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ASSESSMENT OF LABORATORY COMPACTION METHODS FOR GRANULAR BASE LAYER STABILIZED WITH SUSTAINABLE MATERIALS

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KEYWORDS: Granular base, gyratory compaction test, unconfined compressive strength, Foundry sand, Reclaimed Concrete Aggregate.

ABSTRACT
Due to the recent improvement and large capabilities with greater compaction which is introduced by modern construction equipment as well as the higher densities on the roads produced by heavy traffic that the proctor test couldn't reach, it becomes interesting to present the possibility of using the superpave gyratory compactor in laboratory granular base compaction. An extensive experimental work is accomplished to achieve the goals of the study by preparing (108) samples using virgin local granular base materials brought from Al-Nibaee quarry near AL-Taji in Baghdad-Iraq and mixed with foundry sand (FS) and reclaimed concrete aggregate (RCA). The percentages (25, 50, 75 and 100) % of FS and RCA were used for base treatment. All samples were prepared using two compaction methods (modified proctor compaction method and gyratory compaction method). Optimum moisture content (OMC) and maximum dry density (MDD) were determined. Also, the unconfined compressive strength (UCS) test was applied in this study. Samples treated with 75% FS and 100% RCA exhibited the highest values of unconfined compressive strength UCS for the two compaction methods. The results showed as well as the feasibility of using gyratory compactor in granular base compaction, the use of 75% FS and 100% RCA and applied the gyratory compaction method results in highest unconfined compressive strength values reach nearly 253.4 kPa and 716.5 kPa respectively that provided increment about (230.8) % and (835.4) %.

INTRODUCTION
During the development of gyratory compactors from the late 1930s, these compactors have since evolved into laboratory compaction method for hot mix asphalt (HMA) in the U.S. The simulation of aggregate orientation, degradation, field compaction and traffic degradation were achieved using gyratory compaction in HMA production and traffic loading ***(Mokwa et. al, 2008)***.
Through their researches, ***(Mokwa et al., 2008; Ping et al., 2003a)*** showed that the results of using superpave gyratory compactors in soil compaction was more effective, accurate and repeatable than other compactions method due to the similarity in compression efforts produced by SGC to the filed construction conditions.

(Ping et al. 2003a; Browne, 2006) have been noticed that in stu dry densities were higher comparing with proctor ones, in this way, and due to SGC advantages, it could be appropriate for soil compacting as well. In spite of the truth of the possibility using SGC in soils compaction, no protocols or standards to do it yet, many recent studies on unbound materials base their testing procedures on the standard procedures for testing HMA ***(AASHTO T 312 and ASTM D 6925)***.

Starting from the world regards in using waste materials as encouraging step to use it in base layer instead of conventional materials, and since the high costs of using aggregates in roads construction for many places in Iraq, the use of waste materials such as the foundry sand was promising solution that presents economic and environmental advantages as well technically-viable ***(Eman et. al, 2016)***.

Objective of the Research

This research evaluates the effect of laboratory compaction methods on granular base layer stabilized with foundry sand recycled material; and reclaimed concrete aggregate.

Research Justification

The field densities that obtained using the right way and suitable field compaction equipment were higher than those achievable using impact laboratory compaction methods. Using Superpave Gyratory Compaction could be a promising way to get higher laboratory densities than impact once and would be a more suitable method that can reasonable simulated the actual field compaction of granular foundation base layer.

Research Methodology

Origin granular base material and those treated samples with both foundry sand and reclaimed concrete aggregate were prepared using modified Proctor and gyratory compaction tests. The optimum moisture contents and maximum dry densities for each sample were determined and compared for each compaction method. Also three replicates samples of each possible combination are performed at OMC and subjected to unconfined compressive strength test.

MATERIALS AND METHODS

Materials

The materials used in this study were crushed aggregate locally available in Iraq brought from Al-Nibaee quarry at Al-Taji and used in road working, foundry sand brought from casting plants in Sheikh Omar-Baghdad city and reclaimed concrete aggregate collected from waste materials results from the waste concrete blocks of laboratory in the College of Engineering Al-Mustansiriya University.

Aggregate

The State Corporation for Roads & Bridges in Iraq ***(SCRB, 2003)*** established standard specifications for base course. The size of aggregate ranges between passing 3/4 in. (19.0 mm) and retained on No.4 sieve (4.75mm) refers

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for coarse aggregate, while the size of fine aggregate ranges between passing No.4 sieve (4.75mm) and retained on No.200 sieve (0.075mm). Figure (1) illustrates the gradations of aggregate used in this study.

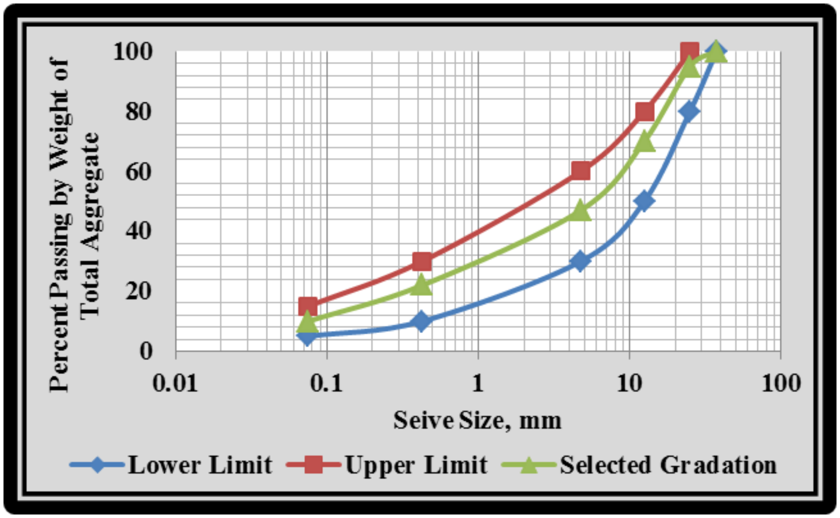

Figure 1. Specification Limits and Gradation for Base Course (SCRB, 2003)

Foundry sand (FS)

The foundry Sand could be defined as a byproduct material of metal casting both ferrous and nonferrous; it is clean, uniformly sized, sub angular to round in shape, high quality silica sand. Virgin and new sands are purchase by foundries to make casting molds, this sand reused for many times which make it eventually unsuitable for use in casting molds. Continuously, the spent foundry sand is removed and replaced with new sand. Finally, this spent portion of foundry sand either used in landfill or recycled in non-foundry applications ***(Greig R., 2017)***. Table (1) lists some of chemical and physical proprieties which depend greatly on type of casting process and industry section.

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Table 1. Typical Properties of Foundry Sand used in Study

Properites	Foundry Sand Values	Standard Specification
Specific Gravity	2.63	ASTM C 854
Bulk Relative Density, kN/m^3	19.37	ASTM C 128
Standard Proctor Max Dry Density, KN/m^3	17.3	ASTM D 698
Optimum Moisture Content, %	12	ASTM D 698
Hydraulic Conductivity (cm/sec)	10^{-7}	ASTM D 5084
Plastic Index	NP to 12	ASTM D 4318
Internal friction angle (drained)	37	ASTM D 3080
Cohesion intercept (drained), KN/m^2	0	ASTM D 3080

Plate 1. Foundry Sand Used in This Study

Reclaimed Concrete Aggregate (RCA)

The use of reclaimed concrete aggregate promised to be a technically-viable solution that offers economic and environmental advantages. Reclaimed concrete aggregate is obtained through broken large parts of concrete blocks materials. Breaking process is made after cleaning recycled Portland cement concrete materials from unwanted materials. Then, from crushing process, reclaimed grains are produced with different gradients. These different

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gradients have been separated by sieve analysis and then prepared to be used. Plate (2) shows reclaimed concrete aggregate materials. Table (2) shows a comparison Between NA & RCA Properties.

Plate 2. Reclaimed Concrete Aggregate Materials (RCA) Used in This Study

Table 2. Physical Properties of NA & RCA,(Sharma and Singla, 2014)

Property	**NA**	**RCA**
Shape and Texture	Well rounded ,smooth to angular and rough	Angular with rough surface
Absorption Capacity	0.8 - 3.7 %	3.7 - 8.7 %
Specific Gravity	2.4 - 2.9	2.1 - 2.4
L.A. Abrasion Test Mass Loss	15 - 30 %	20 - 45 %
Chloride Content	0 - 1.2 kg/m3	0.6 - 7.1 kg/m3

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Preparing Test Specimens

The preparation of specimens for tests includes washing the conventional aggregate then drying to constant weight, separate the desired sizes of aggregate by sieving and recombines with mineral filler to achieve the ***(SCRB, 2003)*** specification gradation requirements for base course. The weight of aggregate and filler are determined by multiplying its percent by the weight of final mixture.

For foundry sand the percentages (25, 50, 75 and 100) are adopted to use in mixture as replacement material with fine aggregate retained on sieve No.200, while the use of RCA is about (25, 50, 75 and 100) percentage replaced from coarse aggregate.

Compaction Process

The experimental work includes preparing the specimens using (5500) gm of aggregate with two compaction methods:

Modified Proctor Compaction Method

A mechanical compaction apparatus and a mold having an internal diameter of 6 in. (152.4mm) and 4.584 in. (116.43mm) height are used during this testing process. The compaction is carried out in five approximately equal layers with 56 blows / layer using 10 Ibs (4.54Kg) hammer with drop of 18in. (457.2mm) according to ***(ASTM D1557)***.

Gyratory Compaction Method

There are no standards or protocols to do gyratory compaction on soils yet. A superpave gyratory compactor (SGC) is used with a mold having 6 in. (150.0 mm) inside diameter and 9.842 in. (250.0 mm) height for gyratory compaction. A 1,25º gyration angle, 30 gyrations per minute frequency and 600 kPa vertical stress are used in this study according to ***(AASHTO T 312 and ASTM D 6925)***. Every specimen is compacted in one lift with 500 gyrations ***(Browne, 2006)***. (54) Samples are prepared; OMC & MDD are determined for each ratio of stabilizer and each compaction method, Table (3) and Figure (2&3). Other (54) samples are compacted at OMC for compressive strength test as shown in Plate (3).

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Table 3. Results of OMC & MDD for Compaction Tests

% Stabilizer Concentration	Modified Proctor Test		Gyratory Test		Modified Proctor Test		Gyratory Test	
	% Moisture content	Dry Density gm/cm^3	% Moisture Content	Dry Density gm/cm^3	% OMC	MDD gm/cm^3	% OMC	MDD gm/cm^3
Untreated	4.8	2.253	5.9	2.243	6.18	2.28	6.03	2.29
	6.21	2.278	6.06	2.288				
	7	2.229	6.8	2.207				
25% FS	5.8	2.287	4.51	2.261	6	2.29	5.80	2.31
	6.07	2.296	5.76	2.310				
	6.9	2.238	6.2	2.273				
50% FS	5.31	2.28	4.6	2.192	5.86	2.30	5.65	2.32
	5.9	2.3	5.58	2.317				
	5.97	2.26	6.18	2.245				
75% FS	4.8	2.187	4.06	2.291	5.30	2.32	4.83	2.34
	5.19	2.317	4.91	2.345				
	6	2.284	6.43	2.268				
100% FS	3.97	2.138	4	2.219	5.27	2.30	4.80	2.33
	5.07	2.293	4.92	2.327				
	5.96	2.265	6.5	2.124				
25% RCA	5.39	2.212	4.3	2.229	6.2	2.26	6.1	2.28
	6.27	2.259	6.03	2.280				
	7.38	2.192	7	2.241				
50% RCA	6.23	2.235	3.8	2.069	6.38	2.25	6.25	2.27
	6.4	2.251	6.12	2.267				
	6.96	2.220	8	2.147				
75% RCA	6.43	2.145	3.4	2.021	6.8	2.23	6.5	2.25
	6.76	2.226	6.5	2.249				
	7	2.204	8.2	2.045				
100% RCA	6.3	2.105	4.2	2.123	7.1	2.19	7	2.23
	7.08	2.191	7	2.228				
	8.25	2.125	8.06	2.105				

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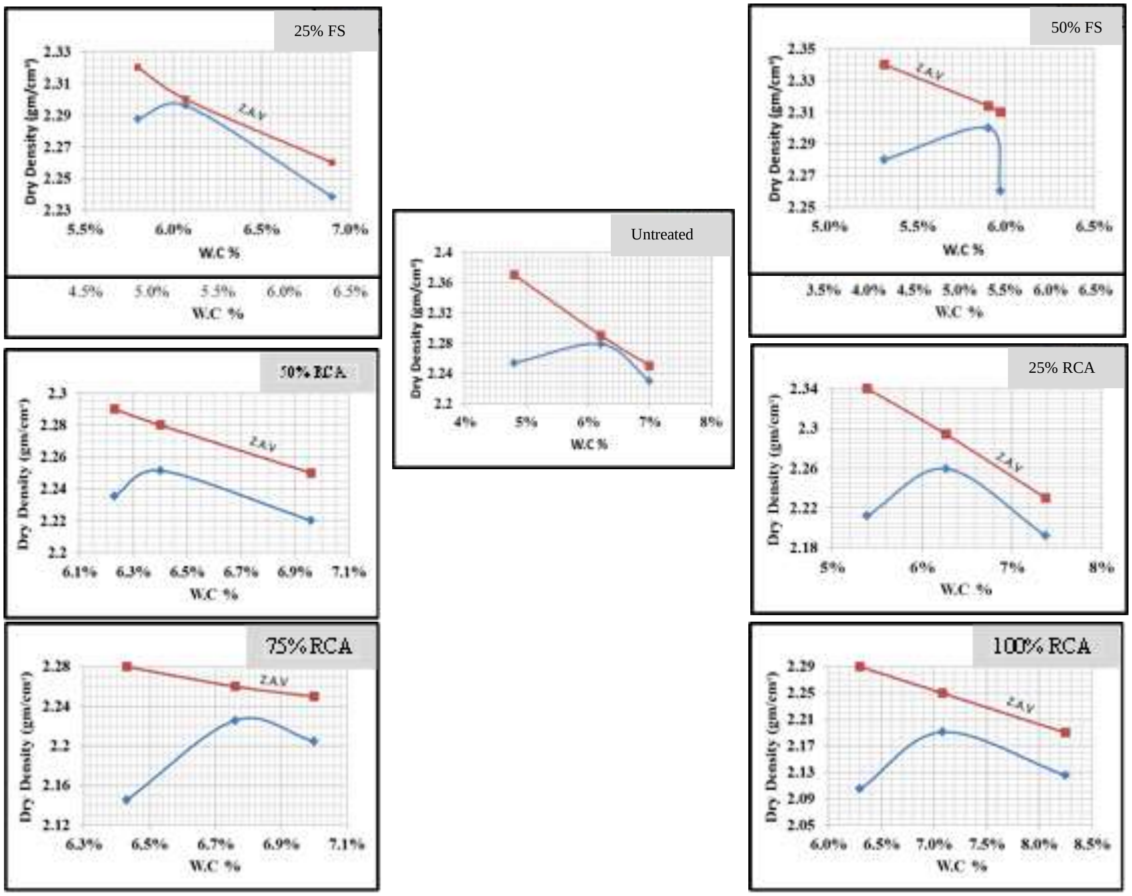

Figure 2. OMC & MDD Results Using Modified Proctor Test

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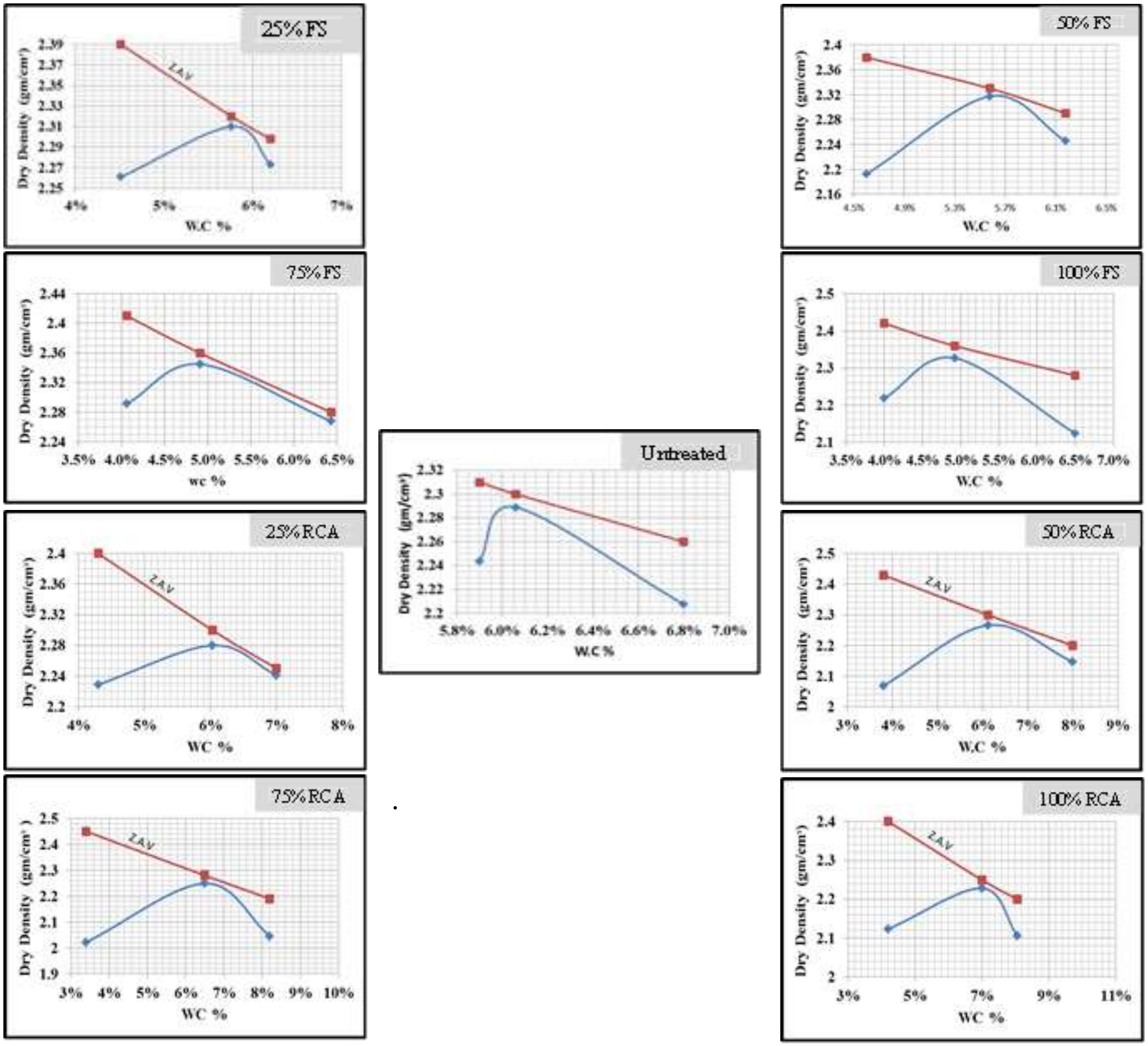

Figure (3) OMC & MDD Results Using Gyratory Test

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a) Modified Proctor Test ***b) Gyratory Test***

Plate 3. Samples Prepared with Different Compaction Method

Effect of Compaction Method and Stabilizer Types on Optimum Moisture Content and Maximum Dry Density

Stabilizer concentration is declared as a percentage of the weight of dry aggregate, while OMC is reported in each case as the percentage of water from the total weight of the dry aggregate and stabilizer.

Figure (4) illustrates the effect of stabilizer type and compaction method on OMC and MDD for granular base material treated with FS.

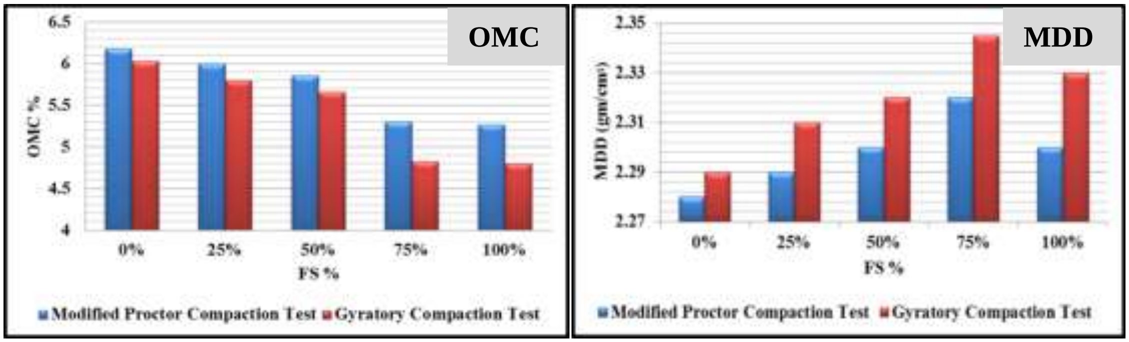

Figure 4. Effect of Compaction Method on OMC and MDD for Granular Base Material Treated with Different Percentages of FS

As the results illustrate a noticeable reduction in OMC, the OMC records (4.83) % for MDD (2.34) gm/cm^3 at 75 % FS when using the gyratory compaction method, this reduction may reach about (21.8) % meet with increment in MDD about (2.63) %, but for the modified proctor compaction method an increment of (1.75) % in MDD is obtained and the OMC is reduced by (14.2) % at the same percentage of stabilizer.
This enhanced that gyratory compaction method provide higher MDD as compared with modified proctor compaction method at minimum OMC.
Figure (5) illustrates that the values of OMC decrease and MDD's values increase for granular base material treated with different percentage of RCA compacted using gyratory compaction and modified proctor compaction methods. Same Figures exhibit a slightly changes in OMC and MDD values; this behavior attribute to the high vertical pressure and the number of gyrations that applied by superpave gyratory compactor.

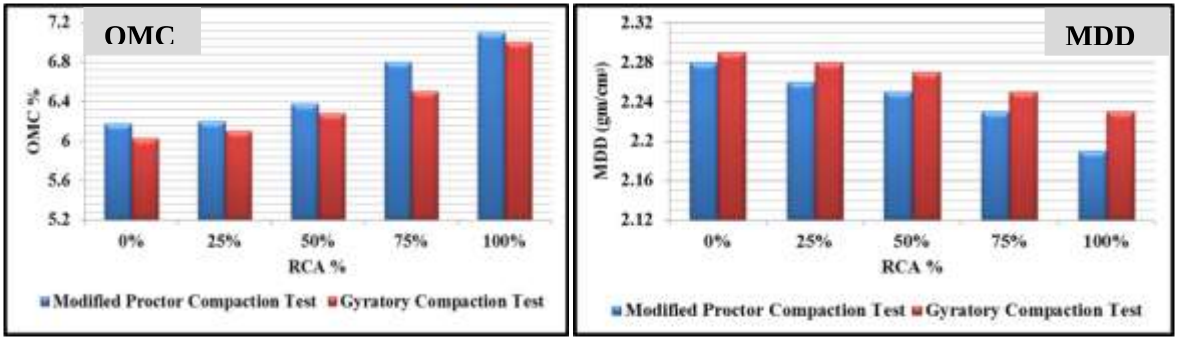

Figure 5. Effect of Compaction Method on OMC and MDD for Granular Base Material treated with RCA.

As depicted in Figure (5) the OMC's values increase due to the percentage increment of RCA in granular base material mixture, this increment in water contents is refer to high absorption capacity of the paste clinging to the RCA. On other side the dry density decrease gradually with RCA percentage increment in granular base material mixture, the reason is that the RCA have a lower relative density than that of virgin aggregate as well as the lightweight of adhered mortar can cause a decrease in density compared to aggregate of same volume.
The granular base layer treated with 100% RCA compacted with gyratory compaction method attains (2.23) gm/cm^3 MDD at (7.0) % OMC, this provide that the increment in OMC comparing with OMC of virgin aggregate for classical compaction method is about (13.3) % and the reduction in MDD is about (2.2) %. On other hand, the increment in OMC for granular base layer compacted with modified proctor method attains (14.9) % and the reduction in MDD is about (3.9) % at same percentage of RCA. This ratio of RCA achieved the highest value of unconfined compressive strength (UCS) for treated granular base layer as we will see in part (4) from this study.

Table (4) illustrates the increment and reduction in OMC and MDD values for granular base material treated with 75% FS and 100% RCA for different compaction method.

Table 4. Reduction and Increment in OMC and MDD for Granular Base Material Compacted with Different Methods and Treated with Different Percentage of Stabilizers

Stabilizer Type and Concentration	% Reduction and Increment in OMC and MDD	Modified Proctor Compaction Test	Gyratory Compaction Test
75% FS	% Reduction in OMC	14.2	21.8
	% Increment in MDD	1.75	2.63
100% RCA	% Increment in OMC	14.9	13.3
	% Reduction in MDD	3.9	2.2

Effect of Compaction Method and Stabilizer Types on Unconfined Compressive Strength

To provide higher strength for local granular base layer in Iraq and to reduce negative environmental impact, a sustainable stabilized improvement materials such as waste FS and crushed RCA have been used in this study. Table (5) and Figure (6) indicated the results of (UCS) for granular base materials treated with FS and RCA. The unconfined compressive strength test was carried out on samples according to ASTM D 2166. UCS values represent average of three samples. All samples prepared with two compaction methods, modified proctor and gyratory compaction tests.

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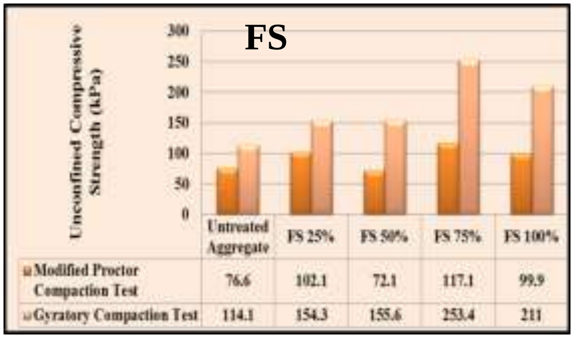
(%) Stabilizer Type	Average UCS (kPa) Modified Proctor Method	(%) Increment	Average UCS (kPa) Gyratory Method	(%) Increment
Virgin Material	76.6	0	114.1	48.9
25% FS	102.1	33.3	154.3	101.4
50% FS	72.1	5.87*	155.6	103.1
75% FS	117.1	52.87	253.4	230.8
100% FS	99.9	30.42	211	175.4
25% RCA	116.5	52.08	218.2	184.8
50% RCA	256.9	235.37	527.9	589.2
75% RCA	259.7	239.03	567.1	640.3
100% RCA	365.2	376.7	716.5	835.4

Table 5. Unconfined Compressive Strength Results

*** % Reduction**



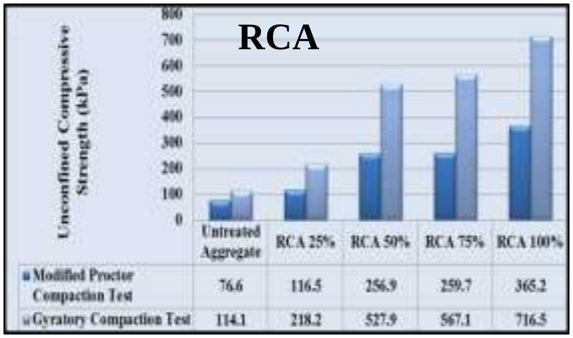
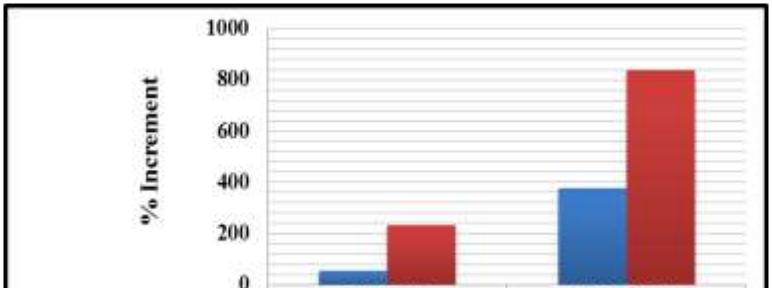


Figure (6): Effect of compaction method on Unconfined Compressive Strength for granular base layer stabilized with FS and RCA

The results for modified proctor compaction test show a reduction with UCS at 50% FS, after this ratio the UCS is increased at 75% FS which denoted as the maximum value and then decrease at 100% FS. In case of gyratory compaction test the maximum value of UCS is (253.4) kPa obtained at 75% FS which about (230.8) % greater than UCS obtained from the modified proctor compaction test for untreated material, as shown in Figure (7).
Also the results indicated that the highest value of UCS for RCA treated granular base material is (716.5) kPa obtained at 100% RCA using gyratory compaction, this value exceed the value obtained using modified proctor compaction test by about (835.4) % at (0) percentage of stabilizer.



	75% FS	100% RCA
Modified Proctor Compaction Method	52.87	376.7
Gyratory Compaction Method	230.8	835.4

Figure 7. Increment of Unconfined Compressive Strength between Two Compaction Methods for Treated Granular Base Layers.

CONCLUSIONS

1. For granular base layer with FS 75%, OMC reduced about (21.8) % and MDD increased about (2.63) % from their original values with untreated base layer when using the gyratory compaction method, while the OMC reduced (14.2) % and MDD increased (1.75) % at the same percentage of stabilizer using modified proctor compaction method.
2. The OMC increased and MDD reduced for granular base material treated with 100% RCA by about (13.3) % and (2.2) % respectively using gyratory compaction method, (14.9) % and (3.9) % using modified proctor compaction method.

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3. The gyratory compaction achieved higher strength as compared with modified proctor compaction; the reason is the rearrangement of compacted particles of granular base due to kneading and shear action which provide densely packed state.
4. The unconfined compressive strength values for granular base samples treated with 75% FS and 100% RCA compacted with gyratory compactor increased by about (230.8) % and (835.4) % respectively more than their values for untreated granular base samples with modified proctor compaction method.

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