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NONLINEAR SIMULATION ANALYSIS OF MECHANICAL BEHAVIOUR OF RUBBERIZED CONCRETE

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ABSTRACT: The main objective is to simulate the representation of rubber concrete with different percentages (0, 20, 40, 60, 80, 100%) of rubber using a finite element approach with ANSYS V.15 software to evaluate the behavior of concrete under the influence of mechanical force by using a standard cylinder to calculate its compressive strength, elasticity modulus and displacements for comparison with the previous experimental study, which showed a very close agreement of 5 to 12% when compared between them. The results showed that when the percentage of rubber increases, it leads to a decrease in the compressive strength, that is, its resistance, and an increase in the corresponding displacements and deformations that occur in them, as a result of the concentration of these stresses in the rubber limits. The results also showed that the meshing distribution of the analyzed elements by the ANSYS gave higher values of compressive strength and a decrease in the corresponding displacements when they were regular i.e. homogeneous compared to the irregular ones. Finally, through statistical analysis, it was found that the mean and arithmetic mean were acceptable and close when comparing the theoretical and practical results.

Keywords: Numerical simulation, compressive strength, rubber concrete, ANSYS, Elastic modulus of Concrete.

1. INTRODUCTION

The recycling of materials to benefit from that in life applications and to get rid of debris or reduce it, including the use of discarded rubber chips in concrete applications began in the early 1990s. These chips, when added, have properties related to non-structural applications. Where studies were conducted about it and the formulation of two-dimensional modeling, while the three-dimensional simulation of rubber concrete in its initial stage [1-3]. This study included the formulation of analytical modeling of rubber concrete using ANSYS software [4] to verify the mechanical stress properties, as it enables the estimation and evaluation of these properties through the available elements and the possibility of analysis by formulating simulations of models that are homogeneous and heterogeneous provided by the ANSYS software [4] within its environment and which can represent the properties of those material and modulus of plasticity. Through these results and comparison, it can conduct more experiments to reach the optimal ratios and the amount of stress related to that i.e rubberized concrete [5,6]. Analysis by finite element techniques is the formulation of simulation models, which enables the prediction of the behavior of the materials included in the components of structures and evaluate it under the influence of different loads imposed on them. Also, conducting practical experiments in the laboratory or the actual reality of the different materials or parts of the facilities is expensive and requires a longer period, as the analysis by the specific elements saves time and is more cost-effective [6]. Through the finite elements, any members or part can be divided into small elements in which the response can be evaluated by a specified number of degrees of freedom. Compounds of structure or parts analyzed by finite elements can be evaluated by a set of functions that are provided at the nodes connecting them. Most solid and geometric products are nonlinear [6-9]. The nonlinear behavior of materials is different from the geometric nonlinear behavior and a distinction must be made between them. As the nonlinear behavior of the materials contains a nonlinear strain-strain relationship, which requires adding the plastic response to the generated part [10]. The accuracy of the models can be increased through the density of the meshes and the properties of the materials, i.e. concrete and synthetic rubber, as well as the criterion of convergence when compared [11]. Vasudevan et al. [12], presented a useful study on the subject of concrete modeling by the specific elements. The ANSYS [4] program is an effective tool in formulating simulations of concrete models whose behavior is non-linear.

2. LITERATURE REVIEW OF RUBBER MATERIALS

Rubber concrete or crumbed rubber concrete (CRC) is the term used to describe the concrete which consists of crumbed rubber that replaces the sand as the main constituent in concrete. Rubber is a polymeric material consisting of long partial chains. It is also called elastic-plastic due to its mixture consisting of elastic and polymeric strings. Rubber is used in various engineering applications and the production of a variety of products such as tires and industrial sealing compounds, as well as in the production of materials used in anti-vibration applications. Rubber cannot deform despite being sub-jested to forces over 500% [4, 5, and 12]. The question arises about the passivity of simulating the mechanical behaviors of CRC using FEM. ANSYS software package program [4] is a good tool in formulating simulations to analyze the behavior of these components i.e (rubber). The accuracy of the design and simulation results depends on the stress-energy and the accurate estimation of the components of the material. It is possible through a program to simulate rubber by hyperplastic compounds. The rubber response is determined by the stress pressure within the material, while its functional parameters are determined by uniaxial, biaxial, and shear tests. Since no experimental values are available for tire rubber, the material parameters can be derived by constructing the flexural energy curve i.e hyperelastic materials parameters involves the incompressibility and shear modulus [12, 13,14].

Ganjian et al. [15], conducted rubber concrete experiments by replacing the coarse aggregate with rubber for the first group, while the second group was replaced with cement discarded tire powder. Replacement ratios in two mixtures by weight were about (5%, 7.5%, and 10%). During the examination, a decrease in the resistance to compression was found when the percentage of rubber was increased about (5-23%). Also, that found the rubber chips concrete has lower compressive strength compared to the ground rubber. It was also found that the calculated concrete modulus of elasticity decreases for both mixtures, but the difference between the rubber chips and the ground ones was small. This is due to the low elastic modulus of rubber tires.

Author, Shinde, and Patel [16] have been modeled the resistance to compression of the compound by its primary functions. Where the coarse aggregate was replaced with rubber for the experiment about 5% and periods 0 to 20%. MIF is a method of analysis that is based on the elasticity theory and is used to accurately assess stresses and displacements. Analysis of the properties of materials is done by their determinants. MEF was used to verify the validity of the discrepancy between stresses and displacements for the practical part. It was concluded that the amount of stress and displacements are close compared with the results of the examination. It was also shown that the forces of pressure and density for models decrease with an increasing percentage of rubber.

Lv et al. [17], developed practical experiments representing the replacement of lightweight aggregates with rubber. The combined eleven designs for mixing with rubber substitutes and during periods about 10%.That found a decrease in the compressive strength of concrete containing rubber by 85% when replacing the aggregate with rubber, where the amount of compressive strength was 41.5 MPa, while the strength of the mixture 100% decreased by about 7.8 MPa. The maximum variation in the amount of strength was about 50% of the levels of replacement with rubber, and this is because the amount of hardened concrete has decreased.

Jafari and Toufigh [18], conducted practical experiments to evaluate the mechanical properties of polymeric concrete containing rubber. It was replaced with rubber as crumbs or chipped in different proportions 10%, 20%, and 30% on intervals. Both destructive and non-destructive tests were conducted, and they found a decrease in the compressive strength of concrete in the range of 24.1%, 52.6%, and 74.7% compared with the cantonal sample. This decrease was because rubber has a lower strength compared to the compressive strength of concrete. The models that were examined failed due to the disengagement between concrete and rubber particles. It was also found that the modulus of elasticity tends to decrease gradually when increasing the percentage of rubber that contains a high concentration of the interfaces as a result of its ductility.

Zheng et al. [19] studied the effect of replacing the coarse aggregate with rubber, which was from crushed and ground tires. The modulus of elasticity and compressive strength of rubber concrete was analyzed at proportions of 15%, 30%, and 40% replacement of coarse aggregate with rubber in the components of the mixture. The goal of this study was to find a relationship between strength and modulus of elasticity for mixtures that contain different substitution ratios i.e replacement ratios of aggregate. The modulus of elasticity is measured from the stress-strain curve when checking the stress of concrete. A decrease in the compressive strength of concrete was also found, which was evaluated by a cylinder with dimensions of 150 diameters and 300 lengths according to ASTM standards. This decrease at rates of 22.3%, 45.8%, and 53.3% for each ratio of volume replacement of coarse aggregate by rubber chips.

Huang et al. [20], conducted tests of a composite model containing multiphase particles. The model is made of rubble and the surrounding transition area, i.e. between them, cement mortar, and rubber. It was replaced by rubber in proportions of 15%, 30%, and 45% of the concrete volume. Strain analysis was carried out between course and rub-bar aggregates in a concrete matrix. So that the imposition of bonding between them i.e. all the components is similar. As in the research, a decrease in the compressive resistance was found and it increased with an increase in the percentage of rubber replacement. It was also found that the stresses were concentrated in the cement mortar area surrounding the rubber chips. Therefore, its increase results in a crack in the model. Also, the size of the rubber flakes whenever it decreases leads to a decrease in stress concentration. Also, the use of high stiffness rubber was found to reduce stress concentration.

Topçu [21], developed a practical examination model to evaluate the compressive strength when replacing rubber at rates of 15%, 30% and 40%, where there was a decrease in the compressive strength with an increase in the percentage of replacement with rubber in the range of 12-19%.

Bantu et al. [22], formulated a two-dimensional simulation of the representation of rubber concrete whereas, the ANSYS 14 program was used for modeling compression pressure analysis when replacing coarse aggregates with rubber in proportions of 5%, 10%, and 15%. To represent the materials, a highly elastic model was used in which the properties of the materials were determined individually for the aggregate. Plane 183 was used to represent the models and materials through analysis and evaluation based on measuring the compressive strength of the model and the different replacement ratios. The results indicated that the compressive forces decreased when the rubber percentages increased.

Li et al. in [23], analyze using the specific finite elements provided by the ANSYS program the concrete containing fibers and rubber chips. The aim was to ascertain the concentration of stresses and their effect on the fibers and rubber. In the modeling, a triangular element with three nodes was used, and the model was defined as a composite component containing rubber, and the process was carried out in two stages within the concrete of its matrix. Rubber is designed as a single unit within a matrix of the concrete. During the analysis, it was found that the presence of fibers results in a low concentration of stresses in the concrete, and on the contrary, rubber contains high concentrations of stresses in concrete.

Mendis et al. [24], conducted a model analysis to show the effect of rubber on the behavior of friable rubber concrete under compressive pressure. The finite elements were modeled by taking cylindrical concrete samples with a diameter of 100 mm and a length of 200 to calculate the compressive strength of concrete. Where that's found a decrease in the compressive resistance with an increase in the proportion of rubber and this study was conducted using a special analysis program Atena 3-D V5 for that [22,25]. The method also included the use of the modulus of elasticity, plasticity, compressive strength, and tensile strength of the materials that make up the concrete, where the stiffness base was determined for evaluating the nonlinear behavior of the models. The meshes were formed by formulating the model that contains 8 nodes using the brick element. It was found that the practical and numerical methods are close in terms of the behavior of any elastic modulus and compressive forces with a slight increase after the emergence of the yield point as a result of this increase in rubber this trend for numerical analysis [9, 22]. Despite several studies addressing the mechanical properties of rubber concrete, there is still an opportunity to model these properties using FEM. Therefore, this study aims to simulate the amount of rubber in concrete with different percentages (0, 20, 40, 60, 80, and 100%) of rubber using a finite element approach with ANSYS V.15 software to evaluate the mechanical behavior of concrete under the influence of mechanical force.

3. STEPS OF METHODOLOGY

3.1 Models Geometry

Models were simulated to study their nonlinear behavior by representing experimental models from the previous study [26], whose laboratory investigations were conducted by the researcher [26]. It included mixtures consisting of a mix of water, cement, sand, and lightweight coarse aggregate. Natural sand and coarse rock aggregates were formed to be fine aggregates [27, 28]. The rubber used in the mixtures was treated to remove the steel fibers and the textile fibbers formed in the concrete. The weight of the rubber unit per cubic meter of concrete was 560 kg/m3 [26]. The rubber granules that were used in the experimental program were (0.119 to 1.27 cm), which was obtained by cutting tires mechanically [26]. The components of the mixtures that were prepared from previous studies can be observed in Table 1 [26]. The simulated model's properties are based on a previous study [26]. The characteristics included dimensions, loads, and supports to the models. The dimensions of the models included taking samples of compression cylinders (150x300 mm) and several 36 models [26]. The samples layout and setup under compressive test as shown in Fig.1. The supports for the models were prepared using a rigid layer at the bottom and the loads were applied to the upper layer of it [26]. To evaluate the compressive strength of models to comparison with the experimental test by dividing the force applied to the cylinder by its cross-sectional area according to standard specification ASTM C39 [29]. Also, the Calculation of the modulus of elasticity for the models was carried out according to the standard specification ASTM C469 [30] by taking the linear part region of the load-strain curves.

3.2 Parameters Properties of Materials

The parameters characteristics of the models that were simulated by the ANSYS software package V.15 [4] program including concrete and rubbers reported by [26] are shown in Table 2.

3.3 Assumptions

Compression test samples were taken for a cylinder with dimensions of 150 by 300 mm, identical to those tested in previews study by experimental test [26]. It was used to predict the plastic behavior of a compound using a multilinear isotropic model. This model accepts hardness and strain at multiple points in the plastic range. Since the point of no plastic strain and yield stress is at the first point of the curve, i.e. the yield point. Since the stress with the strain values increases with that because the plasticity model prevents any point or curve with a slope less than zero, which is not accepted [22].

The following assumptions were taken for modeling concrete that contains rubber in its composition. The density of the rubber is the only parameter defined in the ANSYS software package [22], and the other of the parameters are within the information program i.e (ANSYS inbuilt). In modeling, rubber is designed as a long cylindrical specimen. The distribution of the rubber is also vertical and applied to the load when it is shed. Finally, the bonding between concrete and rubber is perfect [9, 22].

Fig.1 Test setup Details of typical specimens [26]

Table 1 Mix Constituents models Properties [26]

Mix. No.	0% Cont.	20%	40%	60%	80%	100%
W kg.	29.71	29.71	29.71	29.71	29.71	29.71
C kg	61.9	61.9	61.9	61.9	61.9	61.9
S kg	94.0	94.0	94.0	94.0	94.0	94.0
G kg	55.16	44.12	33.09	22.06	11.03	0.00
G.V. m^3	0.07	0.056	0.042	0.028	0.014	0.00
C.R kg	0.00	7.91	15.83	23.74	31.66	39.57
C.R.V. m^3	0.00	0.014	0.028	0.042	0.056	0.07

Cont. : control ; W : Water; C : cement ; S: sand ; G: gravel ; G.V. : gravel volume ; C.R.: Crumb Rubber ; C.R .V.: Crumb Rubber volume

Table 2 Parameters properties of materials [26]

Parameters	Value
Elastic Modulus	21112 MPa
concrete Poisson's ratio	0.18
Concrete Density	2200 kg/m^3
Rubber Density	560 /m^3

3.4 Finite Elements Modelling

The numerical analysis of the models was carried out using the ANSYS software [4] through the finite element model simulation. The modeling process includes selecting the appropriate elements to match the actual behavior of the model components, loading states, and supports. The materials that make up the model include the various components of concrete. As the ANSYS software [4] contains built-in elements that enable simulation of the actual behavior of the materials components. Three-dimensional solid elements were used in this study, where solid187 element was used to model concrete, while to quantify rubber concrete by defining its different coefficients using the modulus of elasticity, as well as defining the non-linear stress-strain curve of concrete with different rubber ratios. This step was used to the model elastomer, meaning that these two solid elements model the basis for representing the models that were numerically analyzed [22]. Also, these two elements have high-stress capabilities, high elasticity, and great deformation. Solid187 element consists of a three-dimension structural solid with 10 nodes and is suitable for irregular modeling meshes. These two components are specified in nodes that are of medium size to increase the accuracy of the results as they record the total response of the materials about the load applied to them [4]. Figs.2 shows the basic components of each of the components used in simulation and modeling details of the different compression specimens models in terms of the number of elements and the connecting nodes between its as shown in Table 3.

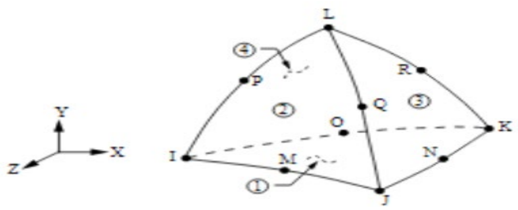


Fig.2 Solid187 element (10 nodes) (ANSYS Manual [4].

Table 3 Elements and nodes number details of compression specimens.

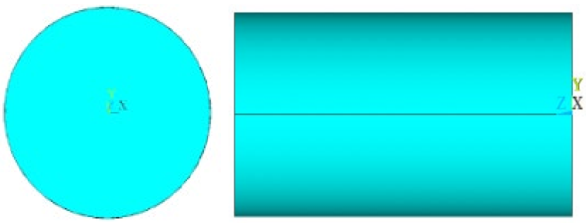
Rubber	Homogenized		Heterogenized	
	Nodes	Elements	Nodes	Elements
0 %	34987	7980	34987	7980
20%	76456	15680	104568	50694
40%	76456	15680	104568	50694
60%	76456	15680	104568	50694
80%	76456	15680	104568	50694
100%	76456	15680	104568	50694

3.4.1 Steps Modelling

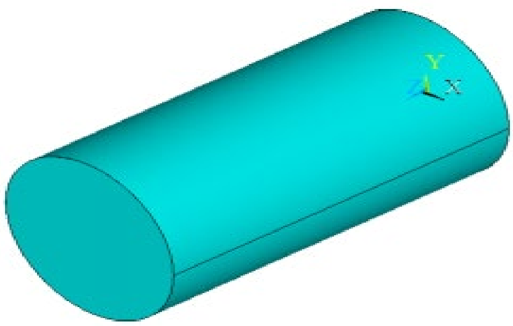
The following steps show how to represent a cylindrical concrete model using the ANSYS program [4]:

- Set the location of the coordinates for drawing areas as shown in Fig 3. a
- The work of the third dimension, i.e. the length of the cylinder 300 mm, or its support, represented by steel plate with a depth of 20 mm, by fixing it in the order of extruding as shown in Figs.3.b.
- After that, makes the Meshing for each part of the model, i.e. the concrete cylinder and the support for it, the steel plate, by including each of the properties of the materials, the constants, and the type of the special element. Any concrete, elements were represented by Solid 187 and Solid 185 steel plates prepared by ANSYS [4].
- When the modeling is completed in terms of dimensions, properties, and constants, the process of dividing a model begins by interlacing it into small elements measuring 10 mm in each direction as shown in Figs.3c and d.
- Interconnection between the parts of the element through the nodes that connect the rubber elements with the rest of the concrete parts. The bonding was imposed as a complete bonding, and nodes were represented as being the same in all parts.
- The permittivity was determined when analyzing by 0.05 and depending on the displacement as a limiting factor during that to find out the nonlinear convergence closely.
- The compressive load is placed on the upper surface of the cylindrical models to match the practical examination taken from the previous study [26] when compared with them in terms of the overall behavior of those models.
- In addition to entering the properties of the different elements of concrete, that is needed to define the coefficient of opening and closing cracks in concrete, which were determined from 0.2 to 0.7, respectively [31, 32, 33].
- The behavior of all components of concrete with rubber was as an integral elastic-plastic material. Also, the conduction of concrete is linear to 0.3fc` and elastic to 0.85fc` of the compressive strength, while it is completely plastic at an as for the assumptions that were adopted when analyzing numerically [31, 32,

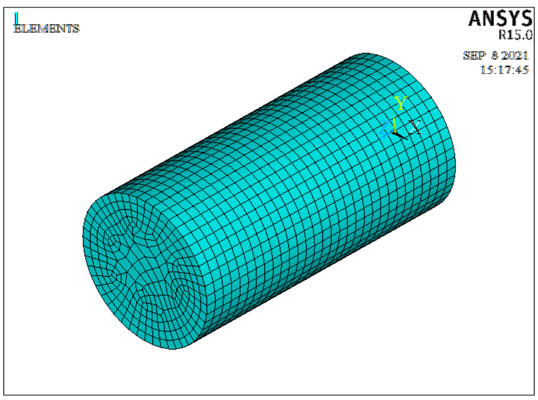
33], the homogeneity of the components of the model and the perfect bond between them and the plane parts remain plane before and after the load is applied. Neglecting the self-weight of the model. It can be seen a model that has been stimulated by the ANSYS program [4] in terms of its components such as predicate states and loading for each side supports represented on both sides of the cylinder when modeling where one of them was restricted in a perpendicular direction to the axis of the cylinder which consider as roller support and the other side was restricted in two directions, which provides support as a pin as shown in Figs 4-6.



(a) Front and Side views of cylinder Model (Area)

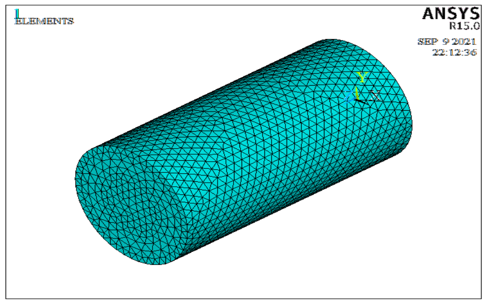


(b) 3D-View of solid cylinder (Volume)



(c)- 3D View of model Mesh (Homogenized)

Fig.3 3D View of Model mesh for a typical compression cylinder



(d) 3D View of model mesh (Heterogenized)

Fig.3 Continue.

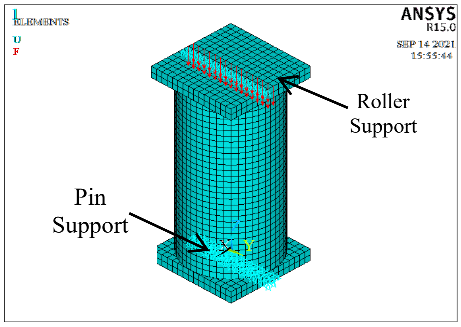


Fig.4 Modeling Supports of Side Ends for typical Cylinder model

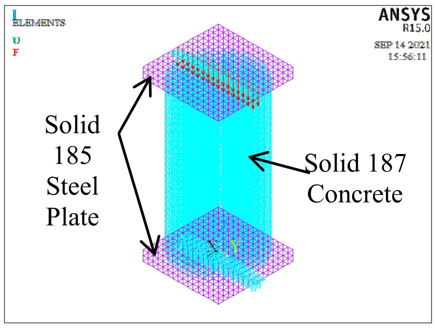
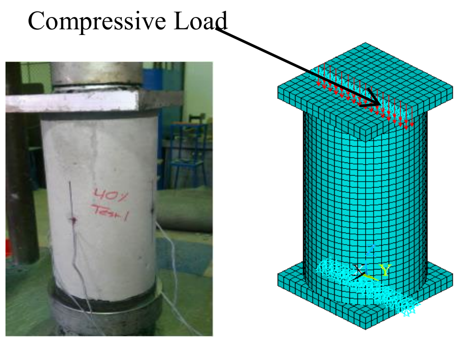


Fig.5 3D views wireframes for the steel plate and concrete elements for a typical cylinder model.



a- Exp. [26] b- Num.

Fig.6 Modeling of Loads for typical Cylinder model

4. RESULTS AND DISCUSSIONS

The results of the numerical analysis using the finite elements by ANSYS [4] were adopted for the compressive strength of cylinder, displacement Δ, modulus of elasticity Ec, and deformation pattern, and compared them with the results of the previous experimental study [26]. The numerical analysis adopted two homogeneous and heterogeneous patterns when dividing the model by the specific elements and for different proportions of rubber in the concrete components (0, 20%, 40%, 60%, 80%, and 100%) by adopting the characteristics of the stress-strain curve for each ratio of the concrete mixture, supports conditions and load applied.

4.1 Displacement Patterns of Model

It can be noted that the displacement patterns at Figs.7,8 show that the upper surface of the model was subjected to higher stress as a result of focusing the load directly on it, and this distortion decreases

Towards the lower surface of the cylinder model. Also, note that the pattern is identical between the comparison models with the homogeneous numerical analysis model as shown in Fig.7. While the heterogeneous numerical analysis model has the displacement skewed from the center of shedding the load and towards the edges as shown in Fig.8, and this shows behavior similar to the models studied previously [26]. The results of the analysis showed that all models failed under compression pressure, which is the displacement in both directions.

4.2 Hydrostatic Pressure of Model

Hydrostatic pressure show that the diagonal radial stresses through the model start from the center of applied load to construct radial distributions about its i.e points of concentration of the applied force [31, 32] as shown in Figs.9,10 for homogeneous and heterogeneous respectively of the stresses are concentrated on the upper and lower surfaces of the cylinder, the pressure model, but with a different intensity, as the places containing rubber are concentrated with a higher intensity than the others of the concrete components [22].

4.3 Von-Misses Stress and Strain of Model

Figs.11,12 shows that the Von-misses stress and strain for the controlled model of homogeneous and heterogeneous respectively, these stress are concentrated at the supports and the load points where their intensity is high, as well as the rubber concentration areas, which gives more distortions[22]. The comparison was made for one percentage of rubber i.e (20%), where the results showed the same behavior under compressive load, but with a more increased effect on behavior i.e, the compressive strength of the models decreases with the increase in the ratios of rubber in the concrete mixture and an increase in displacements and deformations. In general, through the results of the analysis between the variables that were studied to compare with the results of the experimental tests [26], it was found that there is a very good convergence with an error rate of (5 to 12%).

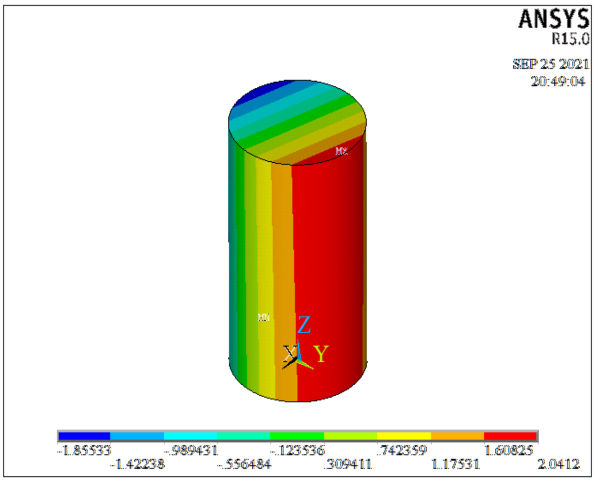


Fig.7 A 3D view for the displacement contour of the typical model (20% rubber) homogeneous

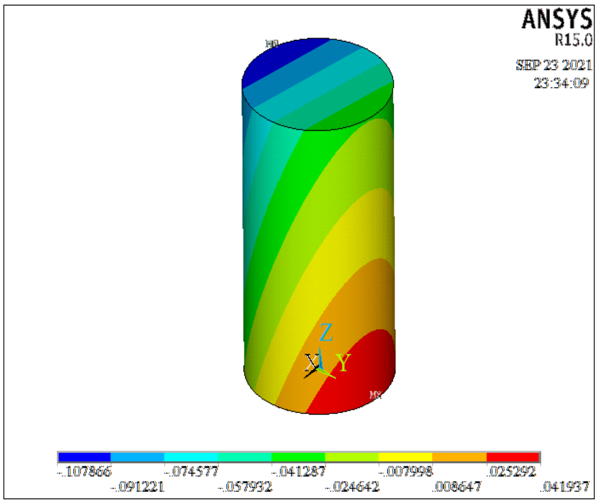


Fig.8 A 3D view for the displacement contour of the typical model (20% rubber) (heterogeneous)

4.4 Displacement - Rubber Content Relations of Models

Figs. 13 and 14 show the displacement plots with the different rubber ratios for each model and both homogeneous and heterogeneous models.

The behavior of almost real homogeneous models is observed through the plasticity model. Whereas, the displacement difference between the numerical and experimental models [26] was less than 8% for the rubber models. It also shows that the displacements increase with the increase in the proportion of rubber.

While for the heterogeneous numerical models when represented numerically, the results showed that the displacement difference between the numerical and experimental results [26] ranged from (2.5-12%) for all models that contain different rubber ratios.

It is also noted that the resistance of the models decreases with the increase in the percentage of rubber, especially when the percentage is more than 40% i.e. (It decreases within the limits of several times the resistance at each rate of increase, as shown in Table 4.

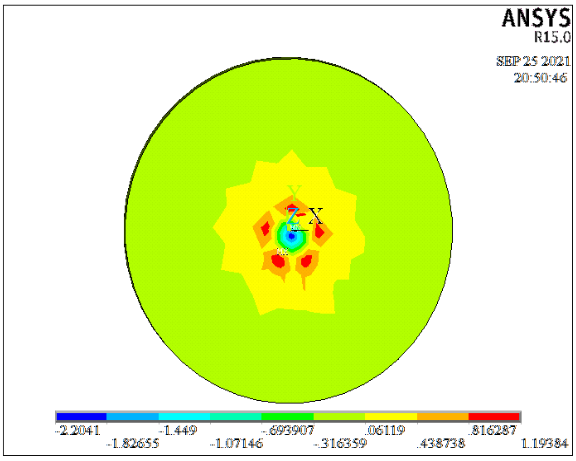


Fig.9 Radial hydrostatic stress of the typical model

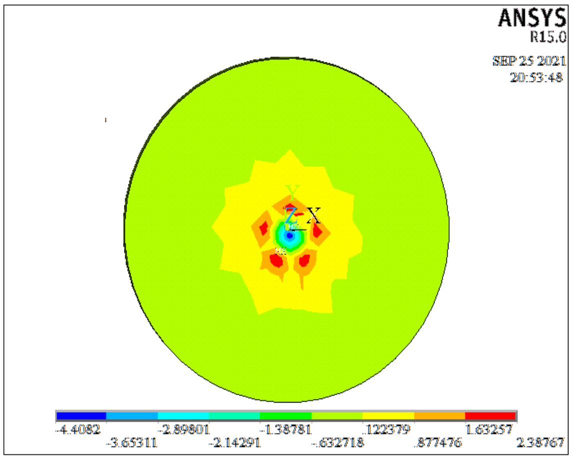


Fig.10 Radial hydrostatic stress of the typical model

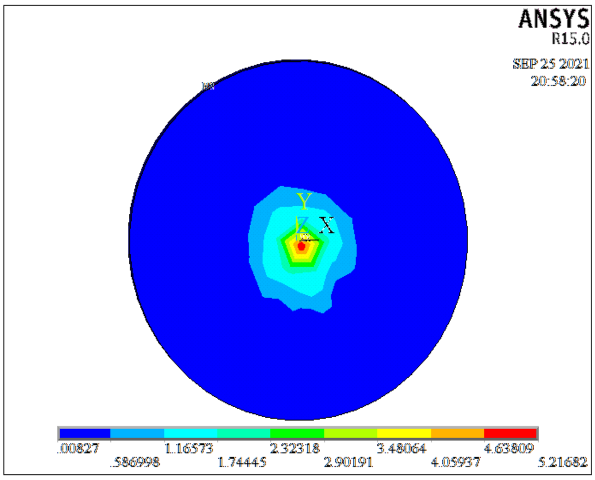


Fig.11 Radial Von-Misses stress of the typical model of the typical model (20% rubber) (heterogeneous)

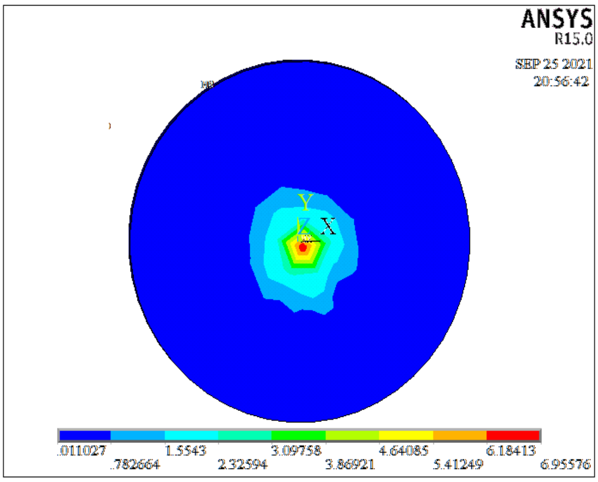


Fig.12 Radial Von-Misses stress of the typical model of the typical model (20% rubber) (Homogenized)

4.5 Compressive Stress-Rubber Content Relations of Models

Figs.15, 16 shows a diagram of the relationship of compressive stress with the percentage of rubber for each of the homogeneous and heterogeneous models. It is noted that the compressive strength decreases with the increase in the percentage of rubber, as the strength decreases by about (50%, 32%, 20%, 18%, and 6%) for each of the percentages of rubber (20%, 40%, 60%, 80%, and 100%) respectively. As the behavior is identical between the results of numerical analysis and experimental results[26], and this behavior can also be observed with other studies [10].

4.6 Modulus of Elasticity-Rubber Content Relations of Models

Figs.17, 18 show the plots of the modulus of elasticity with the different rubber ratios, which shows a very good agreement between the results of the numerical analysis with the experimental in terms of their similar behavior.

It is also noted that the elasticity modulus increases with the increase in the percentage of rubber because rubber gives flexibility to the model according to its design.This effect can be observed when the percentage of rubber increases by more than 40%.

4.7 Normal Stress-Displacement Variation Relations of Numerical models

In general, the displacements for all models that have been analyzed numerically are the highest value at the surface of the upper model i.e cylinder [29], and decreases in the lower direction, as a result of the load transfer mechanism.

The compressive stress of concrete plays a key role in evaluating the response of models because of its importance when evaluating the parts involved in their formation [31,34].

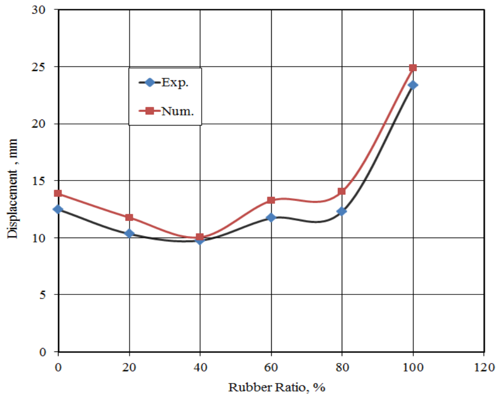


Fig.13 Displacement - rubber content Comparison relations of model (Homogenized)

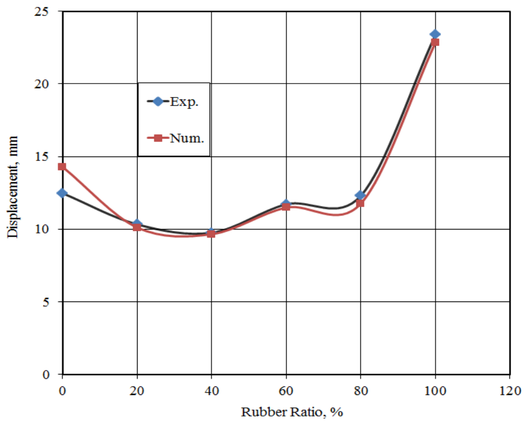


Fig.14 Displacement - rubber content Comparison relations of model (Heterogenized)

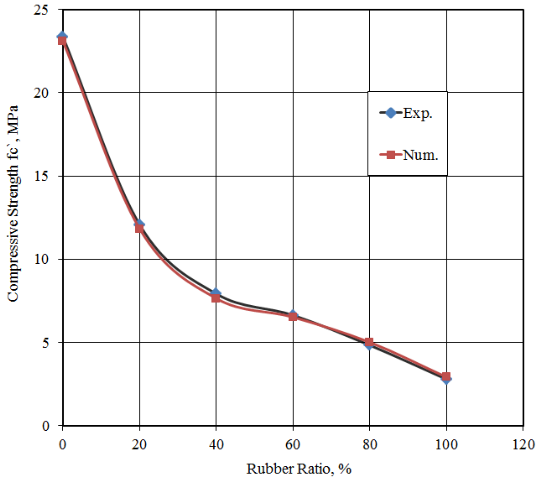


Fig.15 Compressive strength, fc`- rubber content Comparison relations of model (Homogenized)

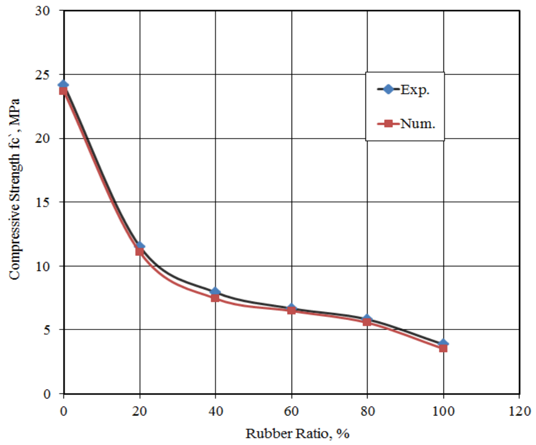


Fig.16 Compressive strength, fc`-rubber content Comparison relations of model (Heterogenized)

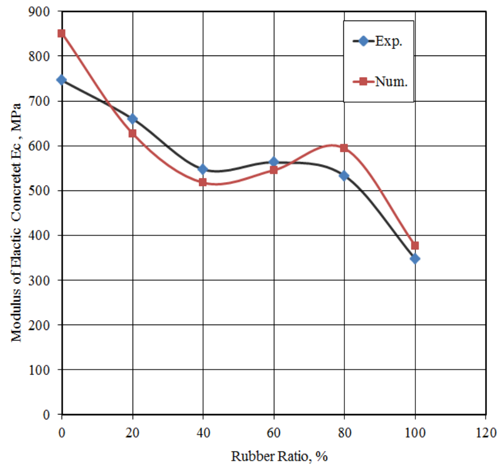


Fig.17 Concrete Elastic Modulus Ec - rubber content Comparison relations of model (Homogenized)

Fig.19 illustrates the relationship of the normal stresses that were taken from the results of the numerical analysis using ANSYS [4], and their variance with the displacements resulting from these stresses.

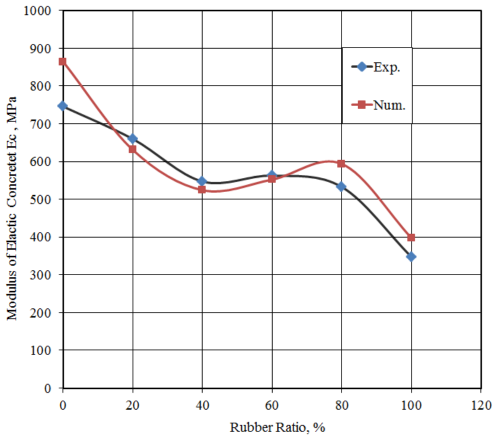


Fig.18 Concrete Elastic Modulus Ec - rubber content Comparison relations of model

It is noted that an increase in the proportion of rubber replaced instead of aggregates gives an increase in the normal stresses within the boundaries of the concrete areas that contain natural aggregates. Also, the results of a numerical analysis showed that the compression resistance is low in the elements that contain a high percentage of rubber.

It can be seen from the two figures, there is little difference between the results of homogeneous and heterogeneous models, up to 7%.

While Fig.19, its shows the identical behavior of rubber concrete, where the stress applied to the model's increases as the percentage of rubber increases, about (20 to 45%) as well as increasing the displacements within the limits of 12 to 25% for the same applied stresses.

4.8 Comparisons The Results Of The Experimental And The Numerical Analysis

Table 4 contains a comparison between the results of the experimental results [26] and the numerical analysis by the ANSYS program [4] involves of two cases of model representation homogeneous and heterogeneous, and the basis of comparison depends on the compressive resistance of the model and the displacement resulting from the load on the surface of the sample.

The results of the comparison showed that there is a convergence between numerical analysis and experimental test results [26], with approximate limits not exceeding (5 to 12%), the amount of convergence.

As for the displacements, their value was higher for the controlling model compared with the experimental models by about (8%).

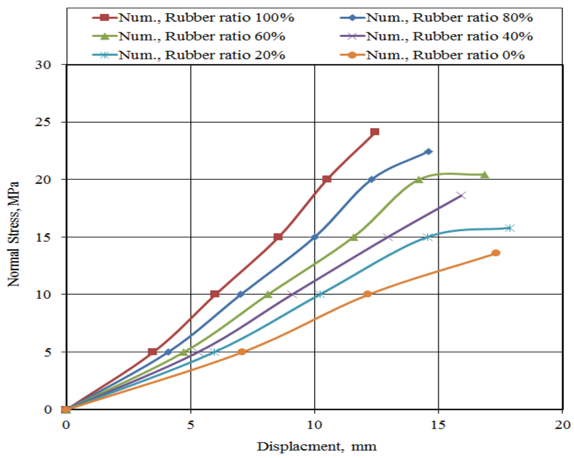
The homogeneous models, their values were close and with little difference on the higher side compared to the heterogeneous model.

In general, all the models it's simulated had almost identical behavior with the experimental results [26].

Table 4 Experimental and Numerical comparison of the Displacement and compressive stress fc` at failure.

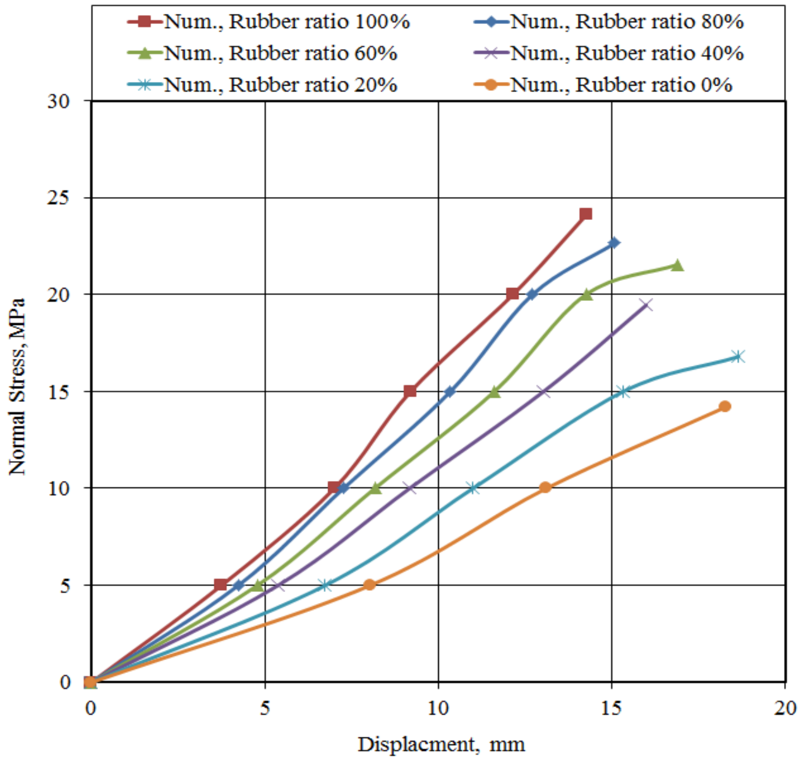
	Experimental[26]		Numerical (Homogenized)		Numerical (Hetrogenized)	
Mix. No.	Disp. mm	f_c' MPa	Disp. mm	f_c' MPa	Disp. mm	f_c' MPa
0	12.47	23.36	13.83	23.78	13.21	24.12
20	10.32	11.77	11.76	11.82	11.23	11.08
40	9.67	7.49	10.08	7.6394	9.88	7.45
60	11.72	6.45	13.26	6.52	12.58	6.48
80	12.31	5.05	14.07	5.01	13.48	5.55
100	25.09	2.91	24.84	2.91	23.66	3.52

Table 5 presented the results of the statistical analysis, which included the arithmetic mean, standard deviation, and the amount of variance of the models depending on the compressive strength, i.e. the stress of the cylinder, as well as the displacement in the failure stage, which showed a convergence between the results of numerical analysis and experimental tests [26].



A- Homogenized

Fig.19 Maximum Normal Stress-Displacement Variation relations of Numerical models for different rubber content ratios.



b- Heterogenized
Fig.19 Continue.

Table 5 Statistical analysis comparison for Ratios of Exp./Num. of the Displacement and compressive stress fc` at failure.

Item	Experimental[26]		Numerical		Ratio Num./Exp.		Numerical		Ratio Num./Exp.	
			(Homogenized)				(Hetrogenized)			
Mix. No.	Disp. mm	*f*c' MPa	Disp. mm	*f*c' MPa	Disp.	*f*c'	Disp. mm	*f*c' MPa	Disp.	*f*c'
0	12.47	23.36	13.83	23.78	1.11	1.018	13.21	24.12	1.06	1.03
20	10.32	11.77	11.76	11.82	1.14	1.01	11.23	11.08	1.09	0.94
40	9.67	7.49	10.08	7.6394	1.04	1.02	9.88	7.45	1.02	0.99
60	11.72	6.45	13.26	6.52	1.13	1.01	12.58	6.48	1.07	1.05
80	12.31	5.05	14.07	5.56	1.143	1.10	13.48	5.55	1.09	1.09
100	25.09	2.91	24.84	3.1	0.99	1.06	23.66	3.52	0.94	1.21
			Mean		1.092	1.036	Mean		1.05	1.04
			Standard deviation		0.0625	0.0382	Standard deviation		0.0571	0.0949
			Variance		0.0032	0.0012	Variance		0.0027	0.0075

4 CONCLUSIONS

This study included a numerical analysis of cylindrical concrete models according to the standard dimensions, which contain different ratios of rubber by the ANSYS program, it contains different elements that help in the representation of those models, and then a comparison between the numerical and experimental results that were taken from the previous study. The following conclusions are noted:

- Numerical analysis is an accurate method for predicting the behavior and mechanical properties of different types of rubber concrete mixtures, if the assumptions, modeling steps, and conditions of the appropriate real elements are taken into account. The performance of the numerical behavior of mechanical properties under the influence of compressive forces that have been modeled based on evaluating the response to displacements, compressive strength, and modulus of elasticity of rubber concrete showed a very good agreement with the experimental results from previous studies. This agreement was confirmed by the statistical analysis represented by the arithmetic mean and standard deviation as well as the rate of variance based on the analysis of Stresses and displacements.

- The compressive strength of the models decreases with the increase in the ratios of rubber (20% to 100%) when compared with the control model by about (50% to 8%). While the stress concentration in rubber concrete models increases with the increase in the percentage of rubber because rubber has a low stiffness compared to the high stiffness of concrete.
- The upper parts of the models contain a higher percentage of cracks than the lower part, and this is the result of the stress concentration applied by the direct load, and this behavior is observed in numerical analysis and experimental results. The tensile forces develop at the boundary between the parts and perpendicular to the load shedding. This occurs as a result of a decrease in the elastic modulus of rubber concrete with an increase in the percentage of rubber, which results in a decrease in the ability of the elastic energy generated in it.
- Rubber is weaker compared to concrete, which results in a model failure as a result of the appearance and formation of cracks around rubber particles. This is due to the nature of the composite and the lack of bonding between the concrete and rubber parts, as well as the distribution of stresses being irregularly distributed throughout the model. Finally, the stress-strain curves of the homogeneous models showed similarity with the experimental results when comparing and then a summary of the stress-strain curve was made to determine the modulus of elasticity, displacements, and forces, while when heterogeneous or composite models require sequential tasks due to the difficulties of randomly distributing rubber within the model.

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6 REFERENCES

1. Pacheco-Torgal F., Ding Y., Jalali S., Properties and Durability of Concrete Containing Polymeric Wastes (tire rubber and polyethylene terephthalate bottles: An overview Construction and Building Materials, Vol.30, 2012, pp. 714–724.
2. Segre N., Joekes I., Use of Tire Rubber Particles in Addition to Cement Paste. Cement and Concrete Research, Vol.30, Issue 9, 2000, 1421-1425.
3. Chan C. W., Yu T., Zhang S. S., Xu Q. F., Compressive Behavior of FRP-Confined Rubber Concrete, Construction and Building Materials, Vol.2, Issue 11, 2019, pp. 416–426.
4. ANSYS, Inc. ANSYS, Fluent User’s Guide, Release 15.07, 2015.
5. Briody C., Duignan B., Jerrams S., Tiernan J., The Implementation of a Viscohy per elastic Numerical Material Model for Simulating the Behaviour of Polymer Foam Materials, Journal of Computational Material Science, in the press, 2012.
6. Ren R., Liang J. F., Liu D. W., Gao J. H., Chen L., Mechanical behavior of crumb rubber concrete under axial compression, Advances in Concrete Construction, Vol.9, Issue3, 2020, pp. 249–256.
7. Siddique R., Naik, T. R., Properties of Concrete Containing Scrap-Tire Rubber–An overview. Waste Management, Vol.24, Issue 6, 2004, pp. 563-569.
8. Toutanji H.A., The Use of Rubber Tire Particles in Concrete to Replace Mineral Aggregates, Cem. Concr. Compos. Vol.18, Issue2, 1996, 135–139.
9. Duarte A. P. C., Silvestre N., Brito J., Julio E., Numerical Study of the Compressive Mechanical Behavior of Rubberized Concrete using the Extended Finite Element Method. Composite Structures, 179, 2017, pp.132-145.
10. Eldin N. N., Senouci A. B., Rubber-tire Particles as Concrete Aggregate. Journal of Materials in Civil Engineering, Vol.5, Issue 4, 1993, 478-496.
11. Al-Tayeb M. M., Baker B. A., Akil H. M., Ismail H., Performance of rubberized and hybrid rubberized concrete structures under static and impact load conditions. Experimental Mechanics, 53(3), 2013, pp. 379-384.
12. Vasudevan G., Kothandaraman S., AzhagarsamyS., Study on Non-linear Flexural Behavior of Reinforced Concrete Beams using ANSYS by Discrete-Reinforcement Modeling. Strength of Materials, 45, 2, 2013, pp.231-241.
13. Bedi R., Chandra S., Singh P., Mechanical Properties of Polymer Concrete, 1–12, 2013.
14. Barbara M., Diaconu D., Serbanoiu A., Burlacu A., Timu C.M. ,Gradinaru ,Effects of Tire Wastes on the Mechanical Properties of Concrete, Proc. Eng. ,181, 2017, pp.346–350.
15. Ganjian E., Khorami M., Maghsoudi A.,

Scrap-Rubber Replacement for Aggregate and Filler in Concrete. Composite Structures, 23, 5, 2009, pp.1828-1836.
16. Asutkar P., Shinde S. B., Patel R., Study on the Behavior of Rubber Aggregates Concrete Beams using an Analytical Approach. Engineering Science and Technology, 20, 1, 2017, pp.151-159.
17. Lv J., Zhou T., Du Q., Wu H., Effects of Rubber Particles on Mechanical Properties of Lightweight Aggregate Concrete. Construction and Building Materials, 91, 2015, pp. 145-149.
18. Jafari K., Toufigh V., Experimental and Analytical Evaluation of Rubberized Polymer Concrete. Construction and Building Materials, 155, 2017, pp.495-510.
19. Zheng L., Huo X. S., Yuan Y., Experimental Investigation on Dynamic Properties of Rubberized concrete. Construction and Building Materials, 22(5), 939-947, 2008.
20. Huang B., Li G., Pang Su. S., Eggers J., Investigation into Waste Tire Rubber-Filled Concrete. Journal of Materials in Civil Engineering, 16, 3, 2004, pp.187-194.
21. Topçu I. B., the Properties of Rubberized Concrete. Cement and Concrete Research, 25, 2, 1995, pp. 304-310.
22. Bantu S. A. I, Venghiac V. M., Budescu M., Taranu N., Numerical Simulation of Concrete with Rubber Aggregates. International Multidisciplinary Scientific GeoConference SGEM. Albena, Bulgaria, 2015, pp.345-352.
23. Li G., Garrick G., Eggers J., Abadie C., Stubblefield M. A., Pang S., Waste Tire Fiber Modified Concrete. Composites Part B: Engineering, 35, 4, 2004, pp.305-312.
24. Mendis A. S., Al-Deen S., Ashraf M., Effect of Rubber Particles on the Flexural Behavior of Reinforced Crumbed Rubber Concrete beams. Construction and Building Materials, 154, 2017, pp. 644-657.
25. Zhang P., Zheng, Y., Wang K., Zhang J., A review on Properties of Fresh and Hardened Geopolymer Mortar", Composites Part B: Engineering, 152, 2018, pp. 79–95.
26. Miller N. M., Tehrani F. M., Mechanical Properties of Rubberized Light Weight Aggregate Concrete. Construction and Building Materials, 147, 2017, pp. 264-271.
27. ACI Committee 318, Building Code Requirements for Structural Concrete, 2014.
28. British Standards Institution (BSI), BS 8110-1, Structural Use of Concrete Part 1: Code of Practice for Design and Construction, 2005.
29. ASTM C39 / C39 M - 16b, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM International, West Conshohocken, PA, 2016.
30. ASTM C496/C496M-11(2011), Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM International, West Conshohocken, PA, 2011.
31. Al-Maliki Hadi et al, Structural Efficiency of Hollow Reinforced Concrete Beams Subjected to Partial Uniformly Distributed Loading: Buildings Journal11(391), 2021.
32. Al-Maliki H.N.G., Al-Balhawi A., Al-Taai S.R., Madhloom H.M., Gamil Y., Structural Behavior Of Precast High Strength Reinforced Concrete Vierendeel Truss Walls: A Numerical Approach. International Journal of GEOMATE, 21(84), 2021, pp.137-150.
33. AL-Maliki Hadi et al, Simulation Nonlinear of Structural Behavior of Hollow Reinforced Concrete Deep Beams strengthened By CFRP. IOP Conf. Series: Materials Science and Engineering 928, 2020.
34. Al-Maliki H.N.G., Alshimmeri A.J.H., Ali A.M., Madhloom H.M. Gamil, Y., Nonlinear Simulation Analysis Of Tapered Reinforced Concrete Column (Solid And Hollow) Behavior Under Axial Load. International Journal of GEOMATE, Vol. 21, Issue 86, 2021, pp.131-146.
35. Al-Ansari N., Alrammahi F., Khassaf S., Abbas S., Madhloom H., Aljaradin M., Study the Slope Stability of Earthen Dam using Dimensional Analysis Technique, International Journal of GEOMATE, Vol. 21, Issue 83, 2021, pp.125-131.