Applying the Digital Image Processing to Understand the Role of Compaction in the behavior of Concrete Mixes

Ragab M. Abd El-Naby, Emad A. M. El-Dardiry and Naji A. Abo Azzom

Civil Engineering Department, Faculty of Engineering at Shoubra, Benha University, Egypt
e_eldardiry@yahoo.co.uk, emad.eldardiry@feng.bu.edu.eg

Abstract: Concrete structures are still suffering from different types of distress such as cracking and deformation. At present, the characterization of the concrete structures is implemented using two different concepts. The first concept is based on performing laboratory-testing methods on prepared concrete specimens. In fact this concept should be taken with great care and cautious. The second concept is based on conducting large scale testing programs implemented directly on the structures. The main disadvantages of this concept are related to its failure to measure the specified characteristics directly and they need back calculation to predict the required properties. Secondly, they are large and expensive equipment. However, both concepts are not beneficial in predicting or describing the mode of failure because they are macro-structural analysis based evaluation. Recently attempts were made to use the Digital Image Analysis technique DIA to evaluate the aggregate gradation of concrete mixes. It is believed that the application of the DIA technique should be extended to evaluate the microstructure characteristics. The experimental program and DIA were carried out on 96 specimens. The compression and tension test were carried out on 72 concrete cylinders made with three different mixes which contained gravel or dolomite as coarse aggregate, and compacted either manually or mechanically. The DIA was implemented on 6 vertical sections and 18 horizontal sections. The results showed that the DIA is an effective technique to evaluate the performance, quality and uniformity of concrete mixes. The results of the compression and tension were in a good agreement with the results of the DIA.

[Ragab M. Abd El-Naby, Emad A. M. El-Dardiry and Naji A. Abo Azzom. **Applying the Digital Image Processing to Understand the Role of Compaction in the behavior of Concrete Mixes.** *J Am Sci* 2014;10(7):128-139]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 18

Keywords: Digital Image Analysis DIA, Orientation angle, Major axis length, Minor axis length, Ferret diameter FD.

1. Introduction

At present time, the Digital Image Analysis gained a lot of potential because it can relate the microstructure characteristics of concrete to its mechanical properties [1, 2]. Moreover, relating the output of the DIA to the numerical analysis helped a lot in the explanation of the mechanisms of failure of the composite materials such as concrete [3, 4]. It should be noted that the concept of the DIA would have an impact on the design methods that based on the concept of relative rigidity [5, 6]. The new concept of design is based on the analysis of the multilayer system and identifying its failure characteristics [1, 7, 8]. However, relating the DIA to the microstructure and the macrostructure analysis should have the following criteria:

1- The combined method can easily and thoroughly explain the mechanisms of failure of the concrete.

2- The method should easily relate the microstructure characteristics to the mechanical properties of the concrete.

3- The method should be easily implemented and should not need special equipment difficult to interpret.

The presented work introduces the DIA technique combined with the finite element analysis to be a reliable method to achieve the following objectives.

2. Objectives:

The presented research work was conducted to achieve the following points:

1. Defining the concept of the DIA technique as well as the main variables that can be used through the analysis of the DIA procedure.
2. Examining the role of the DIA technique as a reliable technique to predict the behavior of the concrete mixes.
3. Providing a three dimensional microstructure analysis of digitalized photos.

3. Experimental Program:

3.1 Outline of testing program:

The presented testing program comprised two main variables, which were the type of the concrete mix as well as the method of compaction. Three different mixes were used to examine the influence of the concrete mix on the produced concrete compressive strength. These mixes were nominated as M_1, M2 and M_3. Also two different methods of compaction which were the manual compaction and the mechanical compaction to verify the role of the compaction can play on the developed concrete compressive strength. The DIA technique was applied to evaluate the effect of the compaction method on the compressive strength. Flow Chart 1 and Flow Chart 2 showed the outline of the implemented experimental program.

3.2 Preparation of the specimens:

PVC pipes of 100mm inner diameter and 200mm height were used to cast the concrete specimens. The concrete mix consisted of ordinary Portland cement, coarse aggregate, fine aggregate and water. The coarse aggregate used was gravel or dolomite and the fine aggregate was natural sand. The proportions of the concrete mixes were shown in Table 1. The maximum aggregate size of the fine aggregate and the coarse aggregate were 3.0mm, and 16mm respectively and the fineness modulus of the fine aggregate was 2.1. After 24 hours from casting, the specimens were removed from the molds by cutting the molds with great care. The specimens were marked and submerged in clean water for 28 days. Then the specimens were prepared for the compression and tension tests and the DIA technique. The results of the compressive and tensile strength were shown in Table 2.

4. DIA Technique:

4.1 DIA procedure:

The DIA technique contained three main steps. The first step dealt with photographing the specimens and characterizing the image. The Second step dealt with converting image to AUTOCAD drawing and the third step involved preparing the AUTOCAD drawing to get the DIA output. At the first step, the specimens were saw-cut either vertically or horizontally as shown in Figure 1. The cross section of the specimen is photographed using digital camera. The camera was parallel to the plane of the cross section of the specimen and the distance between the camera and the specimen is equal to 1 m and this distance has been fixed for all photos for reducing the error in the photo. Figure 2 showed an example for the digitized photo. In the second step, the specimen was cut and trimmed from the whole image and saved as (JPG). Thirdly, the image was converted to an AUTOCAD drawing as shown in Figure 3. Converting the image to AUTOCAD drawing will easily allow implementing a quantitative survey for the aggregate in the photo. The Software called **"**VECTOR DEMO **"**has been used to convert the image from "JPG-Raster" file to "DXF-vector file", which means converting the image to AUTOCAD drawing.

The boundary of the aggregate was manually outlined in the digitized image then a modified image file was obtained when the whole aggregates were contoured. The minimum length which the program can recognize was (4 pixel=$4x10^{-6}$ cm) with no gap jump and the angle sensitivity was (0 degree). The iteration number was (50) so that the program displays the best from all iteration, and the shift tolerance equal (0). To avoid the effect of the curves of the aggregate perimeter, the minimum arc radius was taken (2 pixels=$2x10^{-6}$cm), the tolerance was (2 pixels), and the conjugation tolerance was (2 pixels). Finally, each aggregate particle was presented as Polly-lines-arc and the whole image was saved in "DXF" extension. The saved "DXF" file was opened using AUTOCAD 2007 and for checking the accuracy of the analysis program, the black and white image was put as background to the AUTOCAD drawing. Each aggregate particle was numbered and written inside each aggregate particle using the AUTOCAD as shown in Figure 3. After numbering the aggregate particles, the file has been exported from the AUTOCAD and then saved in EXCEL sheet to implement comprehensive statistical computations. See Figure 2.

4.2 DIA output:

The functions that will be used in the DIA processing can be summarized as follows:

4.2.1 Ferret Diameter (FD) in (cm):

The ferret diameter is defined as the diameter of a fictitious circular object that has the same area as the aggregate. The ferret diameter is calculated from Equation (1) as follows:

Ferret Diameter (FD) = $\sqrt{4 \times Area/\pi}$ **(1)**

The method of drawing the ferret diameter is shown in Figure (5-8).

4.2.2 Major Axes Length (Ma.AL) in (cm)

It is defined as the line joining the two points of the contour of the aggregate that are farthest apart. Figure 4 illustrates the method of drawing the major axis length of each particle using the AUTOCAD.

4.2.3 Minor Axes Length (Mi.AL) in (cm):

The minor axis is defined as the longest line that can be drawn from one boundary point to another so that the line is perpendicular to the major axis. Figure 4 illustrates the method of drawing the minor axis length.

4.2.4 Major axis orientation (θ) (Degree):

The major axis orientation is defined as the angle between the horizontal line (the x-axis) and the major axis. In fact this parameter provides configuration about the mechanism of load transfer between the aggregate and the cement mortar. Figure 5 illustrated the method of measuring the angle of orientation.

4.2.5 Aggregate Area Ratio (AAR):

The aggregate area ratio is defined as the Ratio of the aggregate and the overall area of the sample cross-section. This parameter provides information about the interlock among aggregates and the concrete matrix.

4.2.6 Centroid of aggregate (X, Y):

It is calculated for the whole aggregate using the AUTOCAD and defined as given in equations (2) and (3):

$$\bar{X} = \sum X_i \; A_i / \sum A_i \qquad (2)$$

$$\bar{Y} = \sum Y_i \; A_i / \sum A_i \qquad (3)$$

Where:

Where i is the number of aggregate particle

Xi, Yi, and Ai are the coordinates and the area of the aggregate.

4.2.7 Rigidity of aggregate (I_X, I_y, and I_{xy}):

These functions are important in the characterization of the rigidity of the cross section and can be utilized in describing the two key elements which have a significant influence on both the aggregate gradation and the aggregate orientation. They are calculated for the whole aggregate and defined as given in the following equations:

$$I_x = \sum A_i \; d_y^{\,2} \qquad (4)$$

$$I_y = \sum A_i \; d_x^{\,2} \qquad (5)$$

$$I_{xy} = \sum A_i \; d_{xy} \qquad (6)$$

Where:

I_x, I_y, and I_{xy} are the summations of the moment of inertia with respect to the x-axis and the y-axis. Figure 6 shows an example for the resulted functions obtained from the AUTOCAD to implement statistical analysis.

5. Results and Analysis:

5.1 Vertical sections of mixes contained gravel aggregates:

Table 3 showed the calculated properties of the images for vertical sections of concrete mixes M1, M2, and M3 which contained gravel. The number of aggregates per section ranged from 77 to 109 for the case of manual compaction while it ranged from 83 to 126 in case of mechanical compaction. It was clear that using the super-plasticizer led to increase the number of aggregates while using concrete mix of low W/C led to decrease the number of aggregates in the image. Also, mix M2 and M3 showed the influence of mechanical compaction on the number of aggregates per section. However the area of the aggregates per section supported the influence of mechanical compaction where the area of aggregate of the manually compacted mixes M1, M2, and M3 were 76.913cm^2, 83.798cm^2, and 73.780cm^2 respectively, while it was 96.629cm^2 and 86.078cm^2, and 88.025cm^2 in case of mechanical compaction. The absolute value of the centroid (x, y) of the aggregates of mixes which were mechanically compacted was slightly less than those which were manually compacted. However it is believed that comparisons based on statistical functions are more important.

Using the mechanical method of compaction showed smaller angles of orientation with respect to those mixes that were compacted manually. The angles of orientation of mixes M1, M2 and M3 which were manually compacted were 79.989°, 95.107°, and 87.550° while they were 70.011°, 92.667°, and 81.987° in case of mechanically compaction. The results of aggregate orientation can be related to the mechanisms of load transfer. Lower values of angles of orientation indicate that the major contribution of transferring load is due to bearing. On the other side, higher values of angle of orientation indicate the influence of friction in the mechanism of load transfer. The results of mixes M1 and M2 reflected the negative impact of using super-plasticizer with mixes of (w/c=0.5) as the angles of orientation increased from 79.989° and 70.011° to 95.107° and 92.667° respectively due to the use of super-plasticizer. On the other hand, using super plasticizer with mix M3 of (w/c = 0.44) resulted in decreasing the angles of orientation. The angles of orientation of mixes M2 and M3 (containing super plasticizer) were 95.107° and 92.667° for mix M2 and 87.550° and 81.987° for mix M3.

The results of the moments of inertia I_x and I_y can indicate the influence of the method of compaction and mix type on the flexural rigidity of the mix. The moment of inertia I_x of mixes M1, M2, and M3, which were manually compacted were 27.256 cm^4, 20.084 cm^4, and 23.542 cm^4 while they were 35.716 cm^4, 28.564 cm^4, and 31.446 cm^4 in case of mechanically compacted mixes. Using the manual compaction led to obtaining I_y values 6.909cm^4, 5.347cm^4, and 5.778cm^4 while they were 8.621cm^4, 7.153cm^4, and 6.735cm^4 in case of mechanical compaction. Although slight differences were observed when concerning the absolute values of the ferret diameter, it is believed that the output of the statistical functions such as the coefficient of variation (V).

Table 4 shows the variability of the results in terms of the coefficient of variation (V). The coefficients of variation of the centroid (x, y) of the mechanically compacted mixes were relatively higher than those computed for the manually compacted mixes. It is clear that increasing the coefficient of variation (V) led to the increase of the dispersion of the aggregate in the photo which reflected the case of uniform concrete. In terms of the aggregate orientation, the mechanically compacted mixes showed higher level of variability with respect to the manually compacted mixes. In fact these results reflected the strength of the mix in various directions as its ability to resist load by both bearing and friction will be increased in various directions. The coefficients of variation (V) of the perimeter and ferret diameter of the mechanically compacted mixes were relatively higher than those of manually compacted mixes. For instance the coefficients of variation (V) of the ferret diameter of mechanically compacted mixes M1, M2, and M3 were 33.11%, 41.36%, and 60.895 respectively while they were 31.18%, 35.40%, and 53.77 respectively for the case of manual compaction. It is clear that increasing the coefficient of variation (V) of the ferret diameter indicated the case of well-graded aggregate concrete.

While the absolute values of the moments of inertia of the aggregate express the rigidity of the mix to resist bending stresses, the coefficient of variation (V) of the moments of the inertia expresses the resistance of the mix in various directions. From the result of Table 4, the coefficient of variation (V) of the moment of inertia I_x of mixes compacted mechanically were 144.48%, 129.84%, and 130.58% while they were 125.15%, 120.51%, 118.58% respectively for the case of manually compacted mixes.

5.2 Vertical sections of mixes contained dolomite aggregates:

Tables 5 and 6 showed the statistical functions considered in the analysis. Similar trends to the case of the aggregate were observed. The mechanical compaction led smaller angles of orientation when compared to the case of manual compaction. The perimeter of the aggregate of the image of the mechanically compacted mixes was relatively bigger when compared to that obtained for the case of the manually compacted mixes. The moments of inertia of the aggregates of the mechanically compacted mixes were relatively higher than that obtained for the case of the mixes which were compacted manually. The coefficients of variation of the angle of orientation of the mechanically compacted mixes were relatively higher than that obtained for the case of the manual compaction. Also, the coefficients of variation of the perimeter, the moments of inertia, and the centroid were relatively higher for the case of using the mechanical compaction. These results explained clearly the influence of compaction and mix type on the quality and performance the concrete mixes.

5.3 Comparison among vertical sections of mixes contained gravel and dolomite aggregates:

Tables 3, 5 summarized the properties calculated from the images taken for vertical sections of mixes contained gravel and dolomite aggregates. The angles of orientation of mixes contained dolomite were smaller than that of the mixes contained gravel. For Mix M1 that contained gravel aggregate and compacted manually, the angle of orientation was79.989° while it was 62.581° for the case of dolomite. For the case of mechanical compaction, the angles of orientation were 70.011° and 60.286° for mixes contained gravel and dolomite aggregates respectively. Also, the moments of inertia I_x and I_y of mixes contained dolomite were relatively higher than those contained gravel. The moments of inertia I_x of mixes contained gravel or dolomite and compacted manually were 27.256cm^4 and 33.684cm^4 respectively. For mechanical compaction, they were 35.716cm^4 and 42.192cm^4. The moments of inertia I_y of mixes contained gravel or dolomite and compacted manually were 6.909cm^4 and 11.299cm^4 respectively. For mechanical compaction they were 8.621cm^4 and 16.854cm^4.

The ferret diameter of mixes contained gravel and dolomite and compacted manually was 1.0156cm and 0.955cm respectively. For case of mechanical compaction, the ferret diameter is 1.089cm and 0.992cm. Information about the uniformity and quality of mixes can be explained by the results of statistical function given in Tables 4 and 6. The dispersion of the aggregate in the mix, which reflects the quality and uniformity of the mix, can be expresses by the coefficient of variation of the centroid. It is clear that the higher the coefficient of variation, the higher the expected uniformity of the mix. The coefficient of variation V of the centroid x of manually compacted mixes contained gravel or dolomite aggregates was 2277.00% and 4680.66% respectively while it was 2819.21% and 3000.47% for the centroid y respectively. Similar results were obtained for mixes compacted mechanically. However, mixes compacted mechanically showed more uniformity and quality with respect to those compacted manually as they gave higher values of coefficient of variation. As the load carrying capacity can be expressed in terms of the angle of orientation, the coefficient of variation V of the angle of orientation showed the ability of the mix to resist loads in various directions. The load carrying capacity is mainly dependent of the mechanism of load transfer if it is mainly by bearing or by friction or by both. At the same time, the mechanism of load transfer is proved to be highly dependent of the angle of orientation. The coefficient of variation of the angle of orientation of mixes contained gravel or dolomite and compacted manually was 69.97% and 80.98% respectively. Similar results were observed for the case of mechanical.

5.4 Horizontal sections of mixes contained gravel aggregates:

As the horizontal sections are perpendicular to the direction of the load, therefore the output the DIA will reflect the ability of the mix to resist straining actions in the horizontal directions.

5.4.1 Top sections:

Tables 7 and 8 showed the calculated properties of the images for horizontal sections of concrete mixes contained gravel. The number of aggregates per section ranged from 26 to 30 for the case of manual compaction while it ranged from 33 to 37 for the case of mechanical. The results of Mixes M2 and M3 showed that mechanically compacted sections had bigger number of aggregates when they were compared with the mixes that were manually compacted. Similar trends were observed when considering the area of the cross section of the aggregates in the image. Mechanically compacted mixes showed higher area of aggregates with respect to those, which are manually compacted. As an example, for Mix1, the manually compacted sample had an area of aggregates 34.220 cm^2 while the mechanically compacted sample had an area of aggregates 37.500 cm^2. The absolute value of the centroid (x, y) of the aggregates of mechanically compacted mixes was slightly less than that of the manually compacted mixes. However it was believed that comparisons based on statistical functions are more important.

It was clear from the result that mixes compacted by the mechanical method showed smaller angles of orientation with respect to those mixes compacted using the manual method. The angles of orientation of mixes M1, M2 and M3 which were manually compacted were 74.233°, 89.692°, and 80.600° while they were 68.556°, 100.351°, and 70.281° for the case of mechanically compacted mixes. These results were mainly related to the mechanisms of load transfer. Lower values of angles of orientation indicated the major contribution of transferring load by bearing if it was compared by friction. The results of mixes M1 and M2 reflected the negative impact of using super plasticizer with mixes of (w/c=0.5) as the angles of orientation increased from 74.233° and 68.556° to 89.692° and 100.351° respectively. On the other hand, using super plasticizer with mix M3 of (w/c =0.44) resulted in decreasing the angles of orientation. The angles of orientation of mixes M2 and M3 (containing super plasticizer) were 89.692° and 100.351° for mix M2 and 80.600° and 70.281° for mix M3.

The results of the moments of inertia I_x and I_y clearly explained the relation between the method of compaction and the rigidity of the aggregates. The moment of inertia I_x of mixes M1, M2, and M3, which were manually compacted were 4.349 cm^4, 2.458cm^4, and 4.650cm^4 while they were 5.326cm^4, 5.641cm^4, and 4.905cm^4 for the mixes that were mechanically compacted. Table 8 showed the variability of the results in terms of the coefficient of variation (V). The coefficient of variation of the centroid (x, y) of the mixes compacted mechanically were relatively higher than that computed for the mixes compacted manually. It was clear that increasing the coefficient of variation (V) led to the increase of the dispersion of the aggregate in the photo which indicated the case of uniform concrete. In terms of aggregate orientation, the mechanically compacted mixes showed higher level of variability with respect to the manually compacted mixes which indicated that their ability to resist load by both bearing and friction will be increased in various directions.

The coefficients of variation (V) of the perimeter and ferret diameter of the mechanically compacted mixes were relatively higher than those of manually compacted mixes. For instance, the coefficient of variation (V) of the ferret diameter of mechanically compacted mixes M1, M2, and M3 were 43.183%, 33.617%, and 42.439% respectively while they were 36.524%, 28.760%, and 35.118% respectively for the case of manual compaction. It was clear that increasing the coefficient of variation (V) of the ferret diameter indicated the case of well-graded aggregate concrete. While the absolute values of the moments of inertia of the aggregate express the rigidity of the mix to resist bending stresses, the coefficient of variation (V) of the moments of the inertia expresses the resistance of the mix in various directions. From the result of Table 8, the coefficient of variation (V) of the moment of inertia I_x of mixes compacted mechanically were 147.326%, 134.556%, and 151.115% while they were 133.541%, 123.566%, 131.926% respectively for the case of manually compacted mixes.

5.4.2 Centre sections:

Tables 9 and 10 showed the calculated properties of the images for horizontal sections of concrete mixes contained gravel. The number of aggregates per section ranged from 35 to 39 for the case of manual compaction while it ranged from 24 to 37 for the case of mechanical compaction. The results of mixes M2 and M3 showed that mechanically compacted sections had bigger number of aggregates when they were compared with the mixes that were compacted manually. Similar trends are observed when considering the area of the cross section of the aggregates in the image. Mechanically compacted mixes showed higher area of aggregates with respect to those, which are manually compacted. For mix M1, the manually compacted sample had an area of aggregates 29.306cm^2 while the mechanically compacted sample had an area of aggregates 34.125 cm^2. The absolute value of the centroid (x, y) of the aggregates cross sections of the mixes which were mechanically compacted were slightly less than that of the manually compacted mixes.

It was clear from the result that mixes compacted by the mechanical method showed smaller angles of orientation with respect to those mixes compacted using the manual method. The angles of orientation of mixes M1, M2 and M3 which were manually compacted were 77.857°, 91.216°, and 80.308° while they were 71.514°, 101.750°, and 70.108° for the case of mechanical compaction. The results of mixes M1 and M2 reflected the negative impact of using super plasticizer with mixes of (w/c=0.5) as the angles of orientation increased from 77.857° and 71.514° to

91.216° and 101.750° respectively. On the other hand, using super plasticizer with mix M3 of (w/c=0.44) resulted in decreasing the angles of orientation. The angles of orientation of mixes M2 and M3 (containing super plasticizer) were 91.216° and 101.750° for mix M2 and 80.308° and 70.108° for mix M3.

The moment of inertia I_x of mixes M1, M2, and M3, which were manually compacted are 5.302cm^4, 4.945cm^4, and 4.597cm^4 while they were 7.543cm^4, 9.053cm^4, and 5.044cm^4 for the mixes that were mechanically compacted Table 10 showed the variability of the results in terms of the coefficient of variation (V). The coefficient of variation of the centroid (x, y) of the mixes compacted mechanically were relatively higher than that computed for the mixes compacted manually. In terms of the aggregate orientation, the mechanically compacted mixes showed higher level of variability with respect to the manually compacted mixes. The coefficients of variation (V) of the perimeter and ferret diameter of the mechanically compacted mixes were relatively higher than those of manually compacted mixes. The coefficient of variation (V) of the ferret diameter of mechanically compacted mixes M1, M2, and M3 were 52.877%, 40.127%, and 49.464% respectively while they were 45.423%, 38.858%, and 43.037% respectively for the case of manual compaction. The coefficient of variation (V) of the moment of inertia I_x of mixes compacted mechanically were 168.154%, 137.568%, and 161.351% while they were 138.669%, 122.103%, 134.254% respectively for the case of manual compaction.

5.4.3 Bottom sections:

Tables 11 and 12 showed the calculated properties of the images for horizontal sections of concrete mixes contained gravel. The number of aggregates per section ranged from 40 to 46 for the case of manual compaction while it ranged from 30 to 45 for the case of mechanical compaction. The results of mix M2 and M3 showed that mechanically compacted sections are of bigger number of aggregates when they were compared with the mixes that were manually compacted. Similar trends are observed when considering the area of the cross section of the aggregates in the image. Mechanically compacted mixes showed higher area of aggregates with respect to those, which were manually compacted. The absolute value of the centroid (x, y) of the aggregates cross sections of the mixes which were mechanically compacted was slightly less than that of the manually compacted mixes. It is clear from the result that mixes compacted by the mechanical method showed smaller angles of orientation with respect to those mixes compacted using the manual method. The results of mixes M1 and M2 reflected the negative impact of using super plasticizer with mixes of (w/c=0.5) while it reflected positive impact of using super plasticizer with mix M3 of (w/c =0.44). The results of the moments of inertia I_x and I_y explained the relation between the method of compaction and the rigidities of the aggregates. The moment of inertia I_x of mixes M1, M2, and M3, which were manually compacted are 4.230cm^4, 3.836cm^4, and 4.113cm^4 while they were 5.028cm^4, 5.355cm^4, and 5.147cm^4 for the mixes that were mechanically compacted.

Table 12 shows the variability of the results in terms of the coefficient of variation (V). The coefficient of variation of the centroid (x, y) of the mixes compacted mechanically were relatively higher than that computed for the mixes compacted manually. In terms of the aggregate orientation, the mechanically compacted mixes showed higher level of variability with respect to the manually compacted mixes which reflected the strength of the mix in various. The coefficients of variation (V) of the perimeter and ferret diameter of the mechanically compacted mixes were relatively higher than those of manually compacted mixes. The coefficient of variation (V) of the moment of inertia I_x of mixes compacted mechanically was also higher than that for the case of manually compacted mixes.

5.6 The influence of compaction method and aggregate type on The DIA characteristics:

It was clear that mechanical compaction led to better uniformity and quality. Also, mixes compacted mechanically led to higher resistance to straining actions as the moments of inertia and the perimeter are increased. The DIA technique succeeded to distinguish between the mixes contained gravel or dolomite aggregates. Tables from 13 to 18 showed that the physical and mechanical behavior of mixes contained dolomite were better than those contained gravel.

Table 1: Proportions of the concrete mixes

Mixes	OPC (kg)	Dolomite or Gravel (kg)	Sand (kg)	Water content	W/C Ratio
M_1	400	1200	600	200	0.5
M_2 + super-plasticizer	400	1200	600	200	0.5
M_3 + super-plasticizer	400	1200	600	175	0.44

Table (2): Compressive and tensile strength of concrete cylinders

Type of aggregate	Compaction Type	Compressive strength (kg/cm^2)			Tensile strength (kg/cm^2)		
		M1	M2	M3	M1	M2	M3
Gravel	Manual	250	234	288	30	22	25
	Mechanical	280	267	322	31.7	24	29
Dolomite	Manual	300	277	354	32.86	26	31
	Mechanical	340	311	381	34.98	29	34

Table 3: DIA properties of vertical section of concrete contained gravel

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	95.000	92.000	109.000	126.000	77.000	83.000
Area (cm^2)	76.913	96.629	83.798	86.078	73.780	88.025
Centroid (x) (cm)	-0.091	-0.075	0.172	0.130	0.071	0.057
Centroid (y) (cm)	-0.101	-0.087	0.369	-0.303	0.096	0.071
Orientation angle (°)	79.989	70.011	95.107	92.667	87.550	81.987
Perimeter (cm)	4.191	3.980	3.943	3.805	4.386	3.048
(I_x) (cm^4)	27.256	35.716	20.087	28.564	23.542	31.446
(I_y) (cm^4)	6.909	8.621	5.347	7.153	5.778	6.735
Ferret diameter (cm)	1.016	1.089	1.163	1.125	0.794	0.839

Table 4: DIA variability V% of vertical section of concrete contained gravel

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	95.00	92.00	109.00	126.00	77.00	83.00
Centroid (x) (cm)	-2277.00	-2581.36	1211.63	1366.34	3594.58	-3920.12
Centroid (y) (cm)	-2819.21	-3080.62	-1040.21	-1710.60	-2597.25	-2764.17
Orientation angle(°)	69.97	74.26	55.64	64.09	64.40	73.98
Perimeter (cm)	51.18	60.86	40.04	53.92	45.35	55.35
(I_x) (cm^4)	125.15	144.48	120.51	129.84	118.58	130.58
(I_y) (cm^4)	101.10	130.55	129.68	177.69	119.36	124.73
Ferret diameter (cm)	31.18	33.11	35.40	41.36	53.77	60.89

Table 5: DIA properties of vertical section of concrete contained dolomite

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	100.00	105.00	104.00	137.00	96.00	95.00
Area (cm^2)	84.17	100.88	88.76	91.39	91.22	96.72
Centroid (x) (cm)	-0.07	-0.04	-0.08	0.10	0.04	-0.01
Centroid (y) (cm)	-0.08	-0.05	-0.26	-0.28	-0.04	-0.04
Orientation angle (°)	62.58	60.29	88.83	87.69	81.44	74.48
Perimeter (cm)	3.66	3.81	4.90	6.90	7.56	8.71
(I_x) (cm^4)	33.68	42.19	27.00	32.86	29.43	39.31
(I_y) (cm^4)	11.30	16.85	8.95	11.16	10.22	13.42
Ferret diameter (cm)	0.96	0.99	0.97	1.02	0.99	1.05

Table 6: DIA variability V% of vertical section of concrete contained dolomite

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	100.00	105.00	104.00	137.00	96.00	95.00
Centroid (x) (cm)	-4680.66	-5000.99	-1439.39	1588.65	4493.22	-4900.15
Centroid (y) (cm)	-3000.47	-3693.70	-1322.56	-1755.86	-2996.56	-4205.21
Orientation angle (°)	80.98	90.67	59.86	71.83	71.50	79.47
Perimeter (cm)	55.84	63.54	47.72	59.71	50.44	65.69
(I_x) (cm^4)	130.23	150.38	126.26	137.88	130.47	142.47
(I_y) (cm^4)	136.25	159.21	134.15	184.19	149.20	186.92
Ferret diameter (cm)	35.41	41.22	128.04	135.82	132.71	144.36

Table 7: DIA properties of horizontal section at top of concrete contained gravel

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	30.000	36.000	26.000	37.000	29.000	33.000
Area of agg (cm^2)	34.220	37.500	37.900	48.260	32.712	32.188
Centroid (x) (cm)	-0.106	-0.063	0.286	0.216	0.117	-0.072
Centroid (y) (cm)	0.661	-0.204	-0.830	0.277	0.532	0.225
Orientation (degree)	74.233	68.556	89.692	100.351	80.600	70.281
Perimeter of agg .(cm)	3.781	3.835	3.567	3.880	3.611	3.833
Moment of inertia(Ix) (cm^4)	4.349	5.326	2.458	5.641	4.650	4.905
Moment of inertia(Iy) (cm^4)	4.241	5.700	3.337	6.801	4.486	4.693
Ferret diameter (cm)	1.014	0.967	0.901	1.053	1.099	0.940

Table 8: DIA Variability V% of horizontal section at top of concrete contained gravel

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	30.000	36.000	26.000	37.000	28.000	35.000
Orientation (degree)	70.309	86.864	60.366	67.565	68.156	88.301
Perimeter of agg .(cm)	42.969	53.422	36.465	43.316	45.371	63.132
Moment of inertia(Ix) (cm^4)	133.541	147.326	123.566	134.556	131.926	151.115
Moment of inertia(Iy) (cm^4)	138.394	145.574	132.188	140.559	136.185	150.592
Ferret diameter(cm)	36.524	43.183	28.760	33.617	35.118	42.439

Table 9: DIA properties of horizontal section at center of concrete contained gravel

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	35.000	37.000	37.000	24.000	39.000	37.000
Area of agg (cm^2)	29.306	34.125	27.178	43.037	33.020	36.233
Centroid (x) (cm)	-0.373	-0.112	-0.518	-0.493	0.313	0.142
Centroid (y) (cm)	0.194	-0.079	-0.233	0.285	0.179	-0.063
Orientation angle(°)	77.857	71.514	91.216	101.750	80.308	70.108
Perimeter (cm)	3.507	4.473	3.274	5.052	3.404	3.882
(Ix) (cm^4)	5.302	7.543	4.945	9.053	4.597	5.044
(Iy) (cm^4)	6.831	9.268	4.916	11.284	6.423	8.533
Ferret diameter (cm)	0.969	0.961	0.903	1.007	1.070	0.958

Table 10: DIA Variability V% of horizontal section at center of concrete contained gravel

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	35.000	37.000	37.000	24.000	39.000	37.000
Orientation angle(°)	58.304	68.468	50.233	56.922	56.233	66.660
Perimeter (cm)	38.509	42.070	31.164	37.550	39.632	45.639
(Ix) (cm^4)	138.669	168.154	122.103	137.568	134.254	161.351
(Iy) (cm^4)	133.846	154.955	124.440	144.760	132.640	149.613
Ferret diameter(cm)	45.423	52.877	38.858	40.127	43.037	49.464

Table 11: DIA properties of horizontal section at bottom of concrete contained gravel

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	43	35	46	44	40	37
Area of agg (cm^2)	31.397	36.069	33	35	30.250	34
Centroid (x) (cm)	0.1641	0.1406	-0.2906	0.2359	0.1935	0.1241
Centroid (y) (cm)	-0.3854	0.2743	-0.4217	-0.30665	0.2938	0.2257
Orientation angle (°)	87.4186	71.6857	101.8478	97.0227	84.3888	73.8709
Perimeter (cm)	3.3783	3.4583	3.3521	3.5401	3.35423	3.4022
(Ix) (cm^4)	4.2297	5.0284	3.83649	5.3548	4.1131	5.1470
(Iy) (cm^4)	3.968	5.8629	3.59519783	7.8511	4.5973	5.2759
Ferret diameter (cm)	0.8952	1.0212	0.9403	0.9733	0.9408	1.0177

Table12: DIA variability V% of horizontal section at bottom of concrete contained gravel

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	43.000	35.000	46.000	44.000	36.000	31.000
Orientation angle(°)	63.783	82.118	45.044	58.819	60.478	79.212
Perimeter (cm)	47.641	55.396	45.475	52.190	46.680	54.915
(Ix) (cm^4)	170.027	209.626	152.486	159.692	163.021	196.859
(Iy) (cm^4)	123.898	144.724	113.224	122.037	120.165	142.311
Ferret diameter (cm)	44.758	51.617	41.782	49.088	45.382	49.543

Table 13: DIA properties of horizontal section at top of concrete specimen contained dolomite

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	34	30	48	49	30	32
Area of agg (cm^2)	36.35	39.255	39.12	48.60459	32.821	32.9854
Centroid (x) (cm)	0.18	0.0423	-0.066379	-0.20806	0.1026	0.0621
Centroid (y) (cm)	0.566988	0.0809	-0.056518	0.138331	0.46324	0.1234
Orientation angle (°)	105.3235	79.13333	97.625	100.559184	80.82	71.526
Perimeter (cm)	4.0725	4.0475533	3.701997	3.989622	3.81263	4.12365
(Ix) (cm^4)	5.54019	7.099233	2.66038	5.8273	4.7598	6.6464
(Iy) (cm^4)	4.95007	5.9	3.5448	6.993	4.569	5.65874
Ferret diameter (cm)	0.96054	1.0744259	1.0124	1.39667	2.0125	1.8956

Table 14: DIA variability V% of horizontal section at top of concrete contained dolomite

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	34.000	30.000	48.000	49.000	30.000	32.000
Orientation angle(°)	71.899	87.484	63.570	69.181	70.246	91.126
Perimeter (cm)	52.496	54.946	39.660	46.403	49.356	66.124
(Ix) (cm^4)	137.464	156.847	128.450	137.980	135.624	155.654
(Iy) (cm^4)	173.601	147.761	136.380	145.200	140.322	153.985
Ferret diameter (cm)	48.794	44.588	30.124	35.123	37.756	44.896

Table 15: DIA properties of horizontal section at center of concrete contained dolomite

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	31	37	53	48	39	37
Area of agg (cm^2)	33.126	37.146	30.1265	35.123	35.556	39.1234
Centroid (x) (cm)	-0.1410903	-0.0257	0.283990566	0.249163	0.2164	0.1132
Centroid (y) (cm)	-0.1728742	0.05197297	-0.148701887	0.075571	0.09852	0.0124
Orientation angle(°)	93.06451613	94.08108	93.0377358	103.875	82.5554	73.526
Perimeter (cm)	3.85986452	4.7231	5.601767925	5.556	5.124	4.124
(Ix) (cm^4)	6.00212258	7.9652	6.0403642	10.564	6.123	7.0124
(Iy) (cm^4)	6.9356	9.3264	6.120204	12.987	7.652	9.986
Ferret diameter (cm)	1.07509082	0.989464435	1.6430782	1.1845	1.1234	1.0124

Table 16: DIA Variability V% of horizontal section at center of concrete contained dolomite

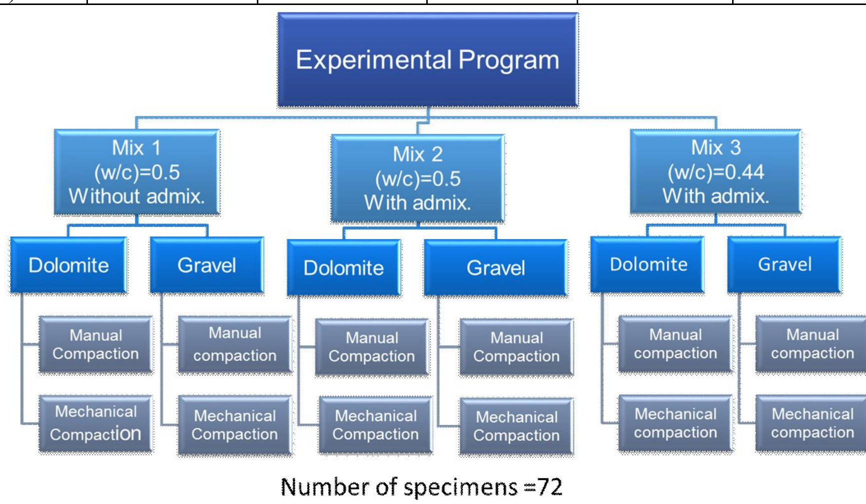
Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	31.00	37.00	53.00	48.00	39.00	37.00
Orientation angle (degree)	58.80	69.58	53.65	61.46	59.32	69.65
Perimeter (cm)	53.81	52.76	35.38	44.58	44.65	49.65
(Ix) (cm^4)	166.09	169.51	127.48	142.82	138.13	166.65
(Iy) (cm^4)	134.45	155.94	130.23	149.54	137.21	153.65
Ferret diameter (cm)	52.86	53.21	40.12	42.32	45.63	53.55

Table 17: DIA properties of horizontal section at bottom of concrete contained dolomite

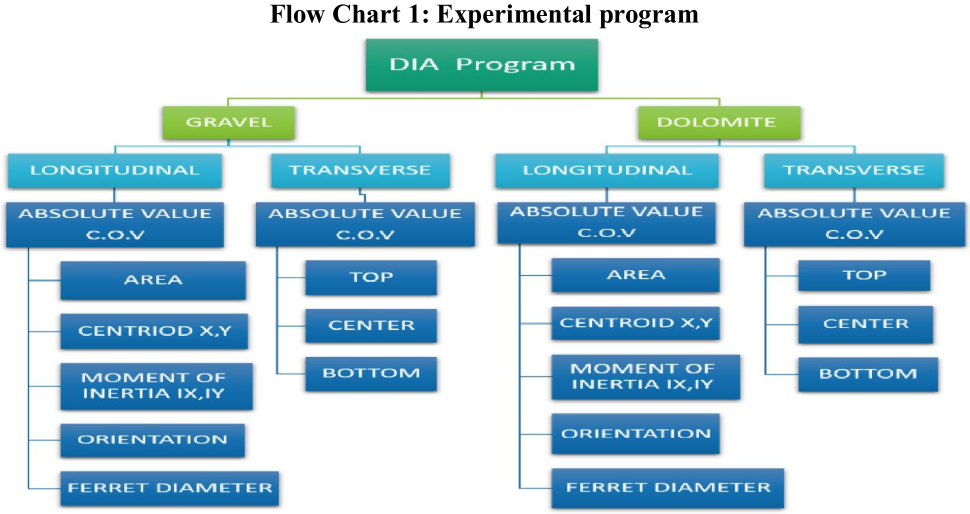
Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	34	35	53	41	36	31
Area of agg (cm^2)	35.00897	39.949031	36.123	37.125	34.565	36.234
Centroid (x) (cm)	0.2834853	-0.1460229	0.152828302	-0.19317	0.0954	0.09658
Centroid (y) (cm)	-0.125476	-0.1433971	-0.1477717	0.252841	0.21644	0.1867
Orientation angle(°)	111	84.82857	104.4339623	99.9512195	86.325	76.4564
Perimeter (cm)	3.82913	3.70455143	5.3532	5.236151	5.3554	6.462
(Ix) (cm^4)	5.80001	5.4113514	5.52507	7.0297	6.1242	8.314
(Iy) (cm^4)	6.26638	5.8512114	5.9221698	9.6416	6.6584	9.2134
Ferret diameter (cm)	1.019676	0.98229831	0.8306392	1.271843	1.1342	0.9875

Table 18: DIA Variability (V%) of horizontal section at bottom of concrete contained dolomite

Mix type	Mix 1		Mix 2		Mix 3	
Compaction type	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical
No. of agg.	34	35	53	41	36	31
Orientation angle(°)	64.294401	83.23945	49.7213	62.3118683	65.654	83.865
Perimeter (cm)	51.9348	56.1670395	48.64	56.41764	50.134	59.634
(Ix) (cm^4)	171.236	210.57587	155.1613	164.75	167.321	199.3111
(Iy) (cm^4)	131.181	145.59982	118.44	126.18	124.985	146.345
Ferret diameter (cm)	49.32972	52.0256009	43.95	50.49165	46.235	53.654



Flow Chart 1: Experimental program



Flow Chart 2: DIA Program

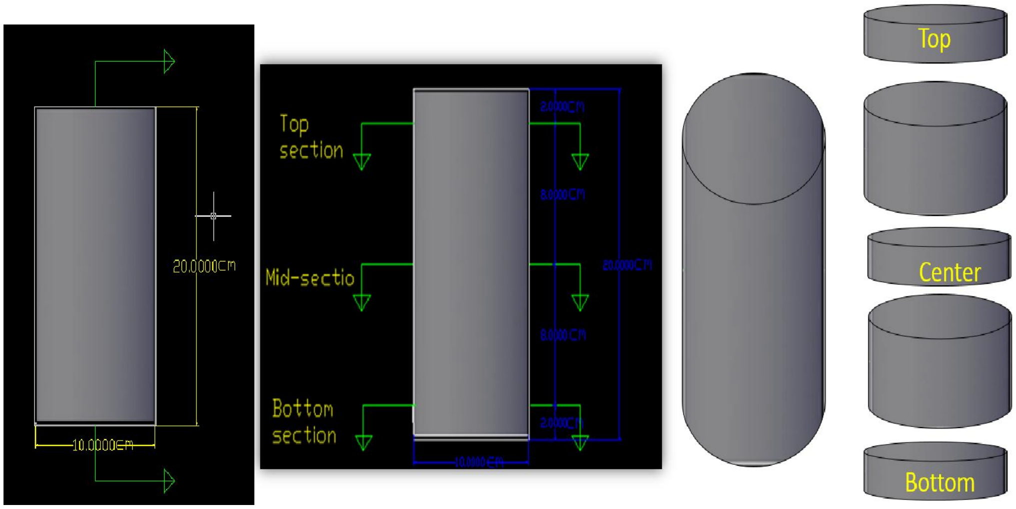


Fig 1: Locations of vertical and horizontal sections

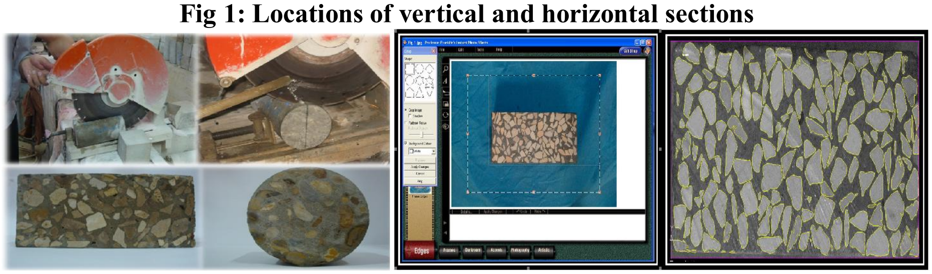


Fig 2: Final Converted Image ("DXF" file)

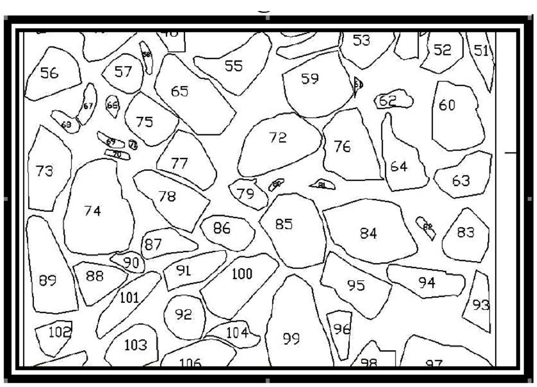


Fig 3: Numbering the Aggregate

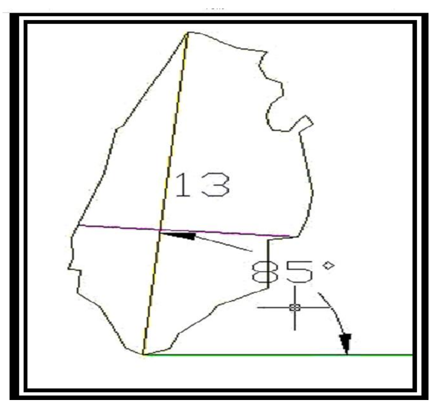


Fig 5: Measuring of Major Axis

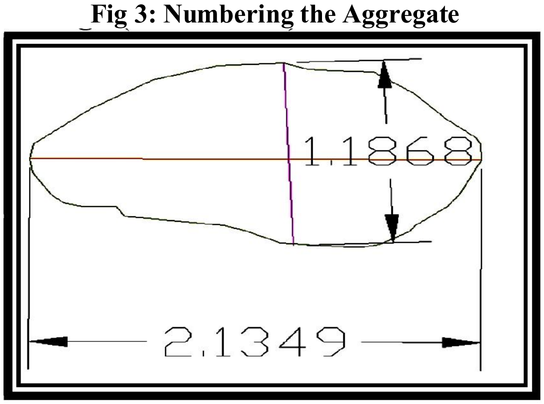


Fig 4: Measuring of Major and Minor Axes length (cm)

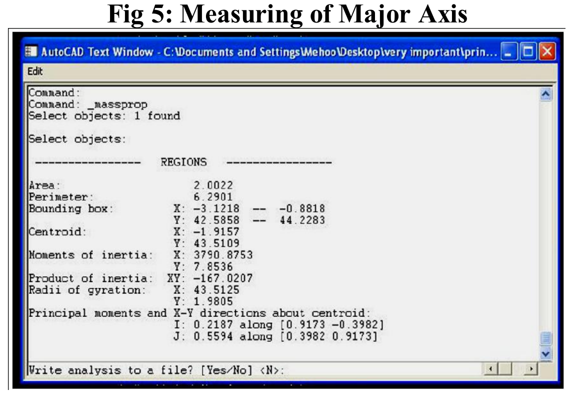


Fig 6: Calculated Output of Aggregate from AutoCAD

6. Major findings

The conducted research work provided an attempt for three dimensional analysis of concrete specimens of different aggregate type and compacted either manually or mechanically. The following paragraphs summarized the important findings that have been deduced from conducting the provided research work:

1. The digital image analysis has succeeded to distinguish between the microstructure of specimens compacted by manual or mechanical methods.
2. The application of the digital image analysis showed that each specimen had its own aggregate distribution and orientation.
3. The compressive strength of the concrete is highly dependent on the mechanism of the load transfer and consequently on the aggregate orientation expressed in terms of the mean slope angle.
4. The bigger the coefficient of variation of the centroid of the aggregate, the better the quality of the mix.
5. The bigger the coefficient of variation of the ferret diameter, the higher the uniformity and the better the grading of the aggregate.
6. The digital image analysis of the horizontal section at bottom showed relatively smaller slope angle, higher coefficients of variations of centroid, ferret diameter, and aggregate rigidity when compared with the top section which indicated the better quality, performance, and uniformity of the bottom section.

References:

1. Abd El-Naby, M. S., and Abd El-Aleem, A. M., R. M., Nour El-Deen,“ Using The DIA Technique to Evaluate the Performance of Asphalt Concrete Mixes“, Al-Azhar Engineering 7th International Conference, AEIC, , Cairo, Egypt, (7-10) April 2003.
2. Chen S., Z.Q. Yue, L.G. Tham, “Digital image-based numerical modeling method for prediction of inhomogeneous rock failure”, Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, People’s Republic of China Accepted 8 March 2004
3. Terada K, Kyoya T, Kazama M, Lee K, Oyang L. Image-based, “modeling and analysis of microstructures for two-scale problems in geomechanics. Int J Numer Anal Methods Geomech 2002; 26:273–97.
4. Investigation of Relationship between Aggregate Shape Parameters and Concrete Strength Using Imaging Techniques, 8th International Congress on Advances in Civil Engineering, 15-17 September 2008 Eastern Mediterranean University, Famagusta, North Cyprus
5. Maas H.G., U. Hampel, Photogrammetric techniques in civil engineering material testing and structure monitoring, Photogrammetric Engineering & Remote Sensing, 72 (1) (2006) 39–45.
6. Pieraccini M., G. Guidi, C. Atzeni, 3D digitizing of cultural heritage, Journal of, Cultural Heritage 2 (1) (2001) 63–70.
7. Struble, L., Skalny, J. and Mindess, S., "A Review of the Cement-Aggregate Bond", Cement and Concrete Research, Vol. 10, No. 2, pp. 277-286, 1980.
8. Stutzman, D. S., Bright, D. S., and Garboczi, E. J.,” Finite Element Stress Computations Applied to Images of Damaged Concrete: A possible New Diagnostic Tool for Concrete Petrography”, National Institute of Standard and Technology, Building Materials and Surface and Microanalysis Science Divisions, Gaithersburg, Maryland 20899, USA.

5/10/2014