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An Experimental Investigation for The Performance of Crumb Rubber and Fly Ash Concrete

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A B S T R A C T

The utilization of recycled rubber tires as a partial substitution of the natural aggregate in concrete is the solution for safe disposal of it. Since that rubber affects the mechanical characteristics of concrete negatively due to the rubber and cement mortar low cohesion, it was necessary to improve these properties by adding pozzolanic additives such as fly ash. The objective of this paper is to study the effect of treated crumb rubber and fly ash on the performance of concrete. The crumb rubber (CR) has been treated with benzene. CR particles were added as a partial substitution of sand by 5%, 10%, 15%, and 20% of its weight, and the cement was replaced with fly ash by 15% of its weight. Many tests were carried out to evaluate mechanical characteristics of hardened concrete such as compressive strength, splitting tensile strength, water absorption, density, and modulus of elasticity. The slump test was conducted to assess the consistency of the concrete. The results showed that the compressive strength of CR mixes decreased by 7.14%, 18.36%, 26.5%, and 35.7% compared with that of the control mix. The tensile strength of CR mixes reduced by 6.5%, 10.8%, 18.9%, and 35.13% than that of the reference mix at the age of 28 days. With an increasing rubber content, the modulus of elasticity reduced, and the water absorption rate of CR mixes increased compared with that of the control mix. The mixture containing 5% CR achieved the highest value of compressive, flexural, and indirect tensile strength, and the lowest water absorption rate in comparison to the other mixtures including CR particles.

1. Introduction

Waste tire rubber disposal has grown to be a significant global environmental concern and a very serious ecological threat. Utilizing recycled rubber tires as a partial substitution of the natural aggregate in concrete is a new approach to getting rid of it. Water penetration depth, flexural, and compressive strength of the CR concrete decreased with respect to the control mixture, but abrasion resistance and water absorption achieved better results (up to 10% replacement) than that of the control mixture [1]. Four kinds of concrete mixes were used, normal strength concrete mix, rubberized mix, steel fiber mix, and hybrid mix with rubber and steel fiber. Twelve samples were examined under conditions of drop-weight impact. Two hammers fell from two distinct heights and resulted in three various energies of transverse impact. To determine the deflection at mid-span versus time, a camera with high speed was used. In comparison to the tested samples, a three-dimensional finite element model was conducted. The findings demonstrated that a hybrid mix of rubber and steel fiber-filled steel tubing achieved the greatest level of cracking resistance, proceeded with steel fiber-filled tubing, while normal concrete-filled tubing demonstrated the smallest level of cracking resistance. The numerical and experimental findings

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are in harmony [2]. The results of the transverse impact on steel tubular filled with concrete and hollow showed that the tensile and compressive strength of steel and concrete increased after impact loading at elevated rates of strain, however, the effect of strain rate disappears when the velocity of initial collision is lower than 10 m/s. The impact method is divided into three phases: peak, stable, and unloading phase. The higher the confining factor the higher the energy of fracture and resistance of impact because concrete-filled steel tubular members exhibit greater ductile behavior [3]. Crumb rubber was utilized as a partial substitution of sand by 10%, 20%, and 30% of volume. Two cylinders with different dimensions were loaded with the indirect tensile strength to determine the influence of dimensions. According to the results, adding 10% of crumb rubber as a partial substitution of fine aggregate reduced the compressive strength of concrete slightly. Concrete resistance to cracking under impact load was improved by the inclusion of small-sized crumb rubber. The failure mode of small-sized crumb rubber concrete under static and impact loads is like that of normal concrete [4]. The influence of sample thickness and length of crack on stress intensity factors of mode 1 and mode 2 have been determined by three-dimensional finite element analysis. A circular disc sample with a center crack was utilized. The ratio of thickness to the radius of the sample ranges from 0.1 to 0.8 were examined numerically. The crumb rubber was added as a partial substitution of fine aggregate by 10% of the volume. Using numerical and experimental methods, the location of the crack initiation in the center cracked circular disc specimen was located at the longest vertical coordinate point on the surface of the notch for various notch inclination angles. Stress intensity factors of mode 1 value has risen at the middle plane of the sample by raising the sample thickness. A 10% sand replacement rate by crumb rubber has not influenced plane stress fracture toughness [5]. The mechanical characteristics of concrete with crumb rubber were enhanced using some treatment techniques including $KMnO_4$, cement coating, and NaOH. In the preparation of specimens with crumb rubber, the sand was substituted with crumb rubber up to 40% of the overall. The sedimentation coefficient of the $KMnO_4$, cement coating, and NaOH showed a significant enhancement, it achieved 99.6%, 99.0%, and 51.8%, respectively, versus the value of 37.2% of untreated CR. Using a small amount of crumb rubber and treating it with NaOH and $KMnO_4$ techniques enhanced the compressive and flexural strength of the concrete. However, the mechanical characteristics decreased with increasing concentrations of CR because of the aggregation of CR particles [6]. The impact and toughness of brittle concrete have been improved by the application of crumb rubber. Because normal concrete is prone to failure from fatigue and impact loads, rubber aggregate flexibility may hold the key to a solution. Even though the mechanical characteristics of crumb rubber concrete have slightly decreased, this can be solved by properly treating the crumb rubber aggregate. Crumb rubber aggregates could be treated using techniques including mechanical, chemical, thermal, and microwave treatment to improve their adhesion to the cement mortar [7]. The rubber fineness employed in the mixture has a direct impact on the fracture energy and other parameters. Numerical models are utilized to investigate the material response during the evolution of its damage using the material parameters derived from these laboratory studies. The embedded discontinuity method (EDM)is the numerical model used to simulate the development of concrete deterioration. The EDM can distribute damage throughout the continuum solid without changing the mesh topology. Results indicated that the experimental curve in the elastic and softening branches can be accurately approximated by numerical approaches [8]. Fly ash, nano-silica, and crumb rubber had an impact on the consistency of the self-compacting concrete and its mechanical characteristics. Twenty mixes with various amounts and ratios of sand (10–40% substitution of cement), crumb rubber (5–15% substitution of sand), and nano-silica (0–4% as an addition) were created as input parameters using the response surface methodology (RSM). The findings showed that the increment of fly ash improved the workability characteristics, whereas it reduced by using CR as a partial replacement of sand and the addition of nano-silica. The fly ash and nano-silica pore-refining impact and pozzolanic reactivity increased the composite strengths. Conversely, an increase in CR content has a detrimental impact on strength, but it considerably improves ductility and deformation capacity [9]. Under a specific constant volume rate of substitution, the automatically made sand of calcite powder concrete is substituted with rubber powder of 20 mesh with the same volume. The combination ratio of rubber powder with 20 and 40 mesh is then changed for investigating the performance of concrete. The findings demonstrated that the slump value increased when rubber powder with 20 mesh was less than a 10% replacement ratio. At the replacement ratio higher than 10% of sand, the concrete slump dramatically reduces, and its flow performance deteriorates. Results showed that by increasing the replacement ratio of rubber powder with 20 mesh, the compressive strength of the sample was significantly reduced. With increasing rubber powder with a mix ratio of 20 and 40 mesh at an equivalent rate of replacement, the compressive strength initially increases and then reduces [10]. The abrasion resistance of normal concrete increased by adding rubber particles. Hydraulic engineering, particularly in abrasion-resistant concrete building components, has a bright future. Rubberized concrete abrasion resistance is studied using the underwater steel-ball technique. The findings demonstrated that rubber particles increase the slump of concrete mixtures. While the rubberized concrete compressive strength reduces linearly with the increase of crumb rubber and its abrasion resistance increases noticeably. When using the same rubber particle size and content, rubberized concrete compressive strength and abrasion resistance are correlated, and larger particles of rubber greatly increase abrasion resistance [11]. Car and truck crumb rubber are two varieties that were used to change samples of asphalt cement. A rotatable and uniform central composite design, temperature (150–180) °C, time (20–60) minutes, car crumb rubber (10–20) by weight, and truck crumb rubber (0–4) by weight were utilized to identify the ductility response mathematical relationships. For the regression analysis and graphic results analysis, Minitab-17 was used. The temperature of 180 °C, along with the 24 cm ductility response were the ideal operating parameters, the contact time of 21 min, the car crumb rubber of 18 wt%, and the truck crumb rubber of 3.5 wt%. The results indicated that these optimized parameters, 4 mm, and 13 kN, significantly improved flow and Marshall stability, respectively, even though the ductility value decreased when compared to the unaltered binder [12]. The influence of heat on CR at 200 °C before incorporation into concrete was studied. The variables in this research were the quantity and size of rubber and the duration of heating. Samples of as-received and heat-treated rubber particles in addition to crumb rubber concrete were analyzed utilizing a Scanning Electron Microscope. The results indicated positive improvements in the performance of concrete. Thermally treated rubber with a size #40 mesh and a 20% rubber content increased the compressive strength by 60.3% [13]. Crumb rubber (CR) was used as a partial substitution of sand by a volume ratio of 0%, 5%, 10%, 15%, and 20%. For 24 hours, crumb rubber has been treated with regular detergent, NaOH, and lime. Additionally, water has been purified. All these procedures were performed to improve the mechanical characteristics of concrete. A lot of characteristics were evaluated such as compressive strength, unit weight, and water absorption. By increasing the ratio of CR, the mechanical characteristics reduced. After CR treatment, the characteristics were enhanced. The lime treatment was the most effective, then NaOH and water treatment. The detergent treatment approach was found to be the least effective of the four methods. Although the strength increased, it caused a loss of strength [14].

Several previous research have studied the effect of crumb rubber on the properties of concrete. It was noticed that concrete affects negatively due to the rubber and cement mortar low cohesion, it was necessary to improve these properties by adding pozzolanic additives such as fly ash as a partial replacement of cement and using benzene treated crumb rubber with different replacement ratios as a partial substitution of fine aggregate.

2. Experimental Program

2.1. Materials

The following materials were used in this study: -

Cement: Type I Portland cement. It has a surface area of 2270 cm^2 /gm in all the mixes.
Fine Aggregate: The used sand fineness modulus was 2.7 and the bulk density was 1790 kg/m^3.
Dolomite: Dolomite of 19 mm maximum nominal size was utilized and bulk density 1660kg/m^3.
Water: Used water free from impurities and organic matter.
Crumb rubber: It was used reserved crumb rubber particles on sieve No. 16. The density of CR was 900 kg/m^3, maximum tensile strength was 8 MP and elongation at failure was 145%.
Superplasticizers: Sikament 163 M was used, which is a liquid additive for high-performance concrete.
Fly Ash: An economical alternative to Portland cement used in long-term bonding, with a fineness of 353 m^2/kg, irregular shape, and non-crystalline.

2.2. Concrete Mixes

Four concrete mixtures were prepared with benzene-treated crumb rubber as a partial substitution for sand by 5%, 10%, 15%, and 20% of its weight. These mixtures were compared to the control mix. 15% of cement by weight was replaced by fly ash in all mixtures to enhance the mechanical characteristics of the concrete mixtures. The ratio of water to cement was 45%. Superplasticizer was added by 2% of cement weight. Crumb rubber particles have been treated with benzene for 30 minutes, followed by a water wash and drying time. Table 1. illustrates the design of the concrete mixture with the British method by weight per cubic meter. These samples were mixed for 2 minutes with a mechanical mixer and have been cured for 7 and 28 days. The samples were tested by subjecting them to indirect tensile, compressive, and bending loads for evaluating their performance.

Table 1. Mix design (Kg/m^3)

Mix	w/c=45%					CR
	Fly Ash	Sikament 163 M	C	Aggregates Coarse	Aggregates Fine	
Control	52.5	7	297.5	1094.64	729.76	-
M1 5% F.A	52.5	7	297.5	1094.64	693.26	36.5
M2 10%F.A	52.5	7	297.5	1094.64	656.76	73
M3 15%F.A	52.5	7	297.5	1094.64	620.26	109.5
M4 20%F.A	52.5	7	297.5	1094.64	583.76	146

3. Testing

3.1. Fresh Concrete Slump Test

The consistency of concrete before setting is determined by the slump test. It is conducted to determine if freshly poured concrete is workable and, consequently, how easily concrete flows. The test is distinguished by its simplicity and ease of implementation [15].

3.2. Compressive Strength Test

Cubic specimens with 15 cm x 15 cm x 15 cm size were subjected to compressive force by compression test machine at 7 and 28 days of curing in water. The rate of the applied load was 140 kg/cm^2/ minute until the specimen collapsed. Calculating compressive strength of samples by dividing the load at collapse by the cross-sectional area [16].

3.3. Flexural Strength Test

A flexure test machine was utilized to determine a modulus of rupture for beams after 7 and 28 days of curing. Beams with 10*10*50 cm size were tested and three specimens were made for each age [17, 18].

3.4. Splitting Tensile Strength Test

The test was conducted on cylinder specimens measuring 15 * 30 cm using a compression machine. Three specimens were made for each age and placed in water for curing. Splitting tensile strength was determined After 7 and 28 days. The applied load gradually increased until the specimens failed [19].

3.5. Water Absorption Test

Cubic specimens with 10*10*10 cm size were put in water for 28 days. For 24 hours, the concrete specimens were put in an oven at a temperature of 110 °C. Each sample was taken out of the oven, and its weight was calculated. After that specimens were submerged for 48 hours in water at a temperature of 21°C. Excess water was toweled off the samples before they were weighed. The water absorption rate was calculated [20].

3.6. Density Test

Hardened concrete density is defined as the mass per unit volume. The density of cubic samples with 15*15*15 cm size was calculated after 28 days of curing [21].

3.7. Modulus of Elasticity

The modulus of elasticity of a concrete mixture measures its final stiffness; it is associated with the cohesion between the kinds of aggregates utilized and the cement paste; thus, modifying components in the mixture demands measuring the modulus of elasticity.

4. Results and Discussion

4.1. Fresh Concrete slump

The slump value was determined to find out how adding CR particles affected the mix workability. The slump values of mixes containing CR particles were found to be lower than those of the control mix as shown in Fig.1. The reason for this decrease in slump values is because of crumb rubber particles have low specific gravity and hydrophobic behavior [22].

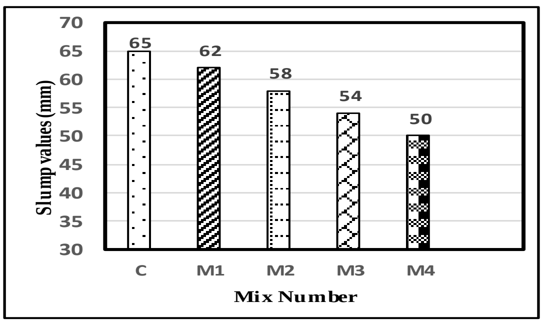

Fig. 1. Slump values for various mixes

4.2. Compressive Strength Test

The compressive strength of mixtures decreases in the case of adding crumb rubber as a partial substitution for sand compared to the control mixture at 7 and 28 days of curing in water, although treating the surface of the rubber with benzene makes it rough. Where the objective of CR treatment with benzene is to get rid of zinc salts present during tires production. These salts weaken the bond between the CR surface and the cement paste. The zinc salts can be dissolved in benzene but not in water. They are eliminated in benzene and increase the roughness of the CR surface. This causes more adhesion between the CR surface and cement paste [23,24,25]. As well as fly ash interacting with hydroxide calcium resulting from the interaction of cement with water, which results in hydrated calcium silicate, which increases the cohesion of concrete, but despite this, the compressive strength of the CR mixtures was lower than that of the control mixture. The compressive strength of CR mixtures was reduced by 7.14%, 18.36%, 26.5%, and 35.7% than that of the control mixture at 28 days of curing. The mixture containing 5% CR achieved the highest value of compressive strength in comparison to the other mixtures including CR particles. It was observed that compared to the control mixture, the compressive strength diminishes as the ratio of crumb rubber rises as shown in Fig. 2. Because the CR particles surface has weak interface transition zone nature and CR particles distribution is non-uniform [22].

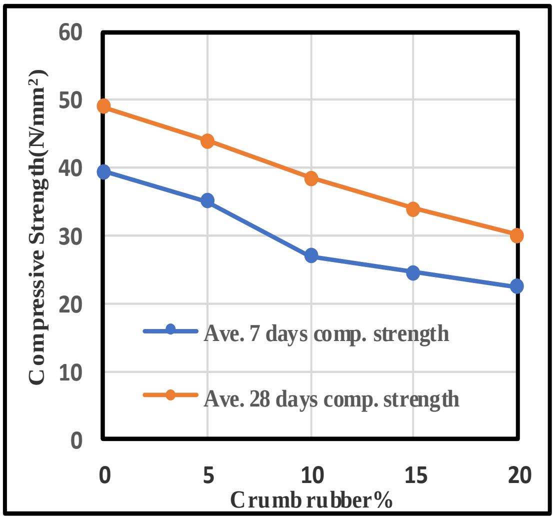

Fig. 2. The compressive strength values for different mixes

4.3. Flexural Strength Test

Fig. 3 demonstrates that the flexural strength decreases in the case of adding crumb rubber as a partial substitution for sand compared to the control mixture at 7 and 28 days of curing in water, although treatment of the rubber surface with benzene and the presence of fly ash. The flexural strength for the mixtures containing CR decreased by 3%, 10.6%, 16.7%, and 24.24% than that of the control mixture at 28 days of curing. The treatment with benzene as well as the addition of fly ash improves the properties of rubberized concrete, but the poor transition zone of the crumb rubber surface causes a reduction in flexural strength compared to the control mix [22]. The mixture containing 5% CR achieved the highest value of flexural strength in comparison to the other mixtures including CR particles.

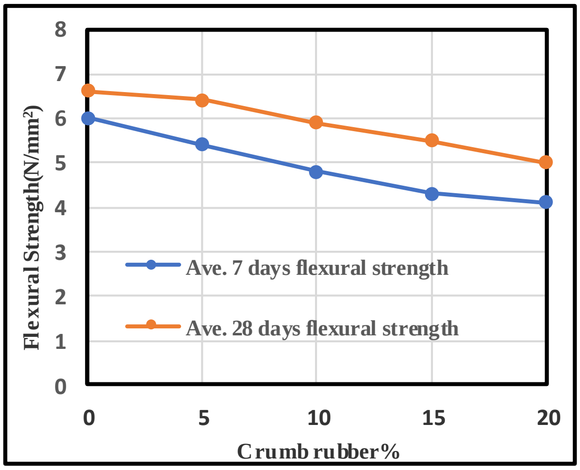

Fig. 3. The flexural strength values for different mixes

4.4. Splitting Tensile Strength Test

It was observed from the results that the splitting tensile strength for mixes with CR particles reduced in comparison to the tensile strength of the control mixture at 7 and 28 days after being cured as shown in Fig. 4. The splitting tensile strength takes the same trend of flexural strength. The tensile strength for mixtures decreases as the crumb rubber ratio rises. The tensile strength decreased by 6.5%, 10.8%, 18.9%, and 35.13% than the tensile strength of the control mix at the age of 28 days. This can be explained by the irregular distribution of CR particles [22]. Compared to the mixes containing CR, the mixture with 5% crumb rubber had the highest value of splitting tensile strength.

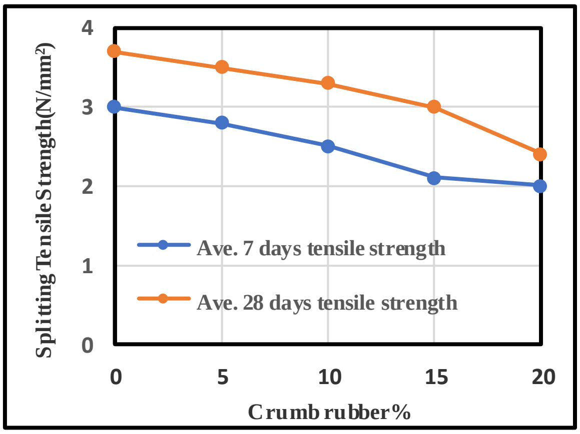

Fig. 4. The splitting tensile strength values for different mixes

4.5. Water Absorption Test

The influence of CR particles treated with benzene and adding fly ash as a partial substitution of cement on the water absorption rate of mixes is illustrated in Fig. 5. It was found that CR mixes absorbed water more quickly than the control mix at 7, 28 days of curing in water. The more crumb rubber particles, the greater the voids [26]. The mixture with 5% crumb rubber as a partial substitution of sand exhibited the lowest water absorption rate of all CR mixes.

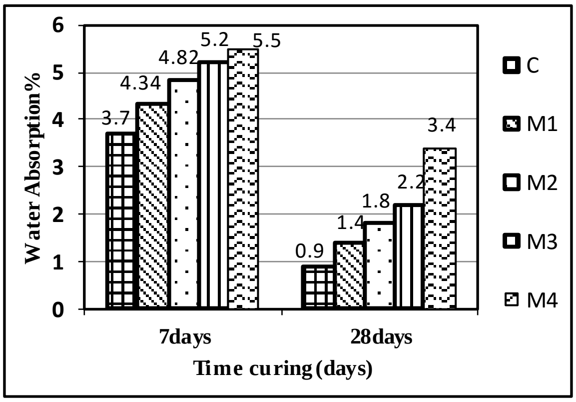

Fig. 5. The rate of water absorption values for various mixes

4.6. Density Test

The density for CR mixes reduced relative to the control mix at 28 days of curing, as seen in Fig. 6. The density of the mixtures reduced when the percentage of CR particles was raised as a partial substitute for fine aggregates. This is due to the low density of CR particles compared to natural aggregates [26].

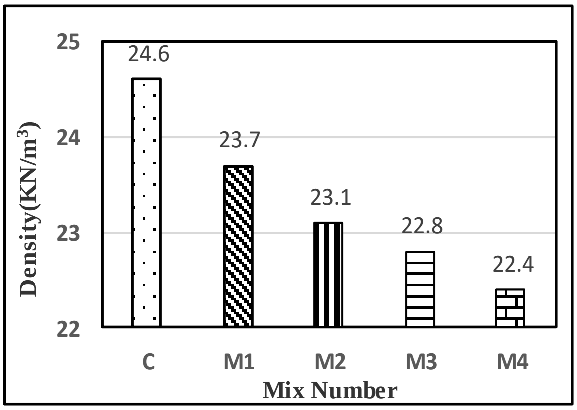

Fig. 6. Density values for different mixtures at 28 days of curing

4.7. Modulus of Elasticity

Fig. 7 presents the findings of the elastic modulus. The modulus of elasticity of CR mixes was found to be lower than that of the control mixture. Furthermore, in comparison to the control mixture, the elastic modulus reduced as the CR particle ratio rose. It decreased by 8.6%, 22.8%, 31.4%, and 42.8% compared to the elastic modulus of the control mixture. This is due to poor adhesion between CR particle's surface and cement mortar [22,27]. Therefore, the brittle characteristics of concrete are enhanced and made more ductile. So rubberized concrete is suitable for non-structural applications.

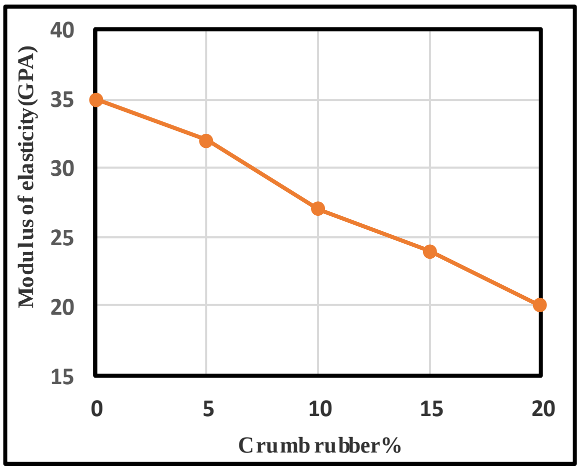

Fig. 7. Elastic modulus for various mixes

5. Conclusions

Based on the assessment and discussion of the experimental tests, we can deduce that:

1. The compressive strength of samples with crumb rubber decreases when the content of crumb rubber increases. Where addition fly ash is intended to reduce the rate of compressive strength decline.
2. The splitting tensile and flexural strength of crumb rubber mixtures had the same direction as the compressive strength. The mixture containing 5% CR achieved the highest flexural, compressive, indirect tensile strength, and the lowest water absorption rate compared with the other mixtures including CR particles.
3. The slump values of CR mixtures reduced as the ratio of CR increases compared with the reference mix.
4. As the ratio of crumb rubber increased, the rate of water absorption of the rubberized mixes increased, the density reduced, and the modulus of elasticity decreased compared to the control mix.

References

[1] Sofi, A., "Effect of waste tire rubber on mechanical and durability properties of concrete – A review", Ain Shams Engineering Journal. Vol. 9, pp. 2691–2700, 2018. https://doi.org/10.1016/j.asej.2017.08.007

[2] Merwad, A.M., El-Sisi, A.A., Mustafa, S.A.A., and Sallam, H.E., "Lateral impact response of rubberized-fibrous concrete-filled steel tubular columns: experiment and numerical study", Buildings. Vol. 12, pp. 1-19, 2022. https://doi.org/10.3390/buildings12101566

[3] Merwad, A.M., Elsisi, A.A., Mustafa, S.A.A., and Sallam, H.E., "Transverse impact on hollow and concrete filled steel tubular members: an overview", The Egyptian International Journal of Engineering Sciences and Technology. Vol. 32, pp. 49-58, 2020. DOI: 10.21608/EIJEST.2021.53931.1031

[4] Sallam, H. E. M., Sherbini, A. S., Seleem, M. H., and Balaha, M. M., "Impact resistance of rubberized concrete", Engineering Research Journal Faculty of Engineering Minoufiya University. Vol. 31, No. 3, pp. 265-271, 2008. DOI: 10.21608/ERJM.2008.69543

[5] Mubaraki, M., Abd-Elhady, A.A., and Sallam, H.E.M., "Mixed mode fracture toughness of recycled tire rubber-filled concrete for airfield rigid pavements", International Journal of Pavement Research and Technology. Vol. 6, No. 1, pp. 8-14. 2013. http://www.ijprt.org.tw/reader/pdf.php?id=271

[6] Assaggaf, R.A., Maslehuddin, M., Al-Dulaijan, S.U., Al-Osta, M.A., Ali, M.R., and Shameem, M., "Cost-effective treatment of crumb rubber to improve the properties of crumb-rubber concrete", Case Studies in Construction Materials. Vol. 16, pp. 1-16, 2022. https://doi.org/10.1016/j.cscm.2022.e00881

[7] Assaggaf, R.A., Ali, M.R., Al-Dulaijan, S.U., and Maslehuddin, M., "Properties of concrete with untreated and treated crumb rubber - A review", Journal of Material Research and Technology. Vol. 11, pp. 1 7 5 3 -1 7 9 8, 2021. https://doi.org/10.1016/j.jmrt.2021.02.019

[8] Retama, J., and Ayala, A.G., "Influence of crumb-rubber in the mechanical response of modified Portland cement concrete", Advances in Civil Engineering. pp. 1-9. 2017. https://doi.org/10.1155/2017/3040818

[9] Rahim, N.I., Mohammed, B.S., Abdulkadir, I., and Dahim, M., "Effect of crumb rubber, fly ash, and nano-silica on the properties of self-compacting concrete using response surface methodology", Materials. Vol. 15, pp. 1-22. 2022. https://doi.org/10.3390/ma15041501

[10] Zhao, Z.F., Zhang, X.Z., Li, L.F., and Yang, Y., "Experimental study of working performance and mechanical properties to rubber with limestone powder concrete", Earth and Environmental Science. Vol. 783, pp.1-6, 2021. DOI:10.1088/1755-1315/783/1/012048

[11] Yun Feng, L., Jiu Chen, A., and Dong Liu, H., "Effect of waste tire rubber particles on concrete abrasion resistance under high- speed water flow", International Journal of Concrete Structures and Materials. pp. 15-37, 2021. https://doi.org/10.1186/s40069-021-00475-8

[12] AlJaberi, F.Y.," A study on the significance of the crumb rubber classification on the ductility test for rubberized asphalt binder". SN Applied Sciences. 1-1472. 2019. https://doi.org/10.1007/s42452-019-1534-9

[13] Abd-Elaal, E., Araby, Sh., Mills, J.E., Youssf, O., Roychand, R., Ma, X., Zhuge, Y., and Gravina, R.J., "Novel approach to improve crumb rubber concrete strength using thermal treatment", Construction and Building Materials. Vol. 229, pp. 1-11. 2019. https://doi.org/10.1016/j.conbuildmat.2019.116901

[14] Awan, H.H., Javed, M.F., Yousaf, A., Aslam, F., Alabduljabbar, H., and Mosavi, A., "Experimental evaluation of untreated and pretreated crumb rubber used in concrete", Crystals. Vol. 11, No. 558, pp. 1-14. 2021. https://doi.org/10.3390/cryst11050558

[15] ASTM Standard Test Method C143: Slump of Hydraulic Cement Concrete

[16] ISO 4012 Concrete-Determination of Compressive Strength of Test Specimens.

[17] ISO 1920 Concrete Tests-Dimensions, Tolerances, and Applicability of Test Specimens.

[18] ISO 4013 Determination of Flexural Strength of Test Specimens.

[19] BS-1881 Testing Concrete, Part 117 Method of Determination of Tensile Splitting Strength.

[20] ASTM C642. Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. Philadelphia (PA): ASTM; 2001.

[21] BS 1881. Part 114 Methods for Determination of Density of Hardened Concrete.

[22] Ren, F., Mo, J., Wang, Q., and Ming Ho, J. Ch., "Crumb rubber as a partial replacement for fine aggregate in concrete: An overview", Constructure and Building Materials, Vol. 343, No. 128049. 2022. https://doi.org/10.1016/j.conbuildmat.2022.128049

[23] Al-Khuzaie, M.G., Al-Humeidawi, B.H., and Al-Saidi, R.F., "Assessment of the mechanical properties of concrete pavement containing crumb rubber tires", Materials Science and Engineering. Vol. 737, pp. 1-13, 2020.

[24] Meddah, A., "Characterization of roller compacted concrete containing rubber-tire wastes". Thesis, National Polytechnic School of Algiers, pp.134, 2015.

[25] Pacheco-Torgal F., Ding Y., and Jalali S., "Properties and durability of concrete containing polymeric wastes (tyre rubber and polyethylene terephthalate bottles): An overview",

Construction and Building Materials. Vol. 30, pp. 714-724. 2012.
https://doi.org/10.1016/j.conbuildmat.2011.11.047

[26] Assaggaf, R.A., Ali, M.I., Al-Dulaijan, S.U., and Maslehuddin, M, "Properties of concrete with untreated and treated crumb rubber – A review. Journal of materials research and technology". Vol. 11, pp. 1753-1798. 2021.

[27] Toma, I.O., Stratulat, S.M.A., Mihai, B., Toma, A., and Taranu, G., "Experimental investigations on the long-term material properties of rubberized Portland cement concrete", Applied science. Vol. 11, pp. 1-17. 2021.
https://doi.org/10.3390/app112210868