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COMPARATIVE STUDY OF THE LIGHTENING OF CONCRETE THROUGH THE USE OF RECYCLED TIRE RUBBER AND EXPANDED CLAY AGGREGATE

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Abstract

The waste of tire rubber is characterized by the generation of huge amounts, which is annually discarded. This waste causes problems for human health and the environment. Thus, the valorization of recycled tire rubber in concrete production is considered as an alternative and sustainable solution. This experimental work is a comparative study, which aims to investigate the possibility of using recycled tire rubber as a fine aggregate in the production of lightweight concrete. To achieve this objective, two types of lightweight concrete containing (35, 70 and 100%) of expanded clay and (5, 10 and 15%) of recycled tire rubber as a fine aggregate were produced. Their fresh properties were investigated using slump, density and air content tests, while the hardened properties were investigated by compressive strength, flexural strength, ultrasonic pulse velocity, and water absorption tests. The results obtained showed that the utilization of both expanded clay aggregate and recycled tire rubber leads to a reduction in density and mechanical strength but increases the porosity of lightweight concrete. However, the lightweight concrete containing the expanded clay aggregate had a higher efficiency factor than those containing recycled tire rubber.

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Key words

- Lightweight concrete,
- Expanded clay aggregate,
- Recycled tire rubber,
- Properties,
- Valorization.

1 INTRODUCTION

The production of lightweight concrete (LWC) is an important technological field; LWC is characterized by a very low density (< than 2000 kg/m^3) (Andressa et al., 2020). The lower density of LWC leads to the reduction of foundation sizes and structural elements (Katrin Schumacher et al., 2020; Basha et al., 2020). Due to its lower density, LWC is also defined by enhanced thermal and sound insulation (Sousa et al., 2004; Hubertova and Hela, 2009; Grabois et al., 2016), higher specific strength and increased fire resistance (Amin et al., 2019; Xi et al., 2019). The performance of LWC is characterized by an important parameter called the "efficiency factor" (EF), which represents the ratio between the density and compressive strength of LWC (Andressa et al., 2020). The production of LWC requires the use of natural or artificial lightweight aggregates. The aggregates mostly used for the production of LWC are expanded clay, sintered fly ash, and expanded shale (Xi et al., 2019). Expanded clay aggregates (ECA) are artificial lightweight aggregates, which are produced by expanding natural clay at a high temperature (around 1200 °C) in a rotary kiln (Ardakani and Yazdanie, 2014; Ayati et al., 2018; Rashed 2018). The utilization of ECA, which has better compressive strength than other lightweight aggregates, decreases the cost of reinforced steel by 20% and reduces the cost of heating and cooling by 50% (Pavithra and Jerosia, 2018; Vijayalakshmi and Ramanagopal, 2018; Sellakkannu and Tamilarasan, 2016). However, LWC containing ECA exhibits a decrease in compressive strength (Sellakkannu and Tamilarasan, 2016; Corinaldesi and Moriconi, 2015). (Bogas and Nogueira,

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2014) added that the use of ECA as a coarse aggregate decreases the tensile strength of LWC by 15-20%. (Sivakumar and Kameshwari, 2015) mentioned that an increase in ECA content progressively decreases the compressive and flexural strength of LWC. (Lakshmi Sravya et al., 2020) recommended the use of cementitious mineral admixtures to avoid a significant drop in the mechanical properties of LWC. (Serkan, 2009) showed that the adding of 10% of fly ash increases the compressive strength and tensile strength of LWC by 8 and 9% respectively. The studies carried out by (Józwiak-Niedzwiedzka, 2005; Shankar, 2016; Shebannavar et al., 2015) showed that ECA had a beneficial effect on the workability of concrete and that concrete containing ECA was more workable than normal weight concrete. (Bogas et al., 2015; Salem et al., 2014) reported that the adding of ECA increases the absorption of LWC by about 55%. (Bogas and Gomes, 2015; Zhang and Gjorv, 1991; Hobbs, 1999) found that ECA harms the durability and resistance to chloride of LWC.

On the other hand, huge amounts of used tire rubber (TR) are generated annually. (Tomas and Gupta, 2016) reported that about 1 billion tons of used TR is produced in the world annually and that more than half of this waste is discarded in landfills. (Azevedo et al., 2012) added that by the year 2030, the amount of TR waste will reach 6 billion tons. This waste causes serious problems for public health and the environment (storage problems, fire risks, and the dissemination of insects). Several studies have been carried out to evaluate the possibility of reusing recycled tire rubber (RTR) in concrete production to eliminate TR waste from the environment. (Bravo and Brito, 2012; Mhaya et al., 2020) concluded that RTR decreases the workability of concrete. (Su et al., 2015) added that larger particles of RTR reduced the workability of concrete less than finer particles. (Siddika et al., 2019) reported that the density of concrete decreased with an increase in RTR content. (Aslani et al., 2018; Si et al., 2018 ; Zhang et al., 2015; Najim and hall, 2012) noted that the adding of RTR reduced the mechanical strength of concrete. The compressive strength dropped by 90% with the total substitution of fine aggregates by RTR (Batayneh et al., 2008). (Bisht and Ramana, 2017) added that the presence of RTR in concrete composition also reduced the elastic modulus of concrete. (Thomas et al., 2014) showed that up to 7.5% RTR can be used as a fine aggregate without a significant decrease in strength. To avoid a significant drop in the strength of concrete containing RTR, several studies recommended the use of RTR with other cementitious additions such as silica fume (AbdelAleem and Hassan, 2018; Gesoglu and Guneyisi, 2007), fly ash (Erhan, 2010), and blast furnace slag (Mhaya et al., 2020). (Yung et al., 2013) noted that 5% of RTR powder provided optimal durability properties for concrete. (Thomas et al., 2015) found that RTR improved the resistance of concrete to acid attacks. (Thomas et al., 2016b) showed that RTR increased the water absorption of concrete. However, it has been shown that the reuse of RTR improves the ductility, abrasion resistance (Li et al., 2018), thermal insulation, and flexibility of concrete (Lv et al., 2015).

2 SIGNIFICANCE OF RESEARCH

Concrete is an important construction material and is among the most widely used materials in the world (Andressa et al., 2020). It has been estimated that 12 billion tons of concrete are produced annually. It has also been estimated that the need for concrete will increase to 18 billion tons by the year 2050 (Singh et al 2017). The higher demand for concrete has led to intensive exploitation of the raw materials used in their production. The utilization of waste and by-products in concrete production is considered as an effective and sustainable solution, which could protect the environment and public health, reduction the consumption of raw materials, and save energy. This work aims to study the possibility of reusing RTR as lightweight aggregates in LWC production through a comparative study examining the performance of LWC containing RTR and other LWC containing ECA. Knowing that ECA production needs a higher amount of energy, the substitution of ECA by RTR could lead to the production of eco-friendly LWC.

3 MATERIALS USED

3.1 Cement

Portland cement (PC) CEMI 42.5 was used in this study. The specific density and specific surface area of PC were 3.11 g/cm^3 and 4308 cm^2/g respectively. The chemical and mineralogical compositions of PC used are illustrated in **Tables 1 and 2**.

Tab. 1 *Chemical composition of PC*

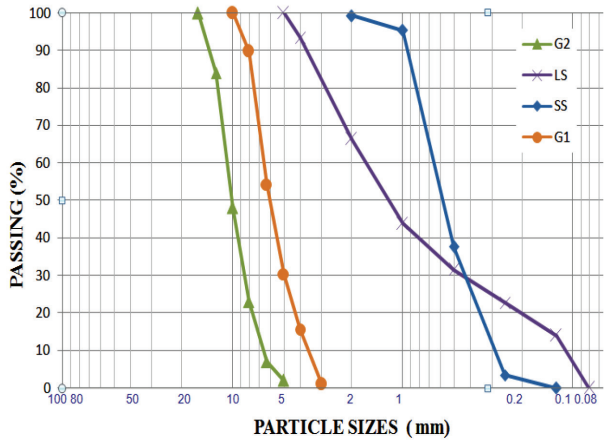
Chemical properties (%)	PC
CaO	64.29
Al_2O_3	4.74
Fe_2O_3	2.89
SiO_2	18.54
MgO	1.34
Na_2O	0.24
K_2O	0.57
Cl-	0.05
SO_3	3.01
Loss in ignition	3.31

Tab. 2 *Mineralogical composition of PC*

Mineralogical Composition (%)	PC
C_4AF	11.25
C_3A	7.50
C_3S	60.45
C_2S	12.24

3.2 Aggregates

Coarse crushed limestone sand (LS) with a specific gravity of 2.64, a water absorption of 0.94%, and a finesse modulus of 3.25 was used as a fine aggregate. Fine siliceous dune



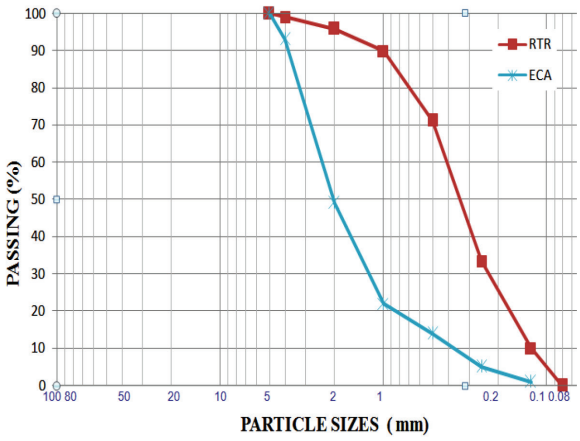


Fig. 1 *Distribution of particle sizes of aggregates used*

sand (SS) with a specific gravity of 2.65, a water absorption of 0.48%, and a finesse modulus of 1.64 was used to correct the grain size distribution of LS. Two crushed limestone gravels (G1 and G2) with nominal maximum sizes of 8 and 15 mm respectively, a specific density of 2.69 g/cm^3, and a water absorption of 0.94% were used as coarse aggregates (CA). Expanded clay aggregate (ECA) with a nominal maximum size and specific density of 4 mm and 1.68 g/cm^3 respectively was used as a lightweight aggregate. The particle distribution of the aggregates is presented in **Fig. 1**.

3.3 Recycled tire rubber (RTR)

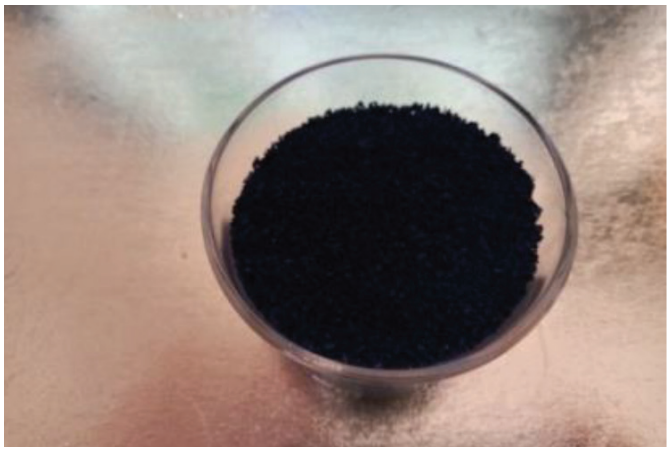


Fig. 2 *RTR used*

The RTR used in this study was obtained by cutting end-of-life tires in small particles, followed by washing them **(Fig. 2)**. The RTR had a maximum size of 4 mm, a specific density of 1.10 g/cm^3, and a water absorption of 1.65%. The particle distribution of RTR is presented in **Fig. 1**.

3.4 Admixture

To obtain the desired workability, viscocrete 665 based on polycarboxylate with a brown color, a density of 1.08 g/cm^3, and a PH of 5 was used as a superplasticizer (SP).

4 MIXING PROCEDURE AND TEST METHODS

Two types of concrete were produced to carry out this study. The first type contains ECA as a lightweight aggregate, while the second type contains RTR. The concrete mix proportions are provided in **Table 3**. The contents of PC, water, and SP were kept constant. ECA and RTR were introduced in the concrete composition by the volumetric substitution of the normal fine aggregate. The substitution rates chosen were 35, 70, and 100% for the ECA and 5, 10, and 15% for the RTR aggregates. The maximum RTR rate was limited to 15% to avoid a significant drop in the mechanical strength of the mixtures.

The solid constituents were mixed for three minutes. Then, the water and SP were mixed with the other constituents for three more minutes. After mixing, the mixture was introduced and vibrated into standard steel molds according to NF P18-405. Cube samples (150×150×150 mm) were used for the compressive strength, pulse velocity and water absorption tests. Prismatic samples (70×70×280 mm) were used for the flexural strength. After 24 hours of molding, the samples were demolded and conserved in water curing (at 23 °C and 100% relative humidity) until their testing days.



Fig. 3 *Preparation of specimens for test.*

The fresh and hardened property tests were performed according to the standards mentioned below. For each test, the results obtained represent the average of three readings.

Tab. 3 *LWC mixtures*

	G1 (Kg/m³)	G2 (Kg/m³)	SS (Kg/m³)	LS (Kg/m³)	PC (Kg/m³)	SP (L/m³)	Water (L/m³)	ECA (Kg/m³)	RTR (Kg/m³)
C0	260	748	150	701	350	2,1	147	0	0
ECAC35	260	748	150	436	350	2,1	147	134	0
ECAC70	260	748	150	214	350	2,1	147	268	0
ECAC100	260	748	150	00	350	2,1	147	382	0
RTRC5	260	748	150	674	350	2,1	147	00	16
RTRC10	260	748	150	637	350	2,1	147	00	32
RTRC15	260	748	150	599	350	2,1	147	00	47

- ✓ Slump test NF EN 12350-2
- ✓ Bulk density in fresh state NF EN 12350-6
- ✓ Air content NF EN12350-7
- ✓ Compressive strength NF EN 12390-3
- ✓ Flexural strength NF EN 12390-5
- ✓ Pulse velocity NF EN 12504-4
- ✓ Water absorption NBN B15-215

5 DISCUSSION OF RESULTS

5.1 Workability

The workability results are shown in **Fig. 4** for the concrete mixtures containing the different volume fractions of ECA and RTR. As can be seen, the adding of ECA insignificantly affects the workability of LWC. The workability decreases from 21 to 20 cm when the ECA content increases from 0 to 100%. The non-reduction of the workability of LWC containing ECA was attributed to the rounded surface of ECA, which facilitates the LWC flow (Rashed et al., 2018). However, the LWC mixtures containing RTR showed a significant decrease when the RTR rate exceeds 10%. For the 15% of the RTR content, the workability dropped by 14.28%. This reduction was explained by the rough nature of the RTR grains, which increase the friction between the LWC components (Holmes et al., 2014; Su et al., 2015).

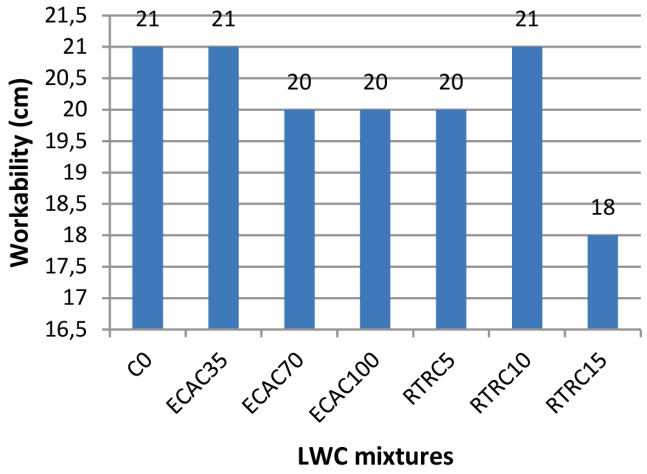


Fig. 4 *Workability of LWC mixtures*

5.2 Bulk density

Fig. 5 shows the bulk density values of the LWC mixtures. The increase in ECA and RTR contents gradually decreases the density of LWC. This decrease is more pronounced for LWC containing ECA. The bulk density decreases by 13.26% and 6.79% when 100% and 15% of ECA and RTR are used respectively. The bulk density of concrete mainly depends on the density and the rates of its components (Siddique et al., 2004). The utilization of ECA and RTR, which have lower densities than the other components, decreases the bulk density of the concrete. This decrease was more pronounced with LWC containing ECA due to the higher contents of ECA in the LWC composition compared to that of LWC containing RTR.

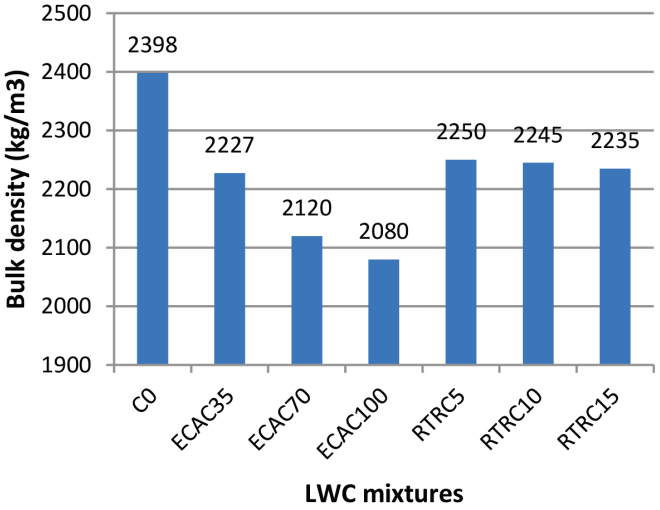


Fig. 5 *Bulk density of LWC mixtures*

5.3 Air content

The air content values are shown in **Fig. 6**. As can be seen, increasing the ECA and RTR content in the LWC composition progressively increases the air content values. It can also be seen that a maximum increase of 171% was recorded with LWC containing 100% of ECA, while LWC containing 15% of RTR exhibited an increase by 66.66%. The increase in the air content value of concrete containing RTR was also shown by (Ling et al., 2010; Siddique et al., 2004) and attributed to the fact that RTR has a non-polar nature, which traps the air bubbles in the composition of the concrete. The increase in the

air content of LC containing ECA is due to the porous nature of ECA, which facilitates the air entrapment (Rashad 2018)

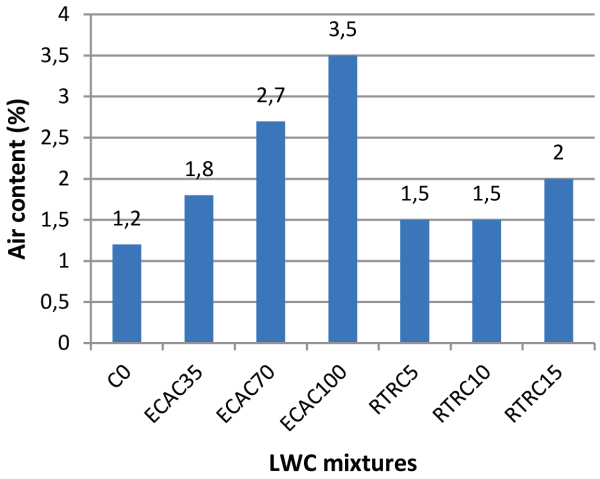


Fig. 6 *Air content of LWC mixtures*

5.4 Compressive strength

The variations of the compressive strength of LWC containing different volumes of ECA and RTR at 7, 28, and 56 days is presented in **Fig. 7**.

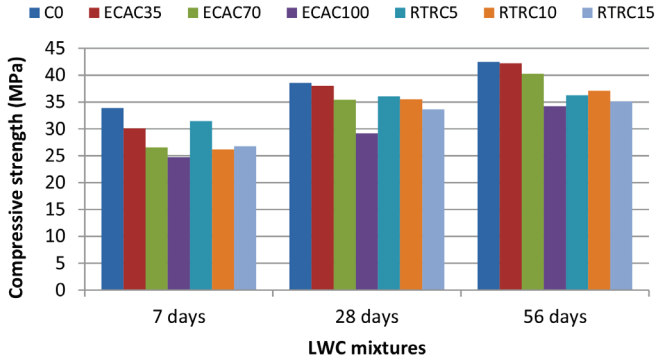


Fig. 7 *Compressive strength of LWC mixtures*

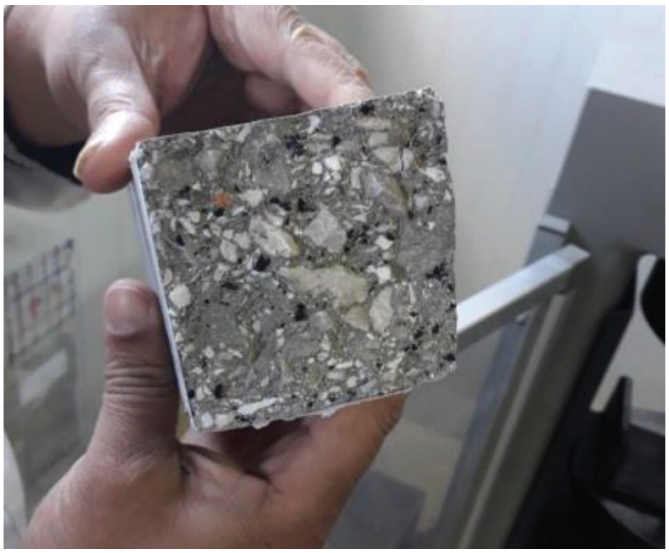


Fig. 8 *Failure mode of LWC containing RTR.*

All the concrete mixtures show a progressive reduction in compressive strength with the increase in the ECA and RTR contents. The reduction in the compressive strength reaches 23.15 and 12.83% for the LWC containing 100 and 15% of ECA and RTR respectively at 28 days. (Bogas and Gomes, 2013) explained the drop in the compressive strength of LWC containing ECA by the fact that 1) ECA has a lower crushing strength, which negatively affects the compressive strength of LWC, 2) ECA has a rounded shape, which decrease the bond with the surrounding paste. (Gangian et al., 2009) attributed the reduction of the compressive strength of concrete containing RTR by the lack of adhesion between the cement paste and RTR **(Fig. 8)**.

5.5 Efficiency factor

The efficiency factor (EF) is a parameter calculated using the ultimate strength per density. The variations of EF of LWC mixtures are illustrated in **Fig. 9**. It can be seen that the addition of 35 and 70% of ECA in an LWC composition leads to an increase in EF by 6.88 and 7.16% respectively. For a further increase in the ECA content, the EF tends to decrease. However, all the LWC mixtures containing RTR exhibit a gradual decrease in EF. The EF decreases from 17.72 to 15.71 when the RTR content increases from 0 to 15%. This decrease is explained by the significant reduction of the compressive strength of LWC containing RTR despite its low content.

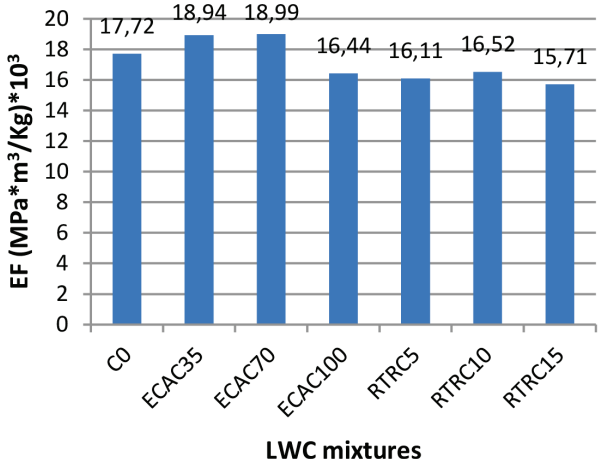


Fig. 9 *Efficiency factor of LWC mixtures*

5.6 Flexural strength

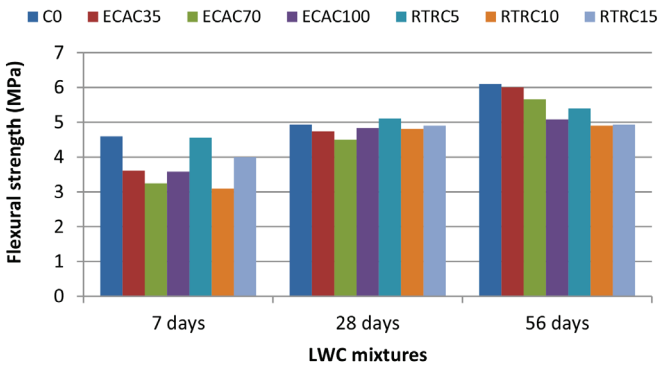


Fig. 10 *Flexural strength of LWC mixtures*

The results of the flexural strength tests are illustrated in **Fig. 10**. Like the compressive strength, the flexural strength of LWC decreases with the addition of ECA and RTR in the LWC composition. At 56 days, the flexural strength decreases from 6.01 to 5.08 and 4.93 MPa, when 100 and 15% of ECA and RTR were used respectively, i.e., a decrease of 15.47 and 17.97% respectively. This decrease is due to the rounded nature of ECA and the lack of adhesion of RTR with cement paste (Bogas and Gomes, 2013; Gangian et al., 2009).

5.7 Ultrasonic pulse velocity (UPV)

Fig. 11 shows the ultrasonic pulse velocity (UPV) of LWC mixtures at 28 days. The control mixture had an ultrasonic pulse velocity of 4.87 km/s, whereas all the LWC containing ECA and RTR had a lower UPV compared with the control concrete. It should be noted that according to ASTM C597, which considers the concrete to be of very good quality when the ultrasonic pulse velocity is higher than 4.5 Km/s, all the LWC mixtures are classified as having a very good quality.

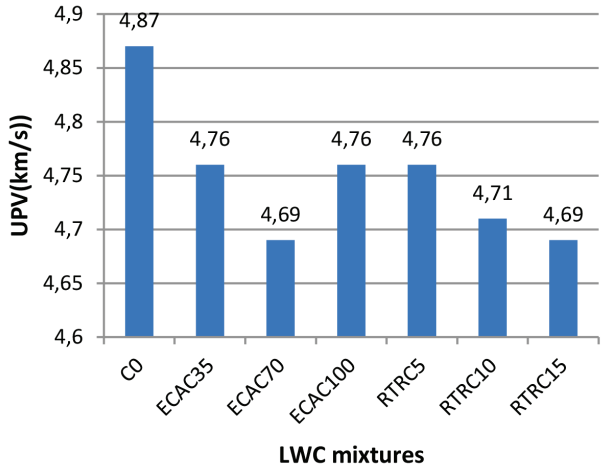


Fig. 11 *UPV of LWC mixtures*

5.8 Water absorption

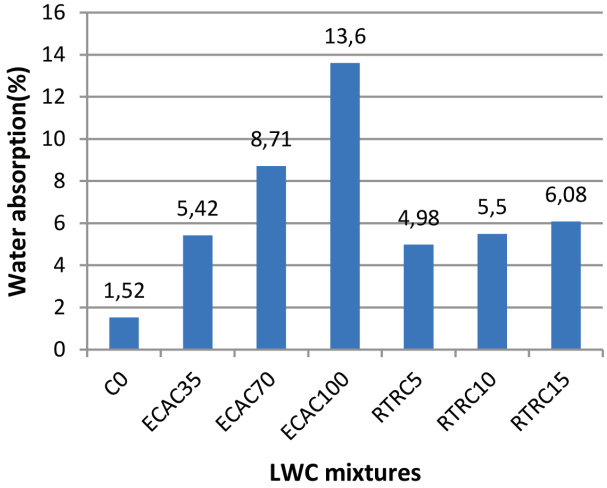


Fig. 12 *Water absorption of LWC mixtures*

The water absorption of LWC mixtures constitutes a major factor that affects their durability and represents the volume of the permeable pores of the LWC mixtures and their connectivity inside the concrete. The water absorption values of FRC mixtures are presented in **Fig. 12**. As can be seen, all the LWC mixtures have water absorption values higher than that of the control concrete. The water absorption gradually increases with the increase in the ECA and RTR contents. The water absorption of the control concrete was 1.52%, while the maximum water absorption values were 13.60 and 6.08% for the LWC containing ECA and RTR, respectively. It can also be seen that the LWC containing 100% of ECA exhibits a maximum increase of the water absorption value by 13.60% compared to that of the control concrete. (Rashed, 2018) attributed the increase in the water absorption of LWC containing ECA to the higher water absorption and the nature of the open voids of ECA, compared with ordinary aggregates, while the increase of water absorption of LWC containing RTR was explained by the lack of bonding between the RTR and cement paste, which facilitates the penetration of water in the LWC composition (Gangian et al., 2009). According to (CEB-FIP 1989), concretes having water absorption of less than 3%, between 3 and 5%, and higher than 5% can be classified as good, average and poor quality. According to this classification, the LWC containing 5% of RTR exhibits an average concrete quality, whereas all the other LWC mixtures have a poor quality.

5.9 Dynamic elastic modulus

The dynamic elastic modulus of the concrete mixtures was evaluated using the following model (Uysal and Yilmaz 2011):

$$E = 10^5 \times V^2 \times \left(\frac{\Delta}{g}\right) \quad (1)$$

E is the dynamic elastic modulus (GPa); V is the ultrasonic pulse velocity (m/s); Δ is the bulk density of concrete (kg/m^3); and g is the gravity acceleration (m/s^2).

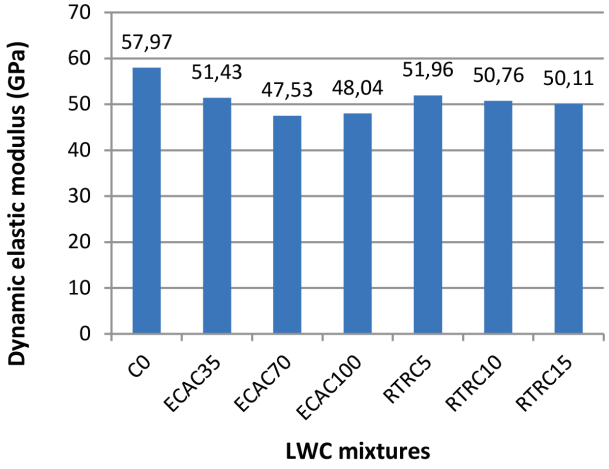


Fig. 13 *Dynamic elastic modulus of LWC mixtures*

The dynamic elastic modulus values of the LWC mixtures are presented in **Fig. 13**. As with the compressive strength, the dynamic elastic modulus decreases with the increase in ECA and RTR in the LWC mixtures. The lower value was obtained

with 10% of ECA, which exhibits a decrease of 18% in the dynamic elastic modulus, while the LWC containing 15% RTR exhibits the lower dynamic elastic modulus of 13.55% for the LWC containing RTR. This reduction in the dynamic elastic modulus was mainly due to the decrease in the compressive strength values (Li et al., 2018).

5 CONCLUSIONS

This work is aimed at studying the possibility of reusing RTR as a fine aggregate to produce LWC through a comparative study between the properties of LWC mixtures containing ECA and RTR as lightweight aggregates. Based on the experimental results, the following conclusions can be drawn:

- The addition of ECA insignificantly affects the workability of LWC, while the RTR decreases the workability when its content exceeds 10%.
- The air content of LWC increases with the increasing ECA and RTR content. The higher value was recorded with 100% of ECA.
- Despite its limited contents compared to the ECA contents, the addition of RTR in the LWC composition leads to a significant reduction in the compressive strength. This significant reduction leads to a decrease in the efficiency factor values of LWC containing RTR compared to that of LWC containing ECA.
- Both ECA and RTR increase the water absorption of LWC. The increase in the water absorption value was more pronounced with LWC containing ECA.

Finally, it can be noted that the use of recycled tire rubber as a lightweight aggregate in the production of lightweight concrete presents promising ecological and technical interests. From the results obtained, the LWC containing RTR can be applied in the fabrication of non-load bearing elements when compressive strength is not required (sealing element, dividing walls, and cleanliness of the concrete), especially when the RTR content exceeds 15%. It should also be noted that the utilization of RTR in the LWC composition leads to the production of eco-friendly materials.

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