



Effect of the Waste Rubber Tires Aggregate on Some Properties of Normal Concrete

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HIGHLIGHTS

- The workability and the strength of rubber concrete are decreased by adding rubber.
- The failure of the rubber concrete samples was not brittle by using chips rubber.
- A good advantage is decreasing the density and the conductivity of rubber concrete.
- The mixed crumb with chips in the concrete gives more insulation by filling voids.

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ABSTRACT

Waste rubber tires are considered to have substantial environmental and economic impacts, and they are non-biodegradable. The aim of this study is to get rid of waste tires as much as possible and study their benefits and effects on concrete using (chips and crumbs) as aggregate substitution to fine and coarse aggregates together in making concrete (CRC) and at different percentages of (5, 10, 15, 20, and 25)% by volume. This use can reduce the risk and effect of waste tires. The tests reported a reduction in workability, compressive, and flexural values with the increase in the substitution rate of rubber, but other properties such as density and thermal conductivity improved, where the registered highest decrease was 2013 kg/cm³ to density and 0.56 (W/m.k) to thermal conductivity with replacement of 50% from waste rubber tiers as an aggregate, the workability registered the highest decrease of 35 mm, compressive strength was 18.5 MPa, and the flexural was 3.35 MPa. However, the failure of the (CRC) samples test was not as brittle and abrupt as in the control sample (NSC) in the flexural test.

1. Introduction

The utilization of waste rubber particles as concrete aggregates can help to mitigate the environmental effects of huge amounts of scrap tires [1]. These wastes are described as toxic and dangerous and have a high impact on the environment, society and the economy [2]. It is a good breeding area for mosquitoes and rodents and is not biodegradable and ignites quickly, causing severe environmental, health, and aesthetic problems. Many attempts have been made to properly use tires in other applications [3-4]. Concrete is the most common material in buildings [5]. One of the most viable solutions could provide the preservation of natural resources [6], reducing the effect on the ecology, garbage disposal, and global warming [7], improving fatigue resistance, ductility, hardness, impact resistance, toughness, and other qualities of concrete [8], and increasing the thermal and sound insulation, as well as energy absorption and fracture resistance [9-10]. It also reduces noise [1]. Thus, waste tires can be used to make asphalt, culverts, paving stones, brick sidewalks, and acoustic panels [2].

Some researchers studied the properties of rubber material of waste tires. Katagiri et al. [11] used particle size of crumb 3-15 mm in concrete. The results are the (LWCs) 15 wt % crumb rubber that can meet the requirement of ASTM standards for structural lightweight concrete and masonry, respectively. After high-temperature exposure, the unit weight loss and compressive strength loss were 25% and 75%, respectively. Torres et al. [2] studied the concrete pavements. They replaced the coarse and fine particles with rubber of size (1-4, 10, and 16 mm) with different percentages of (10, 20, and 30%) and studied the effects on rubber content and rubber size. In addition, 10 mm size rubber particles are the most abundant in the recycling process, and a better percentage is less than 20% content of rubber. Záleská et al. [12] used tires rubber-based (0/4 fine rubber and 4/8 coarse rubber aggregate), showing a decrease in unit weight, mechanical properties, and a significant decrease in the thermal conductivity. Tang et al. [13] stated that with the development of sustainability and recycling of waste tires, modified recycled aggregate concrete has become imperative. The inclusion of rubber particles could greatly minimize mass loss, resulting in a weakening of the material. The use of rubberized concrete with a rubber content of 4% was recommended based on the findings.

Nayyef and Hasan [14] indicated that gravel, sand and additional aggregate, required in the conventional process, are a non-renewable and finite natural resource.

The aim of this study is to reduce costs, get rid of waste tires as much as possible, study their effects on concrete, and improve durability by integrating the strength of crumbs and flexibility of chips in proportions of replacement of (5, 10, 15, 20 and 25)% of coarse and fine aggregates and examining the mechanical and physical properties of compression bending strength, density, and thermal conductivity.

2. Materials

2.1 Cement

Ordinary Portland Cement (OPC) was used in this study as a concrete binder, which corresponds with Iraqi Standard No.5. in 2019 [15]. The setting time of cement was (initial=105 min. and final=2:40 hr: min.) and 33.6 MPa compressive strength after 28 days was achieved. Table 1 shows the chemical analysis.

2.2 Natural aggregates (coarse and fine)

The tests were carried out at the Materials Engineering Laboratories of the University of Babylon. These materials meet the requirements of the Iraqi standard specification No. 45/1984.

1) Coarse aggregate

The crushed coarse aggregate was obtained from the Nabai district of Salah al-Din. Table 2 shows the sifting of coarse aggregate rocks with a maximum size of 10 mm, a volumetric density of 1.56 g/cm³, a specific gravity of 2.38, and an absorption of 0.88%, where the grading of aggregates was as per Iraqi Standard Specification No. 45/1984 [16].

2) Fine aggregate

Natural sand from the AL-Ukhaider area was used as fine aggregate. The specific gravity of fine aggregate is 2.67, the bulk density is 1.76 g/cm³, and the absorption rate is 0.98 %, where the grading of aggregates was as per Iraqi Standard Specification No. 45/1984 [16]. Its chemical and physical properties are shown in Table 3.

2.3 Waste tires (CRA and FRA)

The material of chips rubber aggregate (CRA) with sizes of (5 to 10 mm) max was from torn tires and crumbs rubber aggregate (FRA) with a size of (4.75 mm) max. which was obtained from the Babel tire factory in the Najaf Al-Ashraf governorate and the spent tire recycling plant located in the Diwaniyah tire factory in the Diwaniyah governorate having a specific gravity of 1.03 for (FRA) and 1.14 for (CRA). For cutting the tires, many operations were conducted on the tire to reach the required size. The tire was cut to start with large sizes and then the size decreases continuously leading to more shredding being replaced by the coarse aggregate, which is made from ripped tire chips with a maximum size of 5 to 10 mm, as well as specific mills that convert huge rubber into smaller shredding particles (fine). The output of this operation is crushed tires with sizes that resemble the sand [17]. Ali et al. [18] stated that chemical composition has rubber hydrocarbon (SBR) of 47.7%, carbon black of 30.7%, acetone extract of 15.6%, ash of 2.1%, and a residue chemical balance of 3.9%. Figure 1 shows the sieve analysis.

2.4 Water

In concrete mixtures and specimen treatment, tap water was used. The temperature of the mixing water was kept constant at (25 ± 2 °C).

3. Tests Details

In addition to test compression and flexural strength, the workability, density, and thermal conductivity of rubber concrete were investigated.

3.1 Slump

The objective of this test is to determine the workability of the concrete mixture by measuring the amount of subsidence according to BS 1881-102:1983 [20].

3.2 Density

Density was calculated according to (ASTM C642-13) [21]. The dry density of concrete cubes with a shelf life was calculated by averaging three cubic samples of (10 × 10 × 10) cm (28 days). Samples were dried in the oven for 24 hours at a temperature of 100-110 °C, then they were weighed individually after cooling.

3.3 Thermal Conductivity

Thermal conductivity is the ability to conduct heat. The test was carried out according to the American specification ASTM-C1113-90 [22], and the samples of control mix without rubber and rubber concrete were examined by different percentages. Figure 2 shows the device at Baghdad Central Laboratory.

Table 1: The chemical analysis of cement.

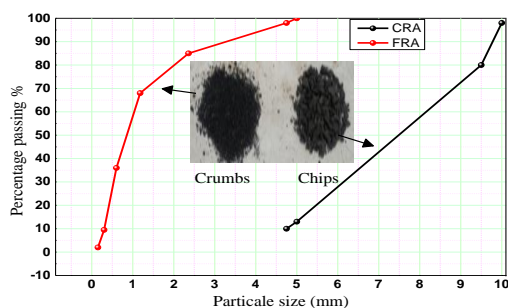
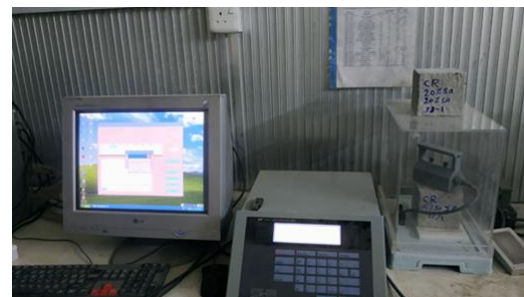
Composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Loss on Ignition	Insoluble Residue
Test Result	20.49	5.74	3.41	61.91	3.70	2.51	1.47	0.53
Limits* No.5	-----	-----	-----	-----	-----	< =2.8	< =4%	< =1.5
Composition	FREELIME		L.S.F	M.S	M.A	C ₃ A		C ₃ S
Test Result	1.73		0.91	2.24	1.68	9.44		38.71
Limits* No.5	-----		-----	-----	-----	< = 3.5 for S.R.P.C		-----

Table 2: Properties of the used coarse aggregate

Sieve size by (mm)	Passed%	Limits* IQS 45,1984 19451984No.45/1984
14	100	100
10	93.9	85-100
5	14.9	0-25
2.36	1.59	0-5
SO ₂ content = 0.08% are (specification requirements 0.1%) of coarse aggregate		

Table 3: Properties of the used fine aggregate.

Sieve size by (mm)	Passed%	Limits.(IQS 45, 1984), zone2
9.5	100	100
4.75	93.1	90-100
2.36	83.9	75-100
1.18	65.9	55-90
0.60	40.59	35-59
0.30	11.49	8-30
0.15	3.11	0-10
Fineness modulus.= 2.1 and SO ₂ content=0.3% are (specification requirements 0.5%)		

**Figure 1:** Sieve analysis of chips and crumbs**Figure 2:** The device of thermal conductivity

3.4 Admixtures

In this study, 0.1% superplasticizer was used to produce regular concrete and rubber concrete. Known commercially as (Hyperplastic PC200), a high-performance superplasticizer for concrete admixture was imported from the company (DCP), and it complies with the requirements of (ASTM C494/C494M,) [19]. The properties of the used HRWRA given by the manufacturer are basis (Modified polycarboxylic ether), light brown color, and a PH value of 6.6 (chloride free).

4. Experimental Work

Six mixtures were made. The first mix is a control mix, without rubber - called Normal Strength Concrete (NSC) where it is required for comparison, and five mixtures are called (Compact Rubber Concrete (CRC)), which are combined between crumbs and chips, in place of the coarse and fine aggregates, and the replacement is in terms of volume. The percentages of replacement are 5%, 10%, 15%, 20%, and 25% by means of chips and crumbs of rubber tires for each of them in the same percentage, where when replacing 10%, the total amount replaced is 20%, and the maximum size of the chips used is 10 mm. As for the size of maximum crumb it was 4.75 mm using codes of CRC 1, CRC 2, CRC 3, CRC 4, and CRC 5.

Additives (superplasticizers) were used in all mixtures at 0.1% to improve workability and to wet the rubber using the same water mixture that makes the wetting process of rubber particles. This may help to increase the adhesion of cement putty. The percentage of cement is constant at 480 kg / m³, the water/cement ratio is 0.41, and the amount of water is 197 kg/m³. The rest of the details of the LWC mixtures (kg/m³) are shown in Table 4 for fine aggregate, coarse aggregate, and rubber tires. For the above type and proportion, mix for two minutes to ensure the mixture, then cement is added and the whole mixture is mixed for one minute. Water is added, then the superplasticizer is gradually added to the mixer and the process with the homogenization of the mixture takes three minutes.

4.1 Compressive Strength

The compressive strength of concrete is a well-known metric that reflects one of the most significant concrete engineering properties that can be used to get a broad image of the material's quality. Three cubes (100×100×100) mm of control mix concrete and rubberized concrete (CRC) were used to assess the compressive power that was obtained according to (BS. 1881: part 116 [20]), which was used to calculate the average value of these cubes. Crushing three cubes at 7, 14, and 28 days using a digital testing machine with a capacity of (1900 kN) and a loading rate of (0.3 MPa/sec) was used to assess the compressive power.

4.2 Flexural strength

The test specimens was (100x100x500) mm in accordance with C78/C78M [23]. The test of the specimen was perpendicular to the face of the specimen and is applied without deflection. The tests were conducted at the University of Babylon/Civil Engineering Laboratories.

$$R = PL/bh^2 \quad (1)$$

where; R= modulus of rupture (MPa) , h = depth of specimen (mm), b = width of specimen (mm),
L = span length (mm), and P = maximum applied load (N).

5. Results And Discussion

5.1 Workability

From the results, as shown in Figure 3, we conclude that the highest percentage was in the control mixture, where it is 60 mm, and it is decreasing to record a 25% stagnation decrease between the control mixture and rubber concrete (CRC), which is the highest decrease we recorded when replacing 50% CRC (chips and crumbs together), which is 35 mm. This decreases when the percentage of rubber is lower, but a continuous and steady decrease in workability is observed with increasing rubber content. However, a possible explanation for this trend is that the increased content of rubber tires has resulted in more air particles being introduced into the mix, and this has been reported by [24], as well as surface roughness and the presence of fibers that cannot be completely separated, even if they are in a very small proportion. This leads to a decrease in the operability of the matrix and this has been reported by [4].

5.2 The Density

The addition of rubber aggregates in concrete affects the dry density of the concrete mixes. It is a good advantage of concrete. We note that 10% to 50% results in a lower density in CRC than the control mix, as in Figure 4, and this is firstly because of the porosity and also because the rubber crumb has a specific gravity of 1.03, which is less than the specific gravity of fine aggregate (2.68). The rubber foil has a specific gravity of 1.14, which is less than the specific gravity of the total coarse aggregate (2.37), and this has been reported by [25-26].

5.1 Thermal Conductivity

Many factors affect the thermal conductivity, such as the material of the composition, the type, the shape of the aggregate, impurities, porosity, etc. Therefore, we note here that the thermal conductivity decreases with the increase of the substitution ratio. The test was carried out after 28 days, as shown in Figure 5. The thermal conductivity test showed that conductivity of the rubber concrete samples decreases significantly compared to the control samples. The presence of crumbs mixed with chips gives more isolation due to the fullness of the spaces. This feature is suitable for non-structural applications requiring thermal insulation at first replacement rates of (10% by volume) whose compressive strength has not decreased significantly and this has been reported by [27-28].

5.2 Compressive Strength

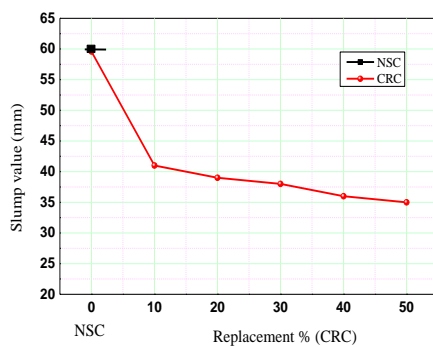
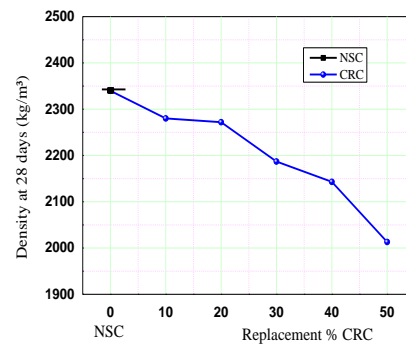
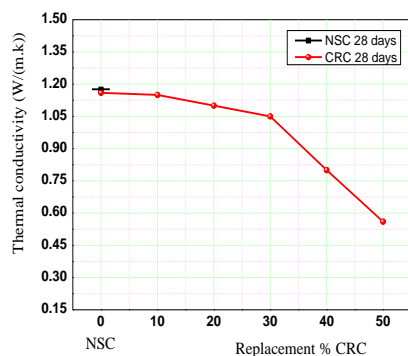
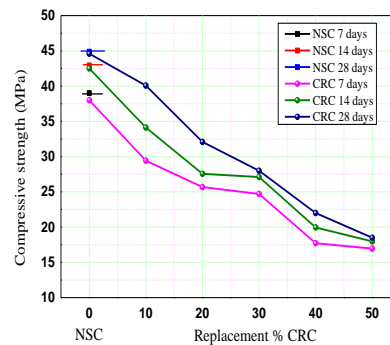
Figure 6 shows the compressive strength of concrete after 7, 14, and 28 days with and without differing proportions of alternate rubber pieces, where the control mixture's highest strength is 44.9 MPa. The strength decreases with the increase in the percentage of added rubber to reach the highest decline of 18.33 MPa with a replacement of 50%. It also explains this decrease in strength. Due to poor bonding with cement paste, which was the main factor for the low strength of rubber concrete compared with control, the rubber particles had low specific gravity, weak hardened and load, and high elasticity. However, the compressive intensity at first replacement rates of (10% by volume) did not show a significant decrease. A similar finding was reported by [1]. Therefore, this might be acceptable for some non-construction applications, and this was similar to [29-30].

Table 4: The details of concrete mixtures (kg / m³).

Type of concrete	Fine Kg/m ³	Coarse Kg/m ³	Cement Kg/m ³	Water Kg/m ³	SP	Crumbs by volume	Chips by volume
NSC	675	1100	480	197	0.1	0.0	0.0
CRC 10%	641.25	1045	480	197	0.1	5%	5%
CRC 20%	607.5	990	480	197	0.1	10%	10%
CRC 30%	573.75	935	480	197	0.1	15%	15%
CRC 40%	540	880	480	197	0.1	20%	20%
CRC 50%	506.25	825	480	197	0.1	25%	25%

5.3 Flexural Strength

Figure 7 shows the results of the flexural test after 28 days. When compared with the control mixture, the rubbercrete (CRC) has a lower strength. The lower resistance of bending strength is consistent with most previous studies. Control samples showed brittle failure and split into two parts with a strength of 4.75 MPa. But there was no split into two parts at replacement of 50% and the strength to rubbercrete was 3.35 MPa. It is evident from this fact that the rubber particles made the concrete more flexible and the sudden brittle failure does not occur. However, only crack, depth, and size of the crack depend on the percentage of rubber and the impact force, as shown in Figure 8, and this has been reported by [31-32].

**Figure 3:** Concrete workability with rubber percent replacement**Figure 4:** Density at 28 days with rubber present replacement**Figure 5:** Thermal conductivity with rubber present replacement**Figure 6:** Compressive strength at different ages with rubber present replacement

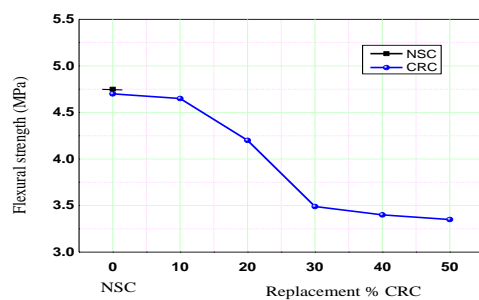


Figure 7: Results of flexural strength with rubber present replacement

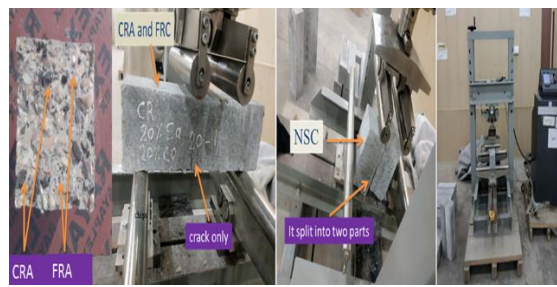


Figure 8: The effect of the rubber aggregate on test flexural and split to sample

6. Conclusions

The use of waste tire rubber in concrete can reduce the risk of the waste tire. Compression, bending, heat transfer, and density tests were carried out for concrete mix containing replacement proportions of (5, 10, 15, 20, and 25)% of waste compressed rubber tires from chips. The results of the tests showed a decrease with the increase in the rate of replacement of rubber and this can be summarized in the following points.

1. The NSC control samples were recorded in workability of 60 mm, compressive strength of 44.88 MPa, and bending of 4.75 MPa, but the decrease of these characteristics was with increasing replacement rates, as it was observed that the substitution ratio of 50% to CRC causes the highest decrease in workability of 35 mm, but the highest increase in compressive strength was 18.5 MPa and bending was 3.35 MPa.

2 - Other properties such as density and thermal conductivity have been improved. The presence of crumbs mixed with chips gives more isolation due to the fullness of the spaces.

3- The failure of the CRC was not as brittle as in the bending test control sample, with replacement ratios at (10, 15, 20 and 25)%, because the rubber aggregate is ductile and does not undergo separation due to the applied force.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

- [1] S. Guo, Q. Dai, R. Si, X. Sun, and C. Lu, Evaluation of properties and performance of rubber-modified concrete for recycling of waste scrap tire, *J. Clean. Prod.*, 148 (2017) 681–689. doi: 10.1016/j.jclepro.2017.02.046.
- [2] R. Pacheco-Torres, E. Cerro-Prada, F. Escolano, and F. Varela, Fatigue performance of waste rubber concrete for rigid road pavements, *Constr. Build. Mater.*, 176 (2018) 539–548. doi: 10.1016/j.conbuildmat.2018.05.030.
- [3] M. A. González, M. A. Rodríguez-Sosa, Y. E. Vásquez-Bautista, E. del C. Rosario, J. C. Durán-Tiburcio, and P. M. Alarcón-Elbal, A survey of tire-breeding mosquitoes (Diptera: Culicidae) in the Dominican Republic: Considerations about a pressing issue, *Biomédica*, 40 (2020) 507–515. doi: 10.7705/biomedica.5200.
- [4] T. Gupta, S. Chaudhary, and R. K. Sharma, Mechanical and durability properties of waste rubber fiber concrete with and without silica fume, *J. Clean. Prod.*, 112 (2016) 702–711. doi: 10.1016/j.jclepro.2015.07.081.
- [5] R. Wang, P. Gao, M. Tian, and Y. Dai, Experimental study on mechanical and waterproof performance of lightweight foamed concrete mixed with crumb rubber, *Constr. Build. Mater.*, 209 (2019) 655–664. doi: 10.1016/j.conbuildmat.2019.03.157.
- [6] A. Sofi, Effect of waste tyre rubber on mechanical and durability properties of concrete – A review, *Ain Shams Eng. J.*, 9 (2018) 2691–2700. doi: 10.1016/j.asej.2017.08.007.
- [7] M. Behera, S. K. Bhattacharyya, A. K. Minocha, R. Deoliya, and S. Maiti, Recycled aggregate from C & D waste & its use in concrete – A breakthrough towards sustainability in construction sector: A review, 68 (2014) 501–516. doi: 10.1016/j.conbuildmat.2014.07.003.
- [8] J. XU, Z. Yao, G. Yang, and Q. Han, Research on crumb rubber concrete: From a multi-scale review, *Construction and Building Materials*, 232 (2020). doi: 10.1016/j.conbuildmat.2019.117282.

- [9] A. O. Atahan and A. Ö. Yücel, Crumb rubber in concrete: Static and dynamic evaluation, *Constr. Build. Mater.*, 36 (2012) 617–622. doi: 10.1016/j.conbuildmat.2012.04.068.
- [10] M. Valente, Rubber / crete : Mechanical properties of scrap to reuse tire-derived rubber in concrete ; A review, 18 (2019) 1–8. doi: 10.1177/2280800019835486.
- [11] T. Kantasiri, P. Kasemsiri, U. Pongsa, and S. Hiziroglu, Properties of light weight concrete containing crumb rubber subjected to high temperature, *Key Eng. Mater.*, 718 (2016) 177–183. doi: 10.4028/www.scientific.net/KEM.718.177.
- [12] M. Záleská, Z. Pavlík, D. Čítek, O. Jankovský, and M. Pavlíková, Eco-friendly concrete with scrap-tyre-rubber-based aggregate –Properties and thermal stability, *Constr. Build. Mater.*, 225 (2019) 709–722. doi: 10.1016/j.conbuildmat.2019.07.168.
- [13] Y. Tang, W. Feng, W. Feng, J. Chen, D. Bao, and L. Li, Compressive properties of rubber-modified recycled aggregate concrete subjected to elevated temperatures, *Constr. Build. Mater.*, 268 (2021). doi: 10.1016/j.conbuildmat.2020.121181.
- [14] D. H. Nayyef and S. S. Hasan, Influence of Recycled Fine Aggregates on Strength Properties of Reactive Powder Mortar, *Eng. Technol. J.*, 38 (2020) 288–294. doi: 10.30684/etj.v38i3a.265.
- [15] Iraqi Code Committee, “Ordinary portland cement, 5 (2019). The Central Organization for Standardization and Quality Control.
- [16] Iraqi Code Committee, Aggregate from natural sources for concrete and construction, IQS No.45 Central Agency for Standardization and Quality Control, Baghdad, (1984).
- [17] M. K. Batayneh, I. Marie, and I. Asi, Promoting the use of crumb rubber concrete in developing countries, *Waste Manag.*, 28 (2008) 2171–2176. doi: 10.1016/j.wasman.2007.09.035.
- [18] I. M. Ali, , A. S. Naje, , & M. S. Nasr. Eco-Friendly Chopped Tire Rubber as Reinforcements in Fly Ash Based Geopolymer Concrete, *Im* (2020) 1–16.
- [19] ASTM C494, Standard specification for chemical admixtures for concrete, ASTM Int., (2015) 1–10.
- [20] BS 1881-120:Method for determination of the compressive strength of concrete cores, *Testing Concrete, Constr. Stand.*, 2 (1983) 1–8.
- [21] C. Aggregates, tandard test method for density , absorption , and Voids in Hardened Concrete, 6–8, doi: 10.1520/C0642-13.5.
- [22] ASTM, Standard test method for thermal conductivity of refractories by hot wire (platinum resistance thermometer technique), ASTM C 1113, (2009) 1–6.
- [23] C. C. Test, T. Drilled, and C. Concrete test, Standard test method for flexural strength of concrete (using simple beam with third-point loading) 1, *Hand*, 78-02 (2010) 1–4. doi: 10.1520/C0078.
- [24] M. M. R. Taha, M. Asce, and M. A. A. El-wahab, Mechanical , fracture , and microstructural investigations, 20 (2008) 640–649. doi: 10.1061/(ASCE)0899-1561(2008)20.
- [25] W. Ruwona, G. Danha, and E. Muzenda, A review on material and energy recovery from waste tyres, *Procedia Manufacturing*, 35 (2019). doi: 10.1016/j.promfg.2019.05.029.
- [26] L. Liu, G. Cai, and X. Liu, Investigation of thermal conductivity and prediction model of recycled tire rubber-sand mixtures as lightweight backfill, *Constr. Build. Mater.*, 248 (2020). doi: 10.1016/j.conbuildmat.2020.118657.
- [27] K. Bisht and P. V. Ramana, Evaluation of mechanical and durability properties of crumb rubber concrete, *Constr. Build. Mater.*, 155 (2017) 811–817. doi: 10.1016/j.conbuildmat.2017.08.131.
- [28] S. M. S. Shtayeh, Utilization of waste tires in the production of non-structural portland cement concrete, Ph.D. Thesis, An-Najah National University, Nablus, Palestine, (2007).
- [29] M. S. Senin, S. Shahidan, S. R. Abdullah, N. A. Guntor, and A. S. Leman, A review on the suitability of rubberized concrete for concrete bridge decks, *IOP Conf. Ser. Mater. Sci. Eng.*, 271 (2017). doi: 10.1088/1757-899X/271/1/012074.
- [30] E. Ganjian, M. Khorami, and A. A. Maghsoudi, Scrap-tyre-rubber replacement for aggregate and filler in concrete, *Constr. Build. Mater.*, 23 (2009) 1828–1836. doi: 10.1016/j.conbuildmat.2008.09.020.
- [31] A. Khitab, F. A. Awan, M. A. Anwar, and A. Mughal, Evaluation of concrete with partial replacement of coarse aggregates by waste rubber particles, *International journal for innovative research in multidisciplinary field*, 3 (2017).