Int. J. Struct. & Civil Engg. Res. 2013

International Journal of Structural and Civil Engineering Research

ISSN 2319 – 6009 www.ijscer.com
Vol. 2, No. 3, August 2013

Research Paper

ALTERATION OF BASALT AND CALCAREOUS AGGREGATES' ROUNDNESS WITH DIFFERENT ABRASION METHODS

Seracettin Arasan[1]*, Suat Akbulut[1] and A Samet Hasiloglu[2]

*Corresponding author:**Seracettin Arasan,** ✉ arasan@atauni.edu.tr

In concrete and asphalt concrete, the shape (roundness) of aggregate particles has been related to durability, workability, shear resistance, tensile strength, stiffness, and fatigue response. The aggregates are constantly subjected to harsh environmental conditions and external forces including static and dynamic loads. As a result, these materials experience various levels of abrasion. Hence, alteration of aggregate roundness with different chemical and mechanical effects is important for engineers. In this research, 40 basalt and calcareous aggregate samples are prepared with different abrasion methods and the roundness of samples is determined using image analysis. As a result, calcareous aggregate is significantly affected from the abrasion methods but basalt aggregate is not.

Keywords: Roundness, Basalt aggregate, Calcareous aggregate, Abrasion, Image analysis

INTRODUCTION

The particle shape characteristics of the aggregate significantly affect the workability, strength, and durability of the concrete (Ozol, 1978; Kwan *et al.,* 1999; Erdogan, 2005; Erdogan *et al.*, 2006) and asphalt concrete (Kuo *et al.*, 1996; Masad *et al.*, 2001; Al-Rousan *et al.*, 2007;Oduroh *et al.*, 2000). Another important characteristic of aggregate that affects concrete properties is the resistance to degradation. Aggregates are exposed to impact and/or abrasion forces during plant operations and compaction. These forces might cause changes in aggregate size distribution leading to field produced mixes different from the laboratory designed ones (Wu *et al.*, 1998). The construction and traffic loading could also cause aggregate abrasion leading to the loss of aggregate angularity, which weakens the mix resistance to applied loads (Gatchalian *et al.* (2006; Enad and Masad, 2007).

In recent years, image analysis has been used in widespread applications in many

---

[1] Ataturk University, Department of Civil Engineering, Erzurum, Turkey.

[2] Ataturk University, Department of Computer Engineering, 25240 Erzurum, Turkey.

disciplines, such as medicine, biology, geography, meteorology, manufacturing, and material science. But, there have been relatively fewer applications of image analysis used in civil engineering. Imaging technology has been used recently to quantify aggregate shape characteristics and several researchers had investigated the role of aggregate shape in concrete and asphalt mixture (Erdogan, 2005; Masad *et al.*, 2001; Al-Rousan *et al.*, 2007; Masad and Button, 2000; Masad *et al.*, 2000; Masad *et al.*, 2005). Some of these studies have focused on characterizing the 3D shape of aggregates (Erdogan *et al.*, 2006; Garboczi, 2002; Garboczi and Bullard, 2004; Fernlund, 2005a; Fernlund, 2005b). 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; Mertens and Elsen, 2006). Also, others have been devoted to developing procedures to describe the shape of aggregates with an emphasis on elongation or form (Barksdale *et al.*, 1991; Rao and Tutumluer, 2000), angularity (Masad *et al.*, 2000; Yudhbir and Abedinzadeh, 1991; Kuo and Freeman, 2000), and texture (Masad and Button, 2000; Hryciw and Raschke, 1996).

As mentioned above, the importance of the roundness and resistance to degradation of aggregate particles on the performance of concrete and asphalt concrete is also well recognized. For this reason, the present study was undertaken to investigate the effect of different abrasion methods to the roundness of basalt and calcareous aggregates using image analysis.

ROUNDNESS OF AGGREGATE

Particle geometry can be fully expressed in terms of three independent properties: form roundness (or angularity), and surface texture. Form, roundness and surface texture are also essentially independent properties of shape because one of them can vary widely without necessarily affecting the other two properties (Barrett, 1980). Particle roundness relates to the relative rounding or angularity (sharpness) of corners and edges (Barrett, 1980; Masad, 2004; Blott and Pye, 2008; Wadell, 1932; Pryor, 1971; Pettijohn *et al.*, 1972).

Most authors proposed charts for determination of particle roundness (Rittenhouse, 1943; Krumbein and Sloss, 1963; Powers, 1953; Alshibli and Alsales, 2004; Powers, 1982). Previous studies had estimated roundness using visual comparison scales (Mackie, 1897; Dunn, 1911). One of the first attempts to quantify the roundness of particles was made by Wentworth (1919). He noted that roundness was dependent on the radius of curvature of the corners of a particle. Different researchers were also using different roundness indexes to describe the shape of particles and even different definitions for the same roundness index (Wadell, 1932; Powers, 1953; . Wentworth, 1922b; Wentworth, 1922c; Cox, 1927; Wadell, 1933; Wadell, 1935; Cailleux, 1947; Dobkins and Folk, 1970; Al-Rousan, 2004; Mitchell and Soga, 2005). Roundness is defined as (Cox, 1927):

$$R(Roundness) = \frac{4.\Pi.A}{P^2} \quad ...(1)$$

This is a shape factor that has a minimum value of 1 for a circle and lower values for shapes having a higher ratio of area (*A)* to perimeter (*P*), longer or thinner shapes, or objects having rough edges.

MATERIALS AND METHODS

Crushed basalt and calcareous aggregate were used in this study. The specific gravities of basalt and calcareous aggregates were found 2.90 and 2.62 according to ASTM D 854, respectively. The imaging system used by the authors consists of a Nikon D80 Camera and Micro 60 mm objective manufactured by Nikon. 100 particles were selected for each aggregate fraction and placed within the sample tray for capturing the images. The output of camera was a 3872-2592 pixel, 32-bit digital image of RGB color. The 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. Thresholding determines the outline of the aggregate particle in a captured image. Clearly, the particle should have a sharp contrast against the background to accurately delineate the actual boundaries. A threshold value of pixel gray level is typically specified, and the actual image is converted to a binary image. This binary image has only black or white (gray level 0 or 255) pixels to clearly identify the particle against its background. 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 particles on white background. After then, output data of ImageJ was transferred to Excel. The output data also contain area, perimeter, L, I, and S values of view of each aggregate in unit of millimeter, and quantity of aggregates. The other properties of used materials test procedures, imaging system and digital image processing steps were also detailed in previously researches of authors (Arasan *et al.,* 2011; Arasan *et al.,* 2011; Polat *et al.,* 2013).

Figure 1: Image Samples of Aggregates

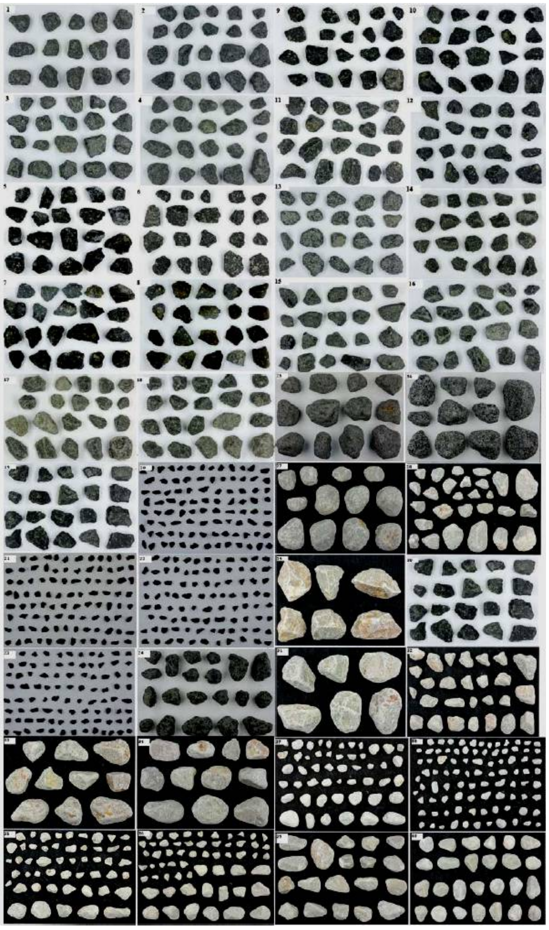

Table 1: Roundness Value and Class of Aggregate Samples				
No.	**Aggregate**	**Method**	**R**	**Class**
1	Basalt	Los Angeles Rattler Machine without steel balls-mixed gradation-number of revolution is 200.000	0,796	Sub Rounded
2	Basalt	Los Angeles Rattler Machine without steel balls-mixed gradation-number of revolution is 80.000	0,784	Sub Rounded
3	Basalt	Los Angeles Rattler Machine without steel balls-not mixed gradation-number of revolution is 3.000	0,670	Angular
4	Basalt	Los Angeles Rattler Machine without steel balls-not mixed gradation-number of revolution is 35.000	0,750	Sub Angular
5	Basalt	Treated with sulfuric acid	0,648	Very Angular
6	Basalt	Rotating with vertical concrete mixer (30 second)	0,666	Angular
7	Basalt	Treated with sulfuric and nitric acids	0,697	Angular
8	Basalt	Treated with nitric acid	0,703	Angular
9	Basalt	M Rotating with vertical concrete mixer (one hour)	0,761	Sub Rounded
10	Basalt	Treated with salt solution	0,682	Angular
11	Basalt	Los Angeles Rattler Machine without steel balls-mixed gradation and treated with salt solution-number of revolution is 6.000	0,653	Angular
12	Basalt	Los Angeles Rattler Machine without steel balls-not mixed gradation-number of revolution is 1.000	0,672	Angular
13	Basalt	Los Angeles Rattler Machine without steel balls-mixed gradation-number of revolution is 6.000	0,725	Sub Angular
14	Basalt	Los Angeles Rattler Machine without steel balls-mixed gradation-number of revolution is 30.000	0,688	Angular
15	Basalt	Los Angeles Rattler Machine with five steel balls-mixed gradation-number of revolution is 500	0,586	Very Angular
16	Basalt	Los Angeles Rattler Machine without steel balls-mixed gradation-number of revolution is 90.000	0,752	Sub Rounded
17	Basalt	Los Angeles Rattler Machine without steel balls-mixed gradation-number of revolution is 80.000	0,611	Angular
18	Basalt	Los Angeles Rattler Machine without steel balls-mixed gradation-number of revolution is 45.000	0,722	Sub Angular
19	Basalt	Raw Aggregates	0,664	Angular
20	Basalt	Los Angeles Rattler Machine with 50% abrasive balls-mixed gradation-number of revolution is 5.000	0,721	Sub Angular

Table 1 (Cont.)

No.	Aggregate	Method	R	Class
21	Basalt	Los Angeles Rattler Machine with 50% abrasive balls-mixed gradation-number of revolution is 33.000	0,735	Sub Angular
22	Basalt	Los Angeles Rattler Machine with 20% abrasive balls-mixed gradation-number of revolution is 20.000	0,745	Sub Angular
23	Basalt	Los Angeles Rattler Machine with 12% abrasive balls-mixed gradation-number of revolution is 50.000	0,755	Sub Rounded
24	Basalt	Los Angeles Rattler Machine with 50% bearing balls (bigger than aggregate)-mixed gradation-number of revolution is 5.000	0,782	Rounded
25	Basalt	Los Angeles Rattler Machine with 50% bearing balls (smaller than aggregate)-mixed gradation-number of revolution is 33.000	0,784	Rounded
26	Basalt	Los Angeles Rattler Machine with 50% bearing balls (smaller than aggregate)-mixed gradation-number of revolution is 40.000	0,772	Rounded
27	Calcareous	Los Angeles Rattler Machine with 50% bearing balls (smaller than aggregate)-mixed gradation-number of revolution is 13.000	0,852	Well Rounded
28	Calcareous	Los Angeles Rattler Machine without steel balls-mixed gradation-number of revolution is 13.000	0,793	Rounded
29	Calcareous	Raw Aggregates	0,725	Sub Angular
30	Basalt	Raw Aggregates	0,664	Angular
31	Calcareous	Los Angeles Rattler Machine without steel balls-not mixed gradation-number of revolution is 2.000	0,798	Rounded
32	Calcareous	Los Angeles Rattler Machine without steel balls-not mixed gradation-number of revolution is 35.000	0,784	Rounded
33	Calcareous	Los Angeles Rattler Machine without steel balls-two gradation-number of revolution is 13.000	0,782	Rounded
34	Calcareous	Los Angeles Rattler Machine without steel balls-two gradation-number of revolution is 40.000	0,818	Well Rounded
35	Calcareous	Los Angeles Rattler Machine without steel balls-aggregates are smaller than 10mm-number of revolution is 30.000	0,785	Rounded
36	Calcareous	Los Angeles Rattler Machine without steel balls-aggregates are smaller than 10mm-number of revolution is 50.000	0,798	Rounded
37	Calcareous	Los Angeles Rattler Machine without steel balls-aggregates are smaller than 10mm-number of revolution is 80.000	0,827	Well Rounded
38	Calcareous	Los Angeles Rattler Machine without steel balls-aggregates are smaller than 5mm-number of revolution is 30.000	0,825	Well Rounded
39	Calcareous	Los Angeles Rattler Machine without steel balls-consecutive two aggregates -number of revolution is 50.000	0,798	Rounded
40	Calcareous	Los Angeles Rattler Machine without steel balls-consecutive two aggregates -number of revolution is 100.000	0,848	Well Rounded

RESULTS AND CONCLUSION

Forty different methods were attempted to basalt and calcareous aggregates for alteration of aggregate roundness with different chemical and mechanical effects. The roundness of samples was determined using and image analysis Equation 1 as described previously. Additionally, the roundness classes of samples were determined by using modified Powers (1953) chart mentioned in Arasan (2011). The roundness values and classes of raw basalt and calcareous aggregates were 0.664, 0.725 and angular, sub-angular, respectively. The images of samples were given in Figure 1. The attempted methods were numbered and these numbers given in figures. It is seen from figures that the roundness of calcareous samples were significantly changed but basalt samples were not.

The samples roundness values, classes and description of applied methods were given in Table 1. Additionally, some significant conclusions were summarized below:

- The raw basalt aggregate had lower roundness value and more angular than calcareous aggregate.
- Sulfuric acid abraded the aggregates and the aggregates became more angular (Method 5).
- Nitric acid and salt solutions did not significantly affect aggregates (Method 7, 8 and 10).
- The sulfuric and nitric acids were melted calcareous aggregate. This result was not given in Table 1.
- If the aggregates (basalt and calcareous) were rotated in Los Angeles Rattler Machine with steel balls, the aggregates crushed and became smaller.
- If the aggregates (basalt and calcareous) were rotated in Los Angeles Rattler Machine without steel balls, the aggregates did not crush and became rounded.
- If the (basalt and calcareous) aggregates were rotated in Los Angeles Rattler Machine with abrasive or bearing balls, the aggregates became rounded.
- If the diameter of abrasive or bearing balls was bigger than aggregate diameter, the aggregates crushed and became smaller.
- The number of revolutions for Los Angeles Rattler Machine significantly affected the level of abrasion.
- The basalt aggregates were more resistant than calcareous aggregate when abrasion put into consideration.

REFERENCES

1. Ozol M A (1978), "Test and Properties of Concrete Aggregates: Chapter 35-Shape, surface texture, surface area, and coatings", STP169B-EB, pp. 584-628.
2. Kwan A K H, Mora C F and Chan H C (1999), "Particle shape analysis of coarse aggregate using digital image processing", *Cement and Concrete Research,* Vol. 29, pp. 1403-1410.
3. Erdogan S T (2005), "Determination of aggregate shape properties using X-ray tomographic methods and the effect of shape on concrete rheology", Ph.D. Dissertation, University of Texas at Austin.

4. Erdogan S T, Quiroga P N, Fowler D W, Saleh H A, Livingston R A, Garboczi E J, Ketcham, P M, Hagedorn J G and Satterfield S G (2006), “Three-dimensional shape analysis of coarse aggregates: New techniques for and preliminary results on several different coarse aggregates and reference rocks”, *Cement and Concrete Research,* Vol. 36, pp. 1619-1627.

5. Kuo C Y, Frost J D, Lai J S and Wang L B (1996), “Three-Dimensional Image Analysis of Aggregate Particles from Orthogonal Projections. Transportation Research Record 1526”, National Research Council , pp. 98-103, Washington DC.

6. Masad E, Olcott D, White T and Tashman L (2001), “Correlation of fine aggregate imaging shape indices with asphalt mixture performance”, Transportation Research Record 1757. Transportation Research Board, National Research Council, Washington DC, pp. 148–156.

7. Al-Rousan T, Masad E, Tutumluer E and Pan T (2007), “Evaluation of image analysis techniques for quantifying aggregate shape characteristics”, *Constr Build Mater,* Vol. 21, pp. 978–990.

8. Oduroh P K, Mahboub K C and Anderson R M (2000), “Flat and Elongated Aggregates in Superpave Regime”, *Journal of Materials in Civil Engineering*, Vol. 12, pp. 124–130.

9. Wu Y, Parker F and Kandhal P (1998), “Aggregate toughness/ abrasion resistance and durability/soundness tests related to asphalt concrete performance in pavements”, Transportation Research Record. 1638, Transportation Research Board, Washington, DC, pp. 85–93.

10. Gatchalian D, Masad E, Chowdhury A and Little D (2006), “Characterization of aggregate resistance to degradation in stone matrix asphalt mixtures”, Transportation Research Record. 1962, Transportation Research Board, Washington, DC, pp. 55–63.

11. Enad M and Masad E (2007), “Experimental Methods for the Evaluation of Aggregate Resistance to Polishing, Abrasion, and Breakage”, *Journal of Materials in Civil Engineering,* Vol. 19, No. 11, pp. 977-985.

12. Masad E and Button J (2000), “Unified imaging approach for measuring aggregate angularity and texture”, *Journal of Computer-Aided Civil and Infrastructure Engineering,* Vol. 15, No. 4, pp. 273-280.

13. Masad E, Button J and Papagiannakis T (2000), “Fine aggregate angularity: automated image analysis approach”, Transportation Research Record 1721, Transportation Research Board, National Research Council, Washington DC, pp. 66–72.

14. Masad E, Saadeh S, Rousan T A, Garboczi E and Little D (2005), “Computations of particle surface characteristics using optical and X-ray CT images”, *Computational Materials Science*, Vol. 34, pp. 406-424.

15. Garboczi E J (2002), “Three-dimensional

mathematical analysis of particle shape using X-ray tomography and spherical harmonics: Application to aggregates used in concrete", *Cement and Concrete Research,* Vol. 32, pp. 1621-1638.

16. Garboczi E J and Bullard J W (2004), "Shape analysis of reference cement", *Cement and Concrete Research,* Vol. 34, pp. 1933–1937.
17. Fernlund J M R (2005a), "Image analysis method for determining 3-D shape of coarse aggregate", *Cement and Concrete Research*, Vol. 35, pp. 1629-1637.
18. Fernlund J M R (2005b), "3-D image analysis size and shape method applied to the evaluation of the Los Angles test", *Engineering Geology,* Vol. 77, pp. 57-67.
19. Mora C F and Kwan A K H (2000), "Sphericity, Shape Factor, and Convexity Measurement of Coarse Aggregate for Concrete Using Digital Image Processing", *Cement and Concrete Research,* Vol. 30, No. 3, pp. 351-358.
20. Fernlund J M R (1998), "The effect of particle form on sieve analysis: a test by image analysis", *Engineering Geology,* Vol. 50, pp. 111–124.
21. Mora C F, Kwan A K H and Chan H C (1998), "Particle Size Distribution Analysis Of Coarse Aggregate Using Digital Image Processing", *Cement and Concrete Research*, Vol. 28, No. 6, pp. 921–932.
22. Mertens G and Elsen J (2006), "Use of computer assisted image analysis for the determination of the grain-size distribution of sands used in mortars", *Cement and Concrete Research,* Vol. 36, pp. 1453-1459.
23. Barksdale R D, Kemp M A, Sheffield W J and Hubbard J L (1991), "Measurement of aggregate shape, surface, area, and roughness, Transportation Research Record 1301", National Research Council, Washington D C, pp. 107–116.
24. Rao C and Tutumluer E (2000), "Determination of volume of aggregates: New image-analysis approach", Transportation Research Record 1721, Transportation Research Board, National Research Council, Washington DC, pp. 73–80.
25. Yudhbir J and R Abedinzadeh (1991), "Quantifying of Particle Shape and Angularity Using the Image Analyzer", *Geotechnical Testing Journal ASTM*, Vol. 14, No. 3, 1991, pp. 296–308.
26. Kuo C Y and Freeman R B (2000), "Imaging Indices for Quantification of Shape, Angularity, and Surface Texture of Aggregates", Transportation Research Record 1721, National Research Council, Washington D C, pp. 57-65.
27. Hryciw R D and S A Raschke (1996), "Development of Computer Vision Technique for In Situ Soil Characterization", In Transportation Research Record 1526, TRB, National Research Council, Washington, DC, pp. 86–97.
28. Barrett P J (1980), "The shape of rock particles, a critical review", *Sedimentology*, 27, pp. 291–303.

29. Masad E (2004), “Aggregate Imaging System (AIMS) basics and applications”, TDOT and FHA Washington DC 2004; Report no. FHWA/TX-05/5-1707-01-1.
30. Blott S J and Pye K (2008), “Particle shape: a review and new methods of characterization and classification”, *Sedimentology*, Vol. 55, pp. 31–63.
31. Wadell H (1932), “Volume, shape, and roundness of rock particles”, *J. Geol.*, Vol. 40, pp. 443–451.
32. Pryor W A (1971), “Grain shape”, In: *Procedures in Sedimentary Petrology* (Ed. R.E. Carver), pp. 131–150. Wiley, New York.
33. Pettijohn F J, Potter P E and Siever R (1972), *Sand and Sandstone*, Springer-Verlag, Berlin, p. 618.
34. Krumbein W C (1941), “Measurement and geological significance of shape and roundness of sedimentary particles”, *J Sed Petrol.,* Vol. 11, pp. 64–72.
35. Rittenhouse G (1943), “A visual method of estimating two dimensional sphericity”, *J. Sed. Petrol.*, Vol. 13, pp. 79–81.
36. Krumbein W C and Sloss L L (1963), “Stratigraphy and Sedimentation”, Second Edition, W.H. Freeman and Company, San Francisco, p. 660.
37. Powers M C (1953), “A new roundness scale for sedimentary particles”,*Vol.* , 23, pp. 117–119.
38. Alshibli K A and Alsales M I (2004), “Characterizing surface roughness and shape of sands using digital microscopy”, *Journal of Computing in Civil Engineering*, Vol. 18, No. 1, pp. 36-45.
39. Powers M C (1982), ‘‘Comparison charts for estimating roundness and sphericity’’, AGI Data Sheets, American Geological Institute, Alexandria, Va.
40. Mackie W (1897), “On the laws that govern the rounding of particles of sand”, *Trans. Edinburgh Geol. Soc.*, Vol. 7, pp. 298–311.
41. Dunn E J (1911), *Pebbles.* Robertson, Melbourne, p. 122.
42. Wentworth C K (1919), “A laboratory and field study of cobble abrasion”, *J. Geol.,* Vol. 27, pp. 507–521.
43. Wentworth C K (1922b), “A method of measuring and plotting the shapes of pebbles”, In: *The Shapes of Pebbles. US Geol. Surv. Bull.*, 730-C, pp. 91–102.
44. Wentworth C K (1922c), “A field study of the shapes of river pebbles”, *In: The Shapes of Pebbles. Bull. US Geol. Surv.*, 730-C, pp. 103–114.
45. Cox E A (1927), “A method for assigning numerical and percentage values to the degree of roundness of sand grains”, *J. Paleontol.*, Vol. 1, pp. 179–183.
46. Wadell H (1933), “Sphericity and roundness of rock particles”, *J. Geol.*, Vol. 41, pp. 310–331.
47. Wadell H (1935), “Volume, shape, and roundness of quartz particles”, *J. Geol.*, Vol. 43, pp. 250–280.
48. Cailleux A (1947), *L’indice d’e´mousse´ des grains de sable et gre‘s. Rev. Ge´omorph. Dyn.*, Vol. 3, pp. 78–87.

49. Dobkins J E Jr and Folk R L (1970), “Shape development on Tahiti-Nui”, *J. Sed. Petrol.*, Vol. 40, pp. 1167–1203.

50. Al-Rousan T (2004), “Characterization of aggregate shape properties using a computer automated system”, Ph.D. Dissertation, Department of Civil Engineering, Texas A&M University, College Station, TX.

51. Mitchell J K and Soga K (2005), “Fundamentals of Soil Behavior”, 3rd Edition, John Wiley & Sons, Inc., Hoboken, New Jersey, p. 577.

52. Arasan S, Akbulut S and Hasiloglu A S (2011), “Effect of particle size and shape on the grain-size distribution using Image analysis”, *International Journal of Civil And Structural Engineering*, Vol. 1, No. 4, pp. 968-985.

53. Arasan S, Yener E, Hattatoglu F, Hinislioglu S and Akbulut S (2011), “Correlation between Shape of Aggregate and Mechanical Properties of Asphalt Concrete: Digital Image Processing Approach”, *Road Materials and Pavement Design*, Vol. 12, No. 2, pp. 239-262.

54. Polat R, Yadollahi M M, Sagsoz A E and Arasan S (2013), “The correlation between aggregate shape and compressive strength of concrete: digital image processing approach”, *International Journal of Structural and Civil Engineering Research* (IJSCER), Vol. 2(3), pp. 1-19.

55. Arasan S (2011), “Determination of some geotechnical properties of granular soils by image analysis”, Ph.D. Thesis (in Turkish with an English summary), Ataturk University, Graduate School of Natural and Applied Science, Erzurum, Turkey.