids content of aggregates (De Larrard, 1999; Dewar, 1999). In fact, flaky, elongated, angular, and unfavorably graded particles lead to higher voids content than, cubical, rounded, and, well-graded particles (Quiroga and Fowler, 2004).

Particle shape is important to the suitability of the aggregates with respect to their usage in several engineering materials. Elongated particles compared to cubic particles have a tendency to break along their long axis. Thus particle form affects the strength of the aggregates and life expectancy of the materials such as concrete, asphalt, and railroad aggregate. Spherical particles result in good rheological character in contrast to platy particles that determine the rheological character of concrete paste. Aggregates with a rough surface compared to a smooth surface will bind more securely in both asphalt and concrete (Fernlund, 2005a). As mentioned above, the importance of the shape of aggregate particles on the performance of fresh concrete is also well recognized. However, a little of studies are focused on the effect of aggregate shape to the hardened concrete properties.

The strength and the stiffness of coarse aggregate directly influence the behavior of hardened concrete. Although in normal concrete, strength is controlled by the paste or by the transition zone between paste and aggregate, the strength of high-performance concrete depends not only on the strength but on the mineralogy of coarse aggregate as well (Alexander, 1989; Cetin, 1998; Ezelding, 1991). Shape of the aggregates contributes to the strength value of concrete. Comparing the strength value between angular and smooth
aggregates when slump is constant, there is no significant variation, as angular aggregates require more water than smooth aggregates. However, if w/c ratio and slump are kept constant with the use of admixture, there may be a reasonable increase in strength with the use angular aggregates.

Aggregate shape appears more and more as one of the key parameters characterizing the quality of aggregate, since it affects the properties of mixtures. When the proportion of flat particles in hydraulic concrete increases, the compression strength decreases, the cement consumption increases and the workability decreases (Frazao and Neto, 1984). Also, the British Standard (1984) allows no more than 35 to 40% of flat particles. Mehta and Monteiro (1993), state that flat and elongated particles should be limited to a maximum of 15% by weight of total aggregate. In general, it is preferable to have somewhat equidimensional rather than flat, thin, or elongated particles. The amount of flat and elongated particles in coarse aggregate samples can be determined following ASTM D 4791 (Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate), using a proportional caliper device. Manual measurements using a caliper device is a tiresome procedure that prohibits its use on a daily basis for quality control of aggregates on construction sites using concrete mixtures.

Alternative methods that permit rapid measurements of particle shape is also essential for good quality control of aggregates (Kuo et al., 1996). Furthermore, particle shape measurements have to be done in a manual way that is not both cumbersome and time-consuming. Herein, Digital Image Processing techniques (DIP) are used to analyze the particle shape characteristics of aggregate (Mora et al., 1998; Kwan et al., 1999; Mora and Kwan, 2000; Kuo and Freeman, 2000; Masad et al., 2001; Al-Rousan et al., 2007).

In recent years, DIP techniques have been found widespread applications in many disciplines, including medicine, biology, geography, meteorology, manufacturing, and material science. Relatively, there have been a few applications of DIP in civil engineering. Several researchers had also investigated the role of aggregate shape in concrete mixture (Erdogan, 2005). Imaging technology has been used recently to quantify aggregate shape characteristics. Some studies have focused on characterizing the 3D shape of aggregates in concrete (Garboczi, 2002; Garboczi and Bullard, 2004; Fernlund, 2005a; Fernlund, 2005b; Erdogan et al., 2006). Others have investigated the determination of shape properties of aggregate (Kwan et al., 1999; Mora and Kwan, 2000) and grain size distribution (Fernlund, 1998; Mora et al., 1998; Fernlund et al., 2007). Also, others have been devoted to developing procedures to describe the shape of aggregates with an emphasis on elongation or form (Masad et al., 1999; Barksdale et al., 1991; Kuo et al., 1996; Brzezicki and Kasperkiewicz, 1999; Weingart and Prowell, 1999; Maerz and Zhou, 1999; Rao and Tutumluer, 2000), angularity (Yudhbir and Abedinzadeh, 1991; Li et al., 1993; Wilson and Klotz, 1996; Masad et al., 2000; Kuo and Freeman, 2000), and texture (Hryciw and Raschke, 1996; Wang and Lai, 1998; Masad and Button, 2000). However, little research has been done in order to finding correlation
between aggregate shape indexes and fresh and hardened concrete performance.

One major problem with the DIP technique is that only the two-dimensional projection of the particles is captured and measured. In other words, the third dimension (i.e., thickness) of the particles is not directly obtainable from the DIP results. Due to this problem, the DIP results have to be expressed in terms of area fractions rather than mass fractions (Yue and Morin, 1996). Consequently, they cannot be compared to those obtained by traditional methods and are more difficult to interpret. Also, there have been a few investigations on three-dimensional image analysis of aggregate (Kuo et al., 1996; Rao and Tutumluer, 2000). In addition, the each of three dimensions of an aggregate is important and should be determined for image analysis studies.

The present study was undertaken to investigate the effect of different type of coarse aggregate effect on the fresh and hardened Portland cement concrete behavior by a means of aggregate shape indexes such as aspect ratio, elongation, flatness, form factor, roundness, shape factor, and sphericity. The concrete produced with natural (uncrushed) river aggregate. Four different type of coarse aggregate was used. These aggregates were selected as flat, elongated, spherical and mixed shape. The shape properties were determined by digital image processing with two different views of aggregates. In this sense, the three dimensions of aggregate, the areas and perimeters of the views were determined. Test results were compared with previous studies and have been discussed.

AGGREGATE SHAPE PROPERTIES

Particle geometry can be fully expressed in terms of three independent properties: form, angularity (or roundness), and surface texture. Figure 1 shows a schematic diagram that illustrates the differences between these properties. Also, form, roundness and surface texture are essentially independent properties of shape because one can vary widely without necessarily affecting the other two properties (Barrett, 1980). Form, the first order property, reflects variations in the proportions of a particle. Angularity, the second order property, reflects variations at the corners, that is, variations superimposed on shape. Surface texture is used to describe the surface irregularity at a scale that is too small to affect the overall shape (Barrett, 1980; Masad, 2004).

Different researchers are using different shape indexes to describe the shape of aggregate particles and even different definitions for the same shape index. Barksdale et al. (1991) defined the flatness as the ratio of thickness to width and the elongation as the ratio of width to length while Kuo et al. (1996) defined the flatness as the ratio of width to thickness and the elongation as the ratio of length to width. They also used different definitions for the shape factor and sphericity. Besides, many researchers discussed the image analysis techniques used by most of the available imaging systems that utilize different mathematical procedures for the analysis of aggregate shape characteristics (Kuo and Freeman, 2000; Masad et al., 2005; Al-Rousan et al., 2007). These measurements have been explained in more detail below.
In this study, for the first order of shape, form, the imaging index proposed is: shape factor, aspect ratio, sphericity, flatness, and elongation are measured for each aggregate particle. To properly characterize the form of an aggregate particle, information about three dimensions of the particle is necessary (longest dimension \([L]\), intermediate dimension \([I]\) and shortest dimension \([S]\)). For the second order of shape, roundness, the imaging index proposed is: roundness is measured for each aggregate particle. It is also clear that form factor reflects changes in aggregate form, roundness, and surface texture (Kuo and Freeman, 2000).

**Shape Factor**: Shape factor is defined as

\[
\text{Shape Factor} = \frac{S}{\sqrt{IL}}
\]

(Kuo et al., 1996; Masad et al., 2001) ...(1)

**Aspect Ratio**: Aspect ratio is defined as

\[
\text{Aspect Ratio} = \frac{L}{I}
\]

(Kuo and Freeman, 2000) ... (2)

**Sphericity**: Sphericity is among a number of indices that have been proposed for measuring the form in terms of the three dimensions.

\[
\text{Sphericity} = 3\frac{\sqrt{\frac{L}{2} S}}{L}
\]

(Krumbein, 1941; Barrett, 1980; Kuo et al., 1996; Masad et al., 2001; Masad, 2004; Al-Rousan et al., 2007)...(3)

**Flatness**: Flatness is defined as

\[
\text{Flatness} = \frac{S}{I}
\]

(Masad, 2004) ...(4)

**Elongation**: Elongation is defined as

\[
\text{Elongation} = \frac{I}{L}
\]

(Masad, 2004) ... (5)

**Roundness**: This is a shape factor that has a minimum value of 1 for a circle and larger values for shapes having a higher ratio of perimeter to area, longer or thinner shapes, or objects having rough edges. For the image analysis system used in this study, Roundness is defined as:

\[
\text{Roundness} = \frac{p^2}{4\pi A}
\]

(Kuo et al., 1996; Al-Rousan et al., 2007) ...(6)

**Form Factor**: Several parameters based on object dimensions have been proposed in the literature to measure different aspects of aggregate shape. Form factor compares the perimeter of an equivalent circle to the
perimeter of the particle. An equivalent circle has the same area as the particle. Because angularity and texture influence the perimeter of a particle, it follows that form factor not only is influenced by particle form but also reflects angularity and texture as well (Masad et al., 2001). Form factor has been used to describe surface irregularity and is defined as:

$$Form\cdot Factor = \frac{4 \cdot \pi \cdot A}{P^2}$$

(Kuo and Freeman, 2000; Masad and Button, 2000; Masad et al., 2001) ...(7)

Furthermore, quantification of form requires the measurement of the length, breadth and thickness of a particle. A number of different identifications have been used historically. Most previous authors have firstly identified the L dimension, defined as the maximum caliper dimension, and have then measured the I and S dimensions orthogonal to L (Blott and Pye, 2008). Zingg (1935) was indicated that the particles classified four base classes as mentioned in Figure 2a with using above measurement system. Also, Sneed and Folk (1958) consider Zingg’s diagram to be inadequate in that it contained only four form classes which divided the field of form variation very unequally. They suggested that only three end-members limit the system of dimensional variation: a prolate spheroid with one long axis and two short ones (L > I = S), an oblate spheroid with two long axes and one short one (L = I > S), and a sphere with all axes equal (L = I = S). A number of different notations have been used historically to refer to these three classes, including, stengelig, flach and kugeligand (Zingg, 1935), rod, disk and cube (Krumbein, 1941), columnar, flat and spherical (Blott and Pye, 2008). Sneed and Folk (1958)’s three classes are also used in this study with different notation as elongated, flat, and spherical, respectively (Figure 2b).

**MATERIALS AND METHODS**

In the study, ASTM Type I Portland cement (CEM I 42.5 R) a product of Limak Cement Plant, Ankara, Turkey and tap water were used for all mixtures throughout the study. Physical properties and chemical composition of
Portland cement are shown in Tables 1 and 2, respectively. The cement content was not varied as 500 kg/m$^3$ for a constant all specimens. Super plasticizer (SP)-Glenium 303 produced from BASF was used in tests. Properties of SP are shown in Table 3.

<table>
<thead>
<tr>
<th>Table 1: Physical Properties of Portland Cement</th>
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<tbody>
<tr>
<td><strong>CEM I 42.5 (Ordinary Portland Cement)</strong></td>
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<tr>
<td><strong>Results</strong></td>
</tr>
<tr>
<td><strong>CEM I 42.5 (Ordinary Portland Cement)</strong></td>
</tr>
<tr>
<td><strong>(min)</strong></td>
</tr>
<tr>
<td>2 days Compressive Strength, (N/mm$^2$)</td>
</tr>
<tr>
<td>7 days Compressive Strength, (N/ mm$^2$)</td>
</tr>
<tr>
<td>28 days Compressive Strength, ( N/mm$^2$)</td>
</tr>
<tr>
<td>Initial set time, (minute)</td>
</tr>
<tr>
<td>Final set time (minute)</td>
</tr>
<tr>
<td>Volume expansion, (mm)</td>
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<tr>
<td>Specific surface, (cm$^2$/gr)</td>
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<tr>
<td>Specific gravity</td>
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</tbody>
</table>

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<tr>
<th>Table 2: Chemical Properties of Portland Cement</th>
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<tbody>
<tr>
<td><strong>Results</strong></td>
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<tr>
<td><strong>Heating loss (%)</strong></td>
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<tr>
<td><strong>Insoluble matter (%)</strong></td>
</tr>
<tr>
<td><strong>Cl$_2$ (%)</strong></td>
</tr>
<tr>
<td><strong>SiO$_2$ (%)</strong></td>
</tr>
<tr>
<td><strong>Al$_2$O$_3$ (%)</strong></td>
</tr>
<tr>
<td><strong>Fe$_2$O$_3$ (%)</strong></td>
</tr>
<tr>
<td><strong>CaO (%)</strong></td>
</tr>
<tr>
<td><strong>MgO (%)</strong></td>
</tr>
<tr>
<td><strong>SO$_4$ (%)</strong></td>
</tr>
<tr>
<td><strong>Main constituent (%)</strong></td>
</tr>
<tr>
<td><strong>C$_3$S</strong></td>
</tr>
<tr>
<td><strong>C$_2$S</strong></td>
</tr>
<tr>
<td><strong>C$_3$A</strong></td>
</tr>
<tr>
<td><strong>C$_4$AF</strong></td>
</tr>
<tr>
<td>Material Structure</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Color</td>
</tr>
<tr>
<td>Specific gravity (g/cm³)</td>
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<tr>
<td>The chlorine content % (EN 480-10)</td>
</tr>
<tr>
<td>Alkali content % (EN 480-12)</td>
</tr>
</tbody>
</table>

*Note: +20 °C, relative humidity of 50% was obtained.

Natural river aggregate was used as the aggregate material. The maximum size of coarse aggregate was 16 mm. The particle size distribution of aggregates in the study is 30% for 0-2 mm, 15% for 2-4 mm, 20% for 4-8 mm and 35% for 8-16 mm (Figure 3). The saturated surface dry specific weights of aggregates used in the study, 2.56 for 0-2 mm, 2.60 for 2-4 mm, 2.61 for 4-8 mm and 2.62 for 8-16 mm, respectively. In this study, first size fractions in coarse aggregate were selected by hand as flat, elongated, and spherical as mentioned below. In addition, a control mixture containing all of aggregate shapes was prepared. So, four different aggregate mixture types were selected by a means of shape properties. For the imaging process, four aggregate fractions were analyzed as flat, elongated, spherical, and mixed for 16 to 8 mm in this study. Designation codes of the aggregate fractions are given in Table 4. The concrete mix proportions are given in Table 5. The same water-to-cement ratio for all mixtures was selected to be 0.30. Concrete mixtures have been made according to C 192/C 192M – 02.

For each mix, three specimens of 100 mm diameter and 200 mm height were prepared. After 1 day of moist curing, specimens from each mixture were cured in lime-saturated water at 23±1 °C until 28 days. The compressive strength tests were performed with ELE Autotest 3000 testing machine as defined in TS EN 12390-3. All the results are obtained 28 day specimens of each mix type and each result is from an average of three test specimens.

**Compressive Strength Test**

The compressive strength test was conducted according to ASTM C 39 “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.” In general, compressive strength was tested at ages of 28 days on three 10 cm × 20 cm cylinders. Before testing, the specimens were cured in a moisture room at 100% humidity.
Table 4: Designation Codes of the Aggregate Fractions

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Aggregate Type</th>
<th>Aggregate Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>Natural Aggregate (16 to 8 mm)</td>
<td>Flat</td>
</tr>
<tr>
<td>M2</td>
<td></td>
<td>Elongate</td>
</tr>
<tr>
<td>M3</td>
<td></td>
<td>Spherical</td>
</tr>
<tr>
<td>M4</td>
<td></td>
<td>Mixed (Control)</td>
</tr>
</tbody>
</table>

Table 5: The Mixture Proportions for 1 m³ Concrete

<table>
<thead>
<tr>
<th>Materials</th>
<th>Flat Mixture (M1)</th>
<th>Elongated Mixture (M2)</th>
<th>Spherical Mixture (M3)</th>
<th>Control Mixture (M4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water/cement ratio</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Cement (kg)</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Water (kg)</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>SP agent (kg)</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Natural aggregate (0-2), kg</td>
<td>529</td>
<td>529</td>
<td>529</td>
<td>529</td>
</tr>
<tr>
<td>Natural aggregate (2-4), kg</td>
<td>264</td>
<td>264</td>
<td>264</td>
<td>264</td>
</tr>
<tr>
<td>Natural aggregate (4-8), kg</td>
<td>352</td>
<td>352</td>
<td>352</td>
<td>352</td>
</tr>
<tr>
<td>Natural aggregate (8-16), kg</td>
<td>619</td>
<td>617</td>
<td>618</td>
<td>622</td>
</tr>
</tbody>
</table>

Imaging System

The DIP system used by the authors is a Nikon D80 Camera and Micro 105 mm objective manufactured by Nikon. Figure 4 shows the setup of the system. Two planes, perpendicular to each other, were covered with a scaled paper and fixed together to form the base and the background planes for the image acquisition setup. Whenever taking a picture, a white cotton cloth was placed on the background to obtain better contrast between the aggregate and the background pixels. The tests were performed in a dark room. Four fluorescent light sources have been positioned on the base plane to make the borders of the aggregates more visible for digital measurements. The flashlight of the camera was not utilized during image acquisition.

Figure 5 shows 3-D views of two regularly shaped solids, a rectangular box. Clearly, both the top and front views of the solid are identical rectangles. Using a 2-D image analysis setup consisting of only top camera and capturing an image of each solid would not be effective in distinguishing the 3-D shapes of the solids (Rao and Tutumluer, 2000). In this study two images from top and front views were obtained by imaging system for capturing the each
length of aggregate (i.e., small, intermediate, and long) as showed in Figure 6. One image was obtained from top view and the other image was front view.

**Image Processing**

Digital-image processing consists of converting camera pictures into digital form and applying various mathematical procedures to extract relevant information from the picture. This section describes the image-analysis methods used to aggregate shape properties. The output of camera was a 3872-2592 pixel, 32-bit digital image of RGB color. The aggregate particles had to be identified prior to analysis. Image J was used as the image analysis program. Threshold gray intensity therefore had to be chosen. The gray intensity measured on a given point was compared to the threshold value. Then, the initial gray image was converted into a binary image in which the aggregate particles that have lower gray intensity than the threshold value were set to black while the background was set to white. Applying a global threshold value for all the image worked well only if the objects of interest (aggregate particles) had uniform interior gray level and rested upon a background of different, but uniform, gray level. This was made possible in this study by placing aggregate particles on white background. The original image (32-bit digital image of RGB) (1), 8-bit 256 gray scale image (2), 1-bit binary image (3) and output of Image J image analysis program (4) are shown in Figure 7.

**RESULTS AND DISCUSSION**

In the following sections, the effect of aggregate shape on the behavior of concrete mix by compressive strength has been presented. Also, correlation between the
aggregate shape properties and compressive strength of concrete has been presented. The findings of the experimental tests have been compared with other studies previous studies and discussed.

**Fresh and Hardened Concrete Results**

Compressive strength was conventionally evaluated the main properties of concrete. As a result from Figure 8 spherical aggregate mixture (M3) is the best mixture and flat aggregate mixture (M1) is the weakest mixture. Similarly, Neville (2010) indicated that flat particles produce lower compressive strength. These imply that blade (flat and elongated) and disk (flat) aggregates have low strength.

Fresh concrete unit weight depends on voids in concrete, workability, aggregate grading and aggregate type. As a result from Figure 9 the concrete that has been made with elongated aggregate had the minimum unit weight equivalent with 2.38 and after that the increasing in unit weight has been observed orderly from flat aggregate, spherical and control aggregates that are 2.39, 2.40 and 2.41 orderly.

Aggregates having more angularity and rough surface texture the mechanical bond between the aggregate surface and cement paste, by virtue of interlocking, influences the strength of concrete (Kaplan, 1959). The shape and texture of crushed sand particles could lead to improvements in the strength of concrete due to better interlocking between particles. However, angular fine aggregate produces mortar of lower workability than spherical sands for the same water content, or the same volume of cement paste.

Figure 8 shows that slump of concretes produced with spherical aggregates is more higher than slump of concretes produced with flat, elongated and mix type aggregates. By virtue of, the spherical aggregate surface area is less and because of less friction of spherical aggregates in concrete, workability is good than concretes produced with other aggregate types. Irregular shape and rougher texture of angular aggregate demand more water than spherical aggregated (Neville, 2010). The slump of concretes produced of mixture aggregates is more higher than the slump of concretes produced of flat and elongated aggregates because of that there were spherical aggregates in mixture. According to Shilstone (1990), particle shape has a major influence. Furthermore, mixes containing spherical and equi-dimensional particle sizes have better pumpability and finishability, and produce totally higher strengths and lower shrinkage than mixes containing flat and elongated particles.

Fresh concrete unit weight depends on voids in concrete, workability, aggregate grading and aggregate type. As a result from Figure 9 the concrete that has been made with elongated aggregate had the minimum unit weight equivalent with 2.38 and after that the increasing in unit weight has been observed orderly from flat aggregate, spherical and control aggregates that are 2.39, 2.40 and 2.41 orderly.

The effect of shape and texture of coarse aggregates on strength become significant in
the case of high strength concrete. In addition, shape and surface texture have more pronounced effect on flexural strength than compressive strength (Neville, 2003). Shilstone (1990) stated that well shaped aggregates are more desirable and produce consistent higher strengths than poorly shaped aggregates. The influence of shape and texture of coarse aggregate on the strength of concrete varies in magnitude and depends on the water-cement ratio of the mix.

The effect of shape and surface texture of 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. For these concretes, the hydrated cement paste and the transition zone around the aggregate are relatively weak. Consequently, the water/cement (w/c) ratio controls the mechanical properties of concrete for the same degree of hydration (Donza et al., 2002). In previous studies, it was found that the uncrushed aggregates need lower water than crushed aggregates and uncrushed aggregates cater higher strength in concrete of medium grade. Again uncrushed aggregates are cheaper than crushed aggregates in the market of developing country such as Turkey. So from the study (Sharmin et al., 2006), it can be concluded that uncrushed aggregates are appropriate for medium grade concrete for better performance in terms of strength and economy. Hence, in this study 40-50 MPa concrete mixtures and uncrushed aggregates were selected.

Particle Shape Analysis

Particle shape analysis was carried out in terms of some shape properties. The mean value and Standard Deviation (SD) for each shape properties of aggregates is listed in Table 6. The results showed that there exist distinct morphological characteristics for different particle shapes (i.e., flat, elongate, spherical, and mix).

**Correlation Between Shape Characteristics and Compression Strength**

In the following sections, the correlation between some shape properties of aggregate and compression strength of concrete are
presented in Figures 12, 13, 14, 15, 16 and 17. It can be seen in Figure 12 the positive ($R^2=0.82$) correlation among the shape factor and compressive strength. Increasing in shape factor amount has direct effect on compressive strength increasing. There is a positive correlation ($R=0.89$) between sphericity and compressive strength. It means that lower sphericity index resulted lower values of compressive strength (Figure 13). It can be seen in Figure 14, the best positive ($R^2=0.977$)
It can be seen in Figure 15 the positive (R=0.92) correlation among the shape factor and UPV amounts. Increasing in shape factor amount has direct effect on UPV. There is a positive correlation ($R^2=0.78$) between sphericity and UPV. It means that lower sphericity index resulted lower values of UPV and it is similar to the correlation between sphericity and compressive strength (Figure 16). It can be seen in Figure 17, the best positive ($R^2=0.998$) correlation has been existed among the form factor and UPV.

**CONCLUSION**

A study was undertaken to investigate the effect of different type of aggregates on the compressive strength of concrete by a means of aggregate shape indexes such as aspect ratio, elongation, flatness, form factor, roundness, shape factor, and sphericity. The concrete produced with natural aggregate and four different type of coarse aggregate was used in the tests. These aggregates were selected as flat, elongated, spherical and mixed shape. The shape properties were determined by digital image processing with two different views of aggregates. The following...
conclusions are made based on the test results and on the discussion presented in this study:

· The image analyzer was shown to be a useful tool for quantifying the morphological characteristics of coarse aggregate.

· The test results indicated that a strong correlation between the some shape indexes of aggregate and compressive strength of concrete.

· The particle shape factors were shown to be an adequate measure of the combined contribution of some particle shape factor such as flatness, elongation and sphericity to the compressive strength of an aggregate.

· Spherical particles were desirable for increased compressive strength, UPV, unit weight and slump values of concrete. The more nearly spherical the aggregate, the higher mentioned values.

It should also be pointed out that further studies on the aggregate shape properties with digital image processing are needed to make more reasonable judgments. Further studies will be subjected that the mechanical properties of concrete such as compressive strength can be predicted by using digital image processing.

REFERENCES


57. Weingart R L and Prowell B D (2001), “Flat and Elongated Aggregate Test: Can the VDG-40 Videograder Deliver the Needed Precision and Be Economically Viable.”.


