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Research Article

Correlating the Strength Properties of Roller Compacted Concrete

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Keywords

Roller Compacted Concrete,
Compressive,
Tensile,
Flexural,
Correlation,
Strength.

Abstract

Prediction of the strength properties of roller compacted concrete from mathematical models is significant for rapid decision of the quality of the pavement. In the present assessment, roller compacted concrete slab samples have been prepared in the laboratory using 12% of Portland cement by weight of aggregates. Cube, core, and beam specimens were extracted from the slab samples and tested for compressive, indirect tensile, and flexural strength at the age of 28 days. Strength test results were corelated among each other and mathematical models were obtained. It was observed that low significance of aggregates gradation type on the compressive and tensile strength exists. However, high influence of dense gradation on flexural strength could be detected. The flexural strength of dense graded mixture is higher than that of gap graded mixtures. The compressive strength of gap graded mixture is higher than that of dense graded mixture. It can be concluded that the flexural strength is higher than the tensile strength by (2.17 and 1.24) folds for dense and gap graded mixtures respectively. The compressive strength is higher than tensile strength by (5.72 and 4.87) folds for dense and gap graded mixtures respectively. The compressive strength is higher than the flexural strength by (3.4 and 2.49) folds for dense and gap graded roller compacted concrete respectively. The obtained mathematical models exhibit high coefficient of determination and may be implemented in verification of the specific strength property based on other measured strength properties of roller compacted concrete.

1. Introduction

Adamu et al., [1] incorporate additives such as polymers and fibers into the roller compacted concrete mixture to absorb the deformation and strain energy caused by the repetitive loadings, and to improve the flexural strength of the pavement. Lastly response surface methodology (RSM) analysis was used to develop model for predicting the flexural toughness and ductility index of RCR using CR and NS as the variables. The analysis of variance (ANOVA) showed that the developed models have a good degree of correlation and predicting ability. Hesami et al., [2] investigated the mechanical properties of roller compacted concrete mixture. The compressive strength, tensile strength, and flexural strength of roller compacted concrete mixtures were determined at (7, and 90) days. The test results showed the relationships between the splitting tensile strength, flexural strength, and compressive strength could be utilized. The flexural strength is 0.9 of the compressive strength, while the Splitting tensile strength is 0.5 of the compressive strength. Such correlations vary from the behavior of traditional concrete. The obtained models are listed in Table 1. Adamu et al., [3] used high-volume fly ash as partial replacement for cement to prepare roller compacted concrete mixture while nano-silica was used as an additive to cementitious materials. Response surface methodology was implemented to design, develop statistical models, and carry out the optimization for the mixtures using the variable fly ash and nano-silica content. The mixtures were tested for compressive, flexural, and splitting tensile strengths. The proposed models demonstrated a high correlation among the variables and responses. In Ashrafian et al., [4] study, gene expression programming was implemented to propose novel predictive formulas for the compressive strength of roller compacted concrete which was formulated based on important factor used in mixture proportion. Mean absolute error, root mean square error, and correlation coefficient have been implemented as the internal standard statistical measures and external validation. It was revealed that the artificial neural network ANN model is more capable in predicting the compressive strength of roller compacted concrete. Furthermore, the resistances estimated by ANN have the highest and lowest compliance with the actual compressive strength. It was concluded that the volumetric/weighted (dimensional) model which was evaluated by parametric study, sensitivity analysis, and external validation has better performance than the other models. Mousavi et al., [5] stated that there is no physical relationship between characteristics of concrete and the nondestructive NDT test results. Therefore, using the NDT method in the evaluation of the compressive strength is faced with some errors and need calibration. The use of mathematical and evolutionary models such as fuzzy logic, neural networks, artificial intelligence, and genetic algorithm can be managed based on empirical studies. Two different nondestructive techniques were implemented by Hadianfard and Nikmohammadi, [6] to estimate the compressive strength of the conventional and fiber roller compacted concretes. The first technique was ultrasonic pulse velocity while the second was Schmidt hammer test. Through artificial intelligence concepts and using gene expression programming, some applicable formulae were proposed for prediction of roller compacted concrete strength. The compressive strength was measured by Marín-Uribe and Navarro-Gaete, [7] using cubic specimens and the flexural strength was measured for beam specimen. The study proposes logarithmic and power equations that allow the estimation of the flexural strength of a concrete mix as a function of its compressive strength. Linear or power models are proposed to predict beam flexural strength. Statistical analyses show that the proposed prediction models can be considered sufficiently accurate, and their use is justified. As reported by Ahmed et al., [8], compressive strength has been more reliable and convenient to estimate the quality of the

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concrete and used through correlation to estimate its flexural strength. It is known that this relationship is not a direct proportion. However, it is commonly held that the compressive strength is approximately ten times the flexural strength, which implies a fixed relationship between these two variables. Chhorn et al., [9] revealed that the relationship between the compressive and tensile strengths of the roller compacted concrete should be analyzed. Regression equations are developed to estimate the indirect tensile strengths, which are known as flexural and splitting tensile strengths, using the compressive strength of the RCC. The results show that the flexural strength of roller compacted concrete is within the predicted values obtained from the conventional concrete equations for a given compressive strength. In contrast, the splitting tensile strength is relatively lower than that of the conventional concrete for the given compressive strength. A regression analysis was conducted on the relationship between the compressive and flexural strengths. Among the different types of linear regression equations evaluated, the power equation type was found to be the most suitable. However, the coefficient of determination was low. The obtained models are listed in Table 1.

The aim of the present investigation is to correlate the strength properties of roller compacted concrete pavement (compressive, tensile, and flexural) using mathematical models. Roller compacted concrete slab samples will be constructed, cubes, beams, and cylindrical specimens will be extracted from the slab samples. Specimens will practice mechanical testing to evaluate the strength properties. Data will be analyzed and corelated for obtaining the mathematical models.

Table 1. Proposed models of strength properties of roller compacted concrete by researchers.

Researcher	Model	R^2
Chhorn et al., [9]	Flexural strength = 0.678 (compressive strength) 0.605	0.59
	Flexural strength = 1.143 (compressive strength) 0.369 x (curing days) 0.11	0.72
	Tensile strength = 0.47 (compressive strength) 0.511	0.62
Hesami et al., [2]	Splitting tensile strength = 0.5 compressive strength	0.80
	Flexural strength = 0.9 compressive strength	0.83

2. Materials and Methods

2.1. Portland Cement

Ordinary Portland cement Type I as per Iraqi specification No.5, [10] was implemented. The physical properties of the Portland cement are listed in Table 2.

Table 2. Physical Properties of Portland Cement.

Physical Properties	Test Result	Limits of Iraqi specification No.5, [10]
Specific surface area, Blain's method, m^2/kg	341	≥ 230
Soundness, Autoclave's Method, %	0.03	< 0.8
Setting time, Vicat's method		
Initial setting hour : min	2:35	≥ 45 min
Final setting hour : min	4:45	≤ 10 hours
Compressive strength		
3 days N/mm^2	18.8	≥ 15
7 days N/mm^2	23.3	≥ 23

2.2. Coarse and Fine Aggregates

Crushed aggregates with 25.4 mm nominal maximum size and fine aggregates with 4.75mm maximum size were obtained from Nibae and Al-Ukhaider quarries respectively. The physical properties of coarse and fine aggregates are determined according to ASTM C127, and C128, [11]. Test results and listed in Table 3.

Table 3. Properties of Coarse and Fine aggregates

Type of aggregate	Bulk Specific Gravity	Density (kg/m^3)	Absorption (%)	SO^3 (%)
Crushed coarse aggregate	2.56	1600	1	0.06
Fine aggregate	2.45	1780	3.13	0.45

2.3. Water

Potable water of Baghdad area is used in RCC mixture preparation and Curing.

2.4. Preparation of Dense and Gap Graded Mixtures

The coarse and fine aggregates are washed, oven dried, then sieved to different sizes and stored in plastic containers. Aggregates were recombined to satisfy the requirements of gap or dense gradation with 25 mm nominal maximum size of aggregate. The dense gradation satisfies the Iraqi Standard Specification for Roads and Bridges SCRB, [12], while the gap gradation satisfies the British Standards B.S., 882, [13]. The grain size distribution of both mixtures is demonstrated in Table 4. The concrete mix is designed according to ASTM D-1557, [14] standard. This proportioning method involves establishing a relationship between the density and moisture content of the mix by compacting the mix in molds of 101.6 mm diameter and 116.4 mm height. Oven dried coarse and fine aggregates were implemented. Five different percentages of cement content are implemented (10, 12, 14, 16, 18) by weight of oven dried aggregate and six different percentages of moisture content of a range of (4 -8%) with 1% increment are implemented for determination of the dry density-moisture content relationships. After mixing thoroughly by hand, the mixture was poured into cylinder mold in five successive layers. Each layer had practiced 25 blows of the modified Proctor hammer with 4.5 kg weight, falling from 450 mm height according to ASTM D-1557, [14] (modified proctor) test method. Similar procedure was reported by Sarsam, [15]. A total of 48-cylinder samples were prepared and the dry density of each specimen was determined. The moisture-density relationship was obtained for each type of mixture. Details of proportioning could be referred to Sarsam et al., [16]. A moisture-density test is used to determine the optimum moisture content and maximum density of RCC mixtures for each mixture and the optimum cement content was selected to be 12 % as presented in Sarsam, [17].

Table 4. Grain size distribution Implemented.

Sieve Size (mm)	25.4	19.2	12.5	9.5	4.75	0.6	0.075
Percent Passing by Weight							
Dense Gradation	100	98	85	76	62	26	7
Gap Gradation	100	95	80	75	70	17	7

2.5. Preparation the Roller Compacted Concrete Samples

The mold used to prepare roller compacted slab samples has internal dimensions of (38 x 38 x 10) cm while the roller has (16cm) diameter and (33cm) length and its self-weight was 36 kg. The required weight of the mixture of aggregates, cement, and water for compacting a slab sample to the target density was combined, mixed, and placed in the mold of size (38× 38 × 10) cm and subjected to initial compaction on a vibrating table for 3 cycles of 30 seconds time interval. Then, the mold was placed in front of the roller compactor and subjected to three stages of rolling based on the work done by Sarsam [15]. Each rolling stage was conducted by applying 10 passes of the roller for each rolling direction. This number of passes was felt to be suitable to achieve the good rolling with lowest labor power. The first stage represents the primary compaction which was performed by applying 10 passes with 1.1 kg/cm width load for each direction. The second stage represents the breakdown compaction which was conducted by applying 10 passes using a load of 3.2 kg/cm width for each direction. The third stage represents the final compaction which is demonstrated by application of 10 passes of the roller compactor under 5.3 kg/cm width load for each direction. The rolling process is shown in Figure 1. After finishing the rolling, the slab sample was covered tightly with polythene sheet and left to cure for 24 hours at room temperature of 30 ± 2°C. The samples were withdrawn from the mold and immersed in a water bath for 27 days for curing at 30 ± 2°C. Sawed cubes specimens of (10 x 10 x10) cm were obtained from the roller compacted slab with the aid of diamond saw according to the procedure by ASTM C42/C42M-[11].

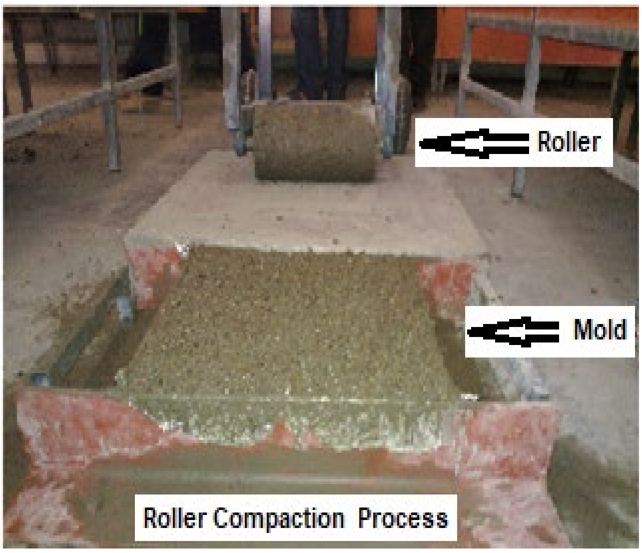

Figure 1. The Roller Compaction Process

The testing for compressive strength was conducted after 28 days curing according to B.S.1881 part 116 [13]. Core specimens of 6.2 cm diameter and 10 cm height were obtained from the slab samples. The core specimens were subjected to splitting tensile strength determination according to ASTM C496- [11]. Sawed beams of sizes (38 × 10 × 8) cm were obtained from the slab samples and tested using three-point and four-points loading schemes. Testing of beams was conducted according to ASTM C78- [11]to determine the flexural strength. Table 5 demonstrates the quantities of materials implemented in the preparation of the roller compacted concrete specimens.

Table 5. Quantities of materials adopted

Gradation	Material	Mixing weight(gm)
Dense	Cement	287
	Water	144
	Fine aggregate	635
	Coarse aggregate	1760
Gap	Cement	282
	Water	164
	Fine aggregate	400
	Coarse aggregate	1947

3. Results and Discussions

3.1. Influence of Aggregates Gradation Type on Strength Parameters of Roller Compacted Concrete

As demonstrated in Figure 2, it can be detected that for indirect tensile strength test (ITS), uniform scatter of test results around the 45° line could be observed.

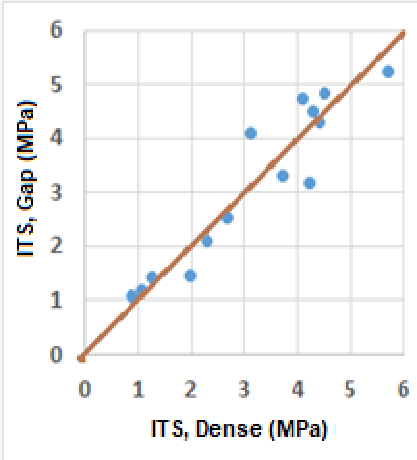

Figure 2. Influence of Gradation on ITS

This can be revealed as that low significance of aggregates gradation type on the ITS exists. This may be attributed to the fact that the splitting tensile strength is mainly dependent on the bonding of aggregates with cement binder and the influence of particles interlock is minimal.

For the flexural strength test, it can be observed from Figure 3 that more than 50 % of the scatter of test results is below the 45° line indicating high influence of dense gradation on flexural strength. This could be attributed to the combined role of aggregate particles interlock and the bond between particles by cement, the dense gradation can provide better flexural resistance than gap graded mixture.

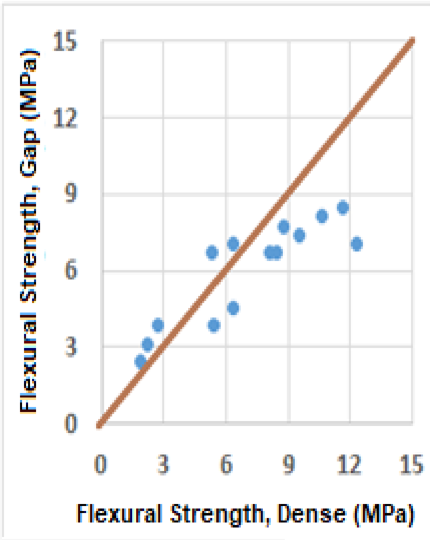

Figure 3. Influence of Gradation on Flexural Strength

Finally, for the compressive strength test, a uniform distribution of the scatter of test results around the 45° line could be noticed in Figure 4. This may indicate low significance of aggregates gradation type on the compressive strength of roller compacted concrete. Such finding agrees with Shafigh et al., [18].

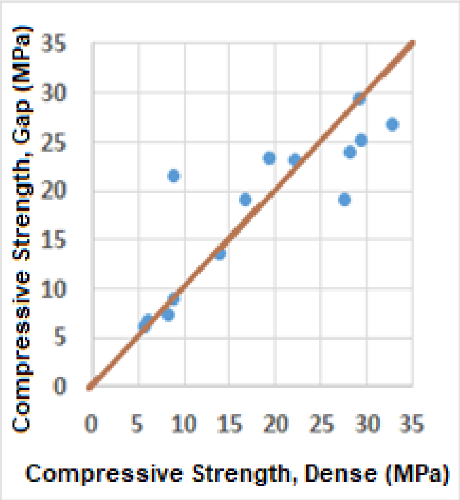

Figure 4. Influence of Gradation on Compressive Strength

3.2. Correlating the Strength Parameters for Roller Compacted Concrete

Figure 5 exhibits the correlation of flexural and tensile strength parameters for dense and gap graded roller compacted concrete, it can be observed that as the flexural strength increases, the tensile strength increases. The mathematical models are presented in Table 5. However, the flexural strength of dense graded mixture is higher than that of gap graded mixtures. Similar behavior was reported by Sarsam, [15]. This could be attributed to the fact that the flexural strength is dependent on the particles interlock, and lower voids which is accomplished by the presence of aggregates particles of different sizes as in the case of dense gradation, while for gap gradation, some missing particles sizes exists while the sand content is higher which impair the particle interlock process. On the other hand, the flexural strength of roller compacted concrete is higher than the tensile strength by (2.17 and 1.24) folds for dense and gap graded mixtures respectively. test results agree with Chhorn et al., [9].

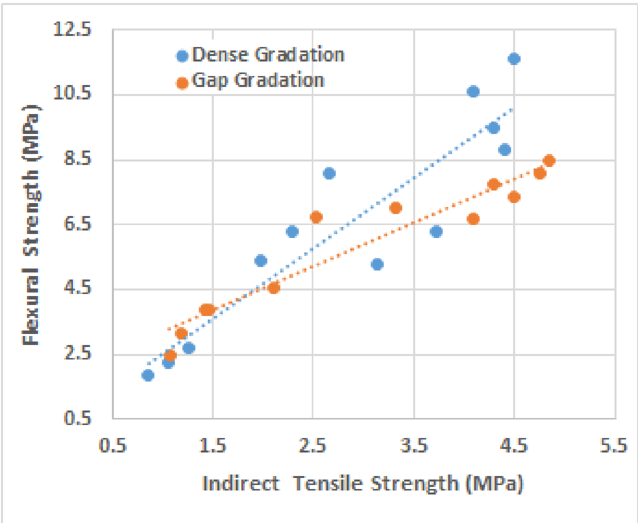

Figure 5. Correlation of Flexural and Tensile Strength Parameters for Roller Compacted Concrete

Figure 6 exhibits correlation of compressive and flexural strength parameters for dense and gap graded roller compacted concrete, it can be noticed that the compressive strength of dense graded mixture is lower than that of gap graded mixture.

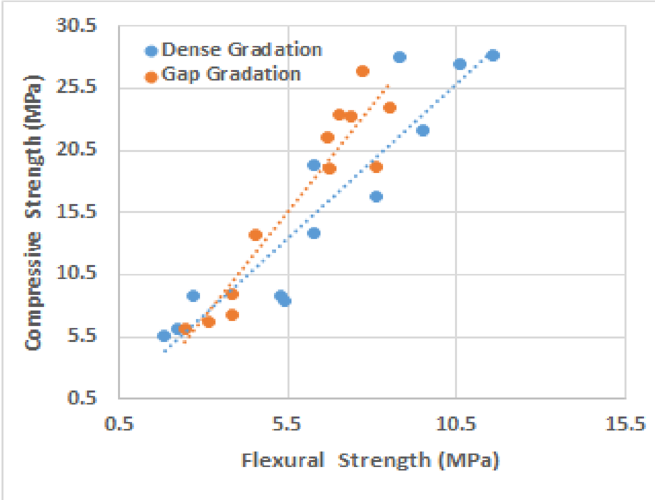

Figure 6. Correlation of Compressive and Flexural Strength Parameters for Roller Compacted Concrete

Such variations in compressive strength between dense and gap mixtures could be attributed to the structure of the roller compacted concrete and to the geometry of the tested specimen. Similar behavior was reported by Vahidi et al., [19]. The compressive strength of roller compacted concrete is provided through the bond between the aggregate particles offered by the cement binder and the particles interlock which can resist the compressive stress. It can be noted that dense gradation provides higher intercept value as compared with gap gradation for the compressive-tensile strength models. However, the compressive strength of roller compacted concrete is higher than tensile strength by (5.72 and 4.87) folds for dense and gap graded mixtures respectively. The compressive strength of roller compacted concrete is higher than the flexural strength by (3.4 and 2.49) folds for dense and gap graded roller compacted concrete respectively. Figure 7 exhibit the correlation of compressive and tensile strength parameters for roller compacted concrete, it can be noted that there is low significance in the variation between the behavior of dense and gap graded mixtures. Such findings do not match with the results reported by Hesami et al., [2].

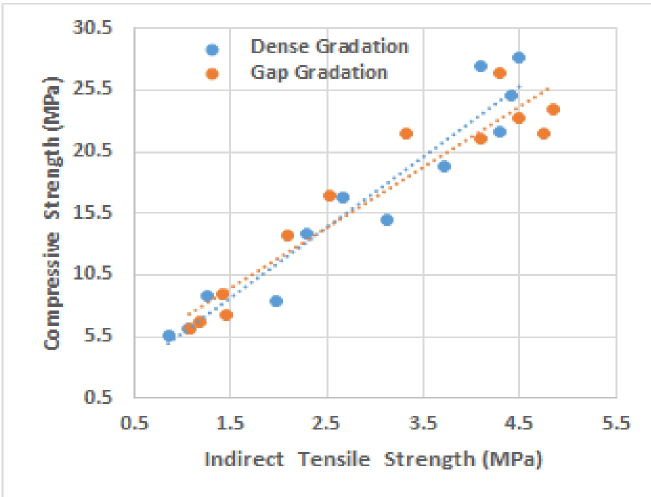

Figure 7. Correlation of Compressive and Tensile Strength Parameters for Roller Compacted Concrete

Table 6 summarizes the obtained mathematical models for roller compacted concrete.

Table 6. Mathematical Models of Strength Parameters

Gradation Type	Mathematical Model	R2
Dense	Compressive Strength (MPa) = 5.722 ITS (MPa) + 0.0655	0.922
	Flexural Strength (MPa) = 2.179 ITS (MPa) + 0.3368	0.836
	Compressive Strength (MPa) = 3.426 Flexural Strength (MPa) – 0.3556	0.892
Gap	Compressive Strength (MPa) = 4.876 ITS (MPa) + 2.149	0.910
	Flexural Strength (MPa) =1.346 ITS (MPa) + 1.852	0.910
	Compressive Strength (MPa) = 2.491 Flexural Strength (MPa) – 0.8581	0.858

4. Conclusions

Based on the limited testing program and the limitations of materials investigated, the following conclusions may be addressed.

- The flexural strength of roller compacted concrete is higher than the tensile strength by (2.17 and 1.24) folds for dense and gap graded mixtures respectively.
- The compressive strength of roller compacted concrete is higher than tensile strength by (5.72 and 4.87) folds for dense and gap graded mixtures respectively.
- The compressive strength of roller compacted concrete is higher than the flexural strength by (3.4 and 2.49) folds for dense and gap graded roller compacted concrete respectively.
- The flexural strength of dense graded mixture is higher than that of gap graded mixtures, while the compressive strength of dense graded mixture is lower than that of gap graded mixture.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. He has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1.] Adamu M., Mohammed B., Shafiq N. Flexural performance of nano silica modified roller compacted rubbercrete. International Journal of advanced and applied sciences 4(9): September (2017). P. 6-18. http://Doi:10.21833/ijaas.2017.09.002.

[2.] Hesami, S., Modarres, A., Soltaninejad, M., & Madani, H. Mechanical properties of roller compacted concrete pavement containing coal waste and limestone powder as partial replacements of cement. Construction and Building Materials, 111, May (2016). P. 625–636. http://doi:10.1016/j.conbuildmat.2016.02.116.

[3.] Adamu, M., Mohammed, B. S., & Mohd, S. L. Mechanical properties and performance of high-volume fly ash roller compacted concrete containing crumb rubber and nano silica. Construction and Building Materials, 171, May (2018). P. 521–538. http://doi:10.1016/j.conbuildmat.2018.03.138.

[4.] Ashrafian A., Gandomi A., Rezaie-Balf M., Emadi M. An evolutionary approach to formulate the compressive strength of roller compacted concrete pavement. Measurement, Volume 152, February (2020) 107309. https://doi.org/10.1016/j.measurement.2019.107309.

[5.] Mousavi S., Aminian P., Gandomi A., Alavi A., and Bolandi H. A new predictive model for compressive strength of HPC using gene expression programming. Advances in Engineering Software, 45, (2012), P. 105–114.

[6.] Hadianfard M. and Nikmohammadi A. Compressive strength prediction of roller-compacted concrete using nondestructive tests through artificial intelligence. Advances in Engineering Research (AER), volume 72 (2017) International Conference on Architectural Engineering and Civil Engineering (AECE-16). P.344-348. http://creativecommons.org/licenses/by-nc/4.0/.

[7.] Marín-Uribe C., and Navarro-Gaete R. Empirical relationships between compressive and flexural strength of concrete containing recycled asphalt material for pavement applications using different specimen configurations. Materiales de Construcción, Vol. 71, Issue 342, April-June (2021), e249. https://doi.org/10.3989/mc.2021.11520.

[8.] Ahmed, M., El Hadi, K., Hasan, M., Mallick, J., Ahmed A. Evaluating the co-relationship between concrete flexural, tensile strength and compressive strength. Int. J. Struct. Eng. 5 (2). (2014). P. 115–131. https://doi.org/10.1504/IJSTRUCTE.2014.060902.

[9.] Chhorn, C.; Hong, S.J.; Lee, S.W. Relationship between compressive and tensile strengths of roller-compacted concrete. J. Traffic Transp. Eng. 5 [3], (2018). P. 215–223. https://doi.org/10.1016/j.jtte.2017.09.002.

[10.] Iraqi Organization of Standards, (1984). IOS 5: 1984, for Portland cement.

[11.] ASTM, American Society for Testing and Materials, ASTM: Road and Paving Material, Vehicle- Pavement System, Annual Book of ASTM Standards, Vol. 04.03. (2016). www.Astm.org.

[12.] SCRB, State commission of roads and bridges, Standard specifications for roads and bridges. Ministry of Housing, and Construction, (2003). Iraq.

[13.] British Standard 882. Concrete Aggregates, British Standards Institution, London, (1965).

[14.] ASTM D-1557, Standard Test Method for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10Ib (4.54 kg) Hammer and 18-in. (457-mm) Drop, Annual Book of ASTM Standards American Society for Testing and Materials. 04(8): (2002). P. 206–210. www.Astm.org.

[15.] Sarsam S. Evaluation of Roller Compacted Concrete Pavement Properties, Engineering and Development, Scientific Journal of AL-Mustansiriah University, 6 (2002) P.59-74.

[16.] Sarsam S., Salih A., Ghazi S. Effect of Hydrated Lime on the Properties of Roller Compacted Concrete. Journal of Engineering Number 3 Volume 19 March. (2013), P. 377-387.

[17.] Sarsam S. I. Assessing the Influence of Aggregates and Cement Types on Fresh Roller Compacted Concrete Mixture. International Research Journal of Multidisciplinary Technovation, Vol 3, Issue 3, (2021). Asian research Association. P. 23-31. DOI: https://doi.org/10.34256/irjmt2134.

[18.] Shafigh P., Hashemi M., Nam B., Asadi I. Laboratory comparison of roller-compacted concrete and ordinary vibrated concrete for pavement structures. Građevinar 72 (2020) 2, P.127-137. https://doi.org/10.14256/JCE.2572.2018.

[19.] Vahidi, E., Malekabadi, M., Rezaei, A., Roshani, M., and Roshani, G. Modeling of mechanical properties of roller compacted concrete containing RHA using ANFIS. Computers and Concrete, 19(4), (2017), P. 435–442.

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