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Original Research Article

EFFECT OF RECYCLED TIRE RUBBER AND MARBLE WASTE ON FRESH AND HARDENED PROPERTIES OF CONCRETE

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A b s t r a c t

This paper investigates the effect of simultaneous adding of recycled tire rubber (RTR) and marble waste (MW) as fine aggregates on the properties of concrete. To achieve this objective, the particles size distribution of crushed sand (CS) was corrected by the use of marble waste sand (MWS), and RTR was used by volumetric substitution (1%, 2%, 3% and 4%) of aggregates in concrete. The fresh properties were investigated using the slump, density and air content tests. Hardened properties were investigated through the compressive strength, flexural strengths, pulse velocity, elastic modulus and water absorption. The obtained results showed that the increase in the substitution rate of RTR reduced the fresh and hardened properties of concrete containing marble waste sand. However, with low substitution rates the properties of concrete remain satisfactory and the utilization of RTR and MWS leads to making a green concrete while protecting the environment.

Keywords: recycled tire rubber, marble waste, green concrete, properties

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1. INTRODUCTION

The reduction in the exploitable reserves of natural aggregates and forecast of a decrease in the production of these aggregates prompted researchers to find alternative supply sources of aggregate for concrete industry (Huang et al 2020, Youssf et al 2020). On the other hand, the industrial activities produce large amounts of wastes annually, which are deposited in landfills. It is becoming evident that the valorization of these wastes is a major environmental issue, and their reuse as aggregates or fibers intended for making new green concrete would be a beneficial alternative for the environment. It would indeed allow the preservation of raw materials and limitation of pollution (Jalal et al 2020).

Among these wastes which cause serious problems for the environment and public health, there is the waste of tires rubber. It was estimated that about 1 billion end-of-life tires are produced in the world annually, more than half of these are discarded in landfills (Thomas and Gupta 2016a). By the year 2030, it was also estimated that 5 billions more will be discarded (Azevedo et al 2012). In the European Union, it was estimated that 3.2 million tonnes of used tires were discarded in 2009 with valorization rate equal to 96% (Bravo and Brito 2012). In the Algerian context, 49.62 thousand tons of rubber tires are imported every year. Knowing that every new sold tire generates end-of-life tire and taking into account the loss of mass due to the wear, the amount of end-of-life tires reaches 45.65 thousand tons, every year (Bekhiti et al 2014). The uncontrolled storage of end-of-life-tires is a source of public health nuisance (pollution, aesthetics, spread of insects and potential fire risks) (Munoz-sanchez et al 2017). Thus, the reuse of these in concrete technology can be effective to limit the environmental pollutions and protect the public health (Xiong et al 2020).

Several studies have been conducted to reuse the RTR as aggregates and filler in various types of concretes. Bravo and Brito (2012) observed that workability of rubber concrete (RC) decreases with the increase in RTR content. Similar result was observed by Mhaya et al (2020). Su et al (2015) concluded that the larger rubber particles give for concrete better workability than the finer particles. The decrease in workability is accompanied by a reduction in density of rubberized concrete, this reduction is influenced by the RTR content and size (Seddika et al 2019).

The effect of RTR on the mechanical properties of concrete has been investigated by several studies (Aslani et al 2018, Bisht and ramana 2017, Najim and hall 2012, Si et al 2018, Zhang et al 2015). They observed a significant reduction in strength and elastic modulus. Batayneh et al (2008) report that with full replacement of fine aggregates with RTR, the compressive strength decrease by 90%. Thomas et al (2014) reported that crumb rubber may be utilized as fine aggregates up to 7.5%, without significant decrease in strength. Raffoul et al

(2016) recommended the combined substitution of fine and coarse aggregates with RTR to minimize the strength reduction. However, it was reported that RTR give higher flexibility for concrete (Lv et al 2015), increase the ductility and concrete ability of energy absorption (Li et al 2018).

Thomas et al (2015) studied the durability properties of rubberized concrete in aggressive environments; they found that RTR enhance the concrete resistance to acid attack. Yung et al (2013) noted that 5% of RTR powder was the optimal substitution rate which led to best durability properties. Thomas et al (2016b) noted that the rubberized concretes have higher water absorption than ordinary concretes.

In order to avoid the large drop in properties of rubberized concrete, several researchers studied the combined use of RTR with other cementitious materials. Erhan (2010) reported that the use of RTR with fly ash led to minimize fresh properties reduction of self compacting concrete. Gesoglu and Guneyisi (2007) found that silica fume decrease chloride penetration depth and improve compressive strength of rubberized concrete. AbdelAleem and Hassan (2018) added that the use of silica fume allows increasing the RTR rate in concrete with enhanced mechanical properties and acceptable fresh properties. Mhaya et al (2020) observed that the incorporation of 20% of granulated blast furnace slag reduce the workability and increase mechanical properties of rubberized concrete. Jalal et al (2019a) showed that the use of 10% of zeolite decrease the workability of concrete by 4%, while it leads to minimize compressive strength reduction by 8%.

On the other hand, large amounts of MW with different sizes are generated every year during sawing, shaping and polishing process for marble industry (Evram et al 2020). Vardhan et al (2019) noted that marble waste constitute about 20-30% of total production of marble industry. In China which is considered as the largest producer of marble in the world, it was estimated that one million tons of marble waste must be disposed every year (Zhang et al 2020). In Turkey, it was noted that the marble waste was reached millions of tons and the storage of this waste was considered impossible (Alyamaç and Ince 2009). The United States, Belgium, India, Brazil, France, Spain, Sweden, Italy, and Egypt also have large reserves of marble (Arel 2016, Vardhan et al 2019). In Algeria, Hebhoub et al (2011) noted that 70% of marble gets wasted during the extraction, processing and polishing stages. These wastes cause environmental problems (Khodabakhshian et al 2018), soil fertility and morphology damage (Zhanget al. 2020) and disposal problem (Choudhary et al 2020). Varadharajan (2020) noted also that the fine particles of marble waste that move with the air cause air pollution and clogging the waterways. The valorization of marble waste in the construction field has emerged as an efficient solution which leads to sustainable development. Currently, one of the principal research tendencies is the reuse of MW in concrete manufacturing in order to develop an environmentally friendly concrete. Several researchers studied the utilization of MW as aggregates and powder in the concrete technology. Rashwan et al (2020) examined the utilization of MW sludge to replace cement in concrete. The results indicated that the workability increase when the marble sludge content increase. Similar result was obtained by Djebien et al (2015). André et al (2014) were used MW as coarse aggregate. They explained the improvement of workability by the low absorption and plan surface of MW. Corinaldesi et al (2010) added that marble waste gives more cohesiveness for concrete and mortar. Topçu et al (2009) studied the properties of self-compacting concrete containing MW. They concluded that the MW reduce the bulk density and increase the air content of self-compacting concrete. They also recommended an optimum amount of MW of 200 Kg/m^3. Gencel et al (2012) attributed the decrease in bulk density to the lower density of MW when compared to the other aggregates. Ergun (2011) noted that the incorporation of 5% of MW leads to improve the compressive strength of concrete by 12%. This improvement of concrete strength was observed by other researchers (Boughamsa et al 2020, corinaldesi et al 2010, Hebhoub et al 2011, Vardhanet al 2019). The enhancement of the mechanical properties of concrete containing MW was attributed to the generation of carbo-aluminates in presence of MW which has certain binding capacity (Chawla et al 2018, Ergun 2011). Aliabdo et al (2014) showed that the use of MW significantly improves the tensile strength of concrete. Vardhan et al (2019) noted that due to its filler effect, MW is more suitable when it is used in the substitution of ordinary fine aggregates for concrete production. Ince et al (2020) used MW as a partial substitution of fine aggregates in concrete. They reported that the utilization of MW improve the sulphate Attack and freeze-thaw resistances of concrete. Singh et al (2019) added that the MW reduces the water permeability and sorptivity with optimum rate of 15%. This tendency was observed also by Gameiro et al (2014). Gencel et al (2012) concluded that the addition of MW reduces the manufacturing cost of concrete paving blocks by 11.76%.

2. RESEARCH SIGNIFICANCE

Concrete is the most common construction material used worldwide (Arel 2016). This leaded to a high demand of aggregates and depletion of natural resources. The valorization of wastes and by-products in concrete technology remains the best solution which leads to reduce the consumption of raw materials, eliminate the wastes and protect the public health. To achieve these objectives, this study investigated for the first time the effect of combined use of RTR and MWS on fresh and hardened properties of concrete. The MWS was used with the RTR to benefit from its positive effects on the properties of concrete. As recommended by Raffoul et al (2016), the rubberized concrete was made by substitution of total volume of aggregates by RTR, and the particles distribution of CS was corrected by MWS. The combined use of MWS and RTR not only leads to increase the wastes content in the concrete composition, but also to use different types of waste and consequently a green concrete will be manufactured. It should also be noted that the use and increase of the waste rate in the concrete composition leads to reduce the cost of the concrete manufacturing.

3. MATERIALS, MIX DESIGN AND TESTS

3.1. Materials

Portland cement (PC) CEM1 42.5 was used in this experimental research; its properties are detailed in Tables 1 and 2.

Crushed aggregates of a limestone rock were used as coarse aggregates (CA) and fine aggregate (FA); two types of gravel (G1 and G2) were used with maximal nominal size of 16 mm and 25 mm respectively. The maximal nominal size of CS used was 4 mm. The properties of the FA and CA are presented in Table 3. WMS was obtained from the crushed process of marble rock in Skikda marble carry (East of Algeria). The WMS was used to correct the grain size distribution of CS (Figure 1). The properties of the MWS are presented in Tables 2-3. The RTR used in this study was obtained by cutting of end-of-life tires in small particles followed by washing of them (Figure 1).

Fig. 1. Wastes used

Table 1. Physical and mechanical properties of PC

Physical and mechanical properties	PC
Initial setting time (min)	75
Final setting time (min)	181
Specific gravity	3.124
Blaine specific surface (cm²/g)	3156
Compressive strength for 2 days (MPa)	27.88
Compressive strength for 7 days (MPa)	42.44
Compressive strength for 28 days (MPa)	57.32
Flexural strength for 2 days (MPa)	5.27
Flexural strength for 7 days (MPa)	7.60
Flexural strength for 28 days (MPa)	8.56

The RTR had a maximum size of 6.30 mm, specific gravity of 1.62 and water absorption of 1.66%. The particle size distribution of crushed and wastes aggregates are shown in Figure 2. To obtain the desired workability, the superplasticizer (SP) used was POLYFLOW SR 5400 based on polycarboxylate with brown color, density of 1.07 and PH of 5.

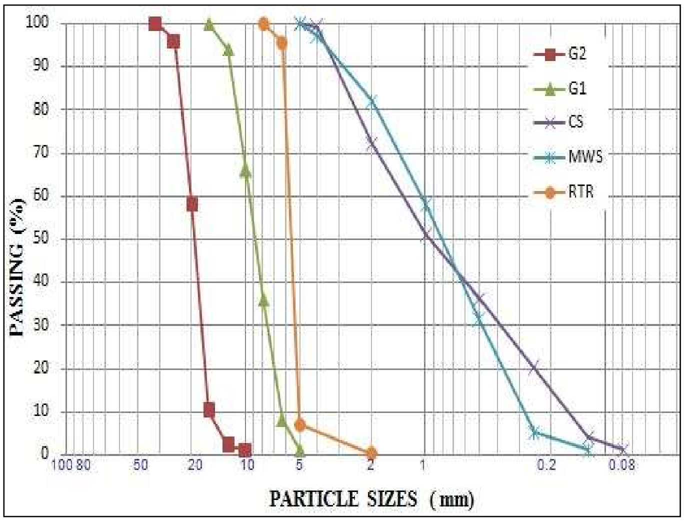

Fig. 2. Particles size distribution of aggregates

Table 2. Chemical properties of PC and MW

Chemical properties (%)	PC	MW
CaO	61.38	53.85
Al_2O_3	5.18	0.38
Fe_2O_3	3.34	0.22
SiO_2	19.97	1.11
MgO	0.99	2.81
Na_2O	0.2	0.15
K_2O	0.44	0.04
Cl^-	0.19	0.02
SO_3	2.90	4
Loss in ignition	3.71	-
C_4AF	10.25	-
C_3A	8.08	-
C_3S	58.45	-
C_2S	13.24	-

Table 3. Properties of aggregates

Properties	Fine aggregates		Coarse aggregates	
	CS	MWS	G1	G2
Specific density	2.6	2.78	2.64	2.64
Sand equivalent (%)	71	71	-	-
Finenes modulus	3.18	2.27	-	-
Methylene blue value	0.5	0.5	-	-
Micro-deval (%)	-	-	17	18
Los Angeles (%)	-	-	20	22

3.2. Mix design and tests

To formulate the control concrete, the Dreux-Gorisse method was used. Thereafter, 1%, 2%, 3% and 4% substitutions of aggregates total volume by RTR were made. The dosages of PC, water and SP are kept constant (Table 4). The superplastizer quantity used in this study was 1% of the cement weight. The MWS was used to correct the finesses modulus of CS. According to ASTM C33, the fineness modulus of fine aggregate should not be less than 2.3 or more than 3.1. It was also recommended to use fine aggregates with finesses modulus closer to the upper limit to obtain a concrete with good workability and strength. Using Abrams formulas (Equations (1)-(2)), the target fineness modulus (FM) was 3.

$$\text{CS (\%)} = \frac{\text{FM} - \text{FM (MWS)}}{\text{FM (CS)} - \text{FM (MWS)}} = 80.21\% \quad (3.1)$$

$$\text{MWS (\%)} = \frac{\text{FM (CS)} - \text{FM}}{\text{FM (CS)} - \text{FM (MWS)}} = 19.78\% \quad (3.2)$$

Where: CS (%): Proportion of CS; MWS (%): Proportion of MWS; FM (MWS): Finesses modulus of MWS; FM (CS): Finesses modulus of CS; FM: The target finesses modulus.

To ensure good homogeneity for all 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 by immersion tests. Prismatic samples (70×70×280 mm) were used for the flexural strength. After 24 hours of casting, the samples were demoulded and conserved in water curing until the date of test.

Table 4. Concrete mixtures

	G2 (Kg/m^3)	**G1 (Kg/m^3)**	**CS (Kg/m^3)**	**PC (Kg/m^3)**	**SP (L/m^3)**	**Water (L/m^3)**	**MWS (Kg/m^3)**	**RTR (Kg/m^3)**
MC	306	612	695.08	350	3.27	147	178.46	00
MRC1	303.10	606.30	688.14	350	3.27	147	176.67	11.04
MRC2	299.99	599.91	681.17	350	3.27	147	174.88	22.07
MRC3	296.89	593.79	674.23	350	3.27	147	173.09	33,14
MRC4	293.83	587.87	667.26	350	3.27	147	171.33	44.15

The fresh and hardened properties tests were performed according to standards mentioned in Table 5. Eighteen samples were produced for each concrete mixture and for each test the obtained result represents the average of three readings.

Table 5. Tests used

Tests	Standards
Slump test	NF EN 12350-2
Bulk Density	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 by immersion	NBN B15-215

4. RESULTS AND DISCUSSION

4.1. Workability

Figure 3 presents the slump values of concrete mixtures. It is observed that the workability decreases with the increase of RTR content in concrete. The slump value drops from 18 cm to 12 cm when 4% of RTR is included. This trend was confirmed by several studies (Holmes et al 2014, Mhaya et al 2020, Su et al 2015). It was attributed to the friction increasing between the concrete components in presence of RTR due to the rough nature of their grains, and the higher water absorption of RTR compared to the natural aggregates. However, it is observed that the loss in the workability remains insignificant when the RTR rate does not exceed 2%. This is explained by the cohesiveness effect that the MWS plays, which leads to minimizing the friction between the grains and ensures good flow of concrete (Corinaldesi et al 2010, Djebien et al 2018).

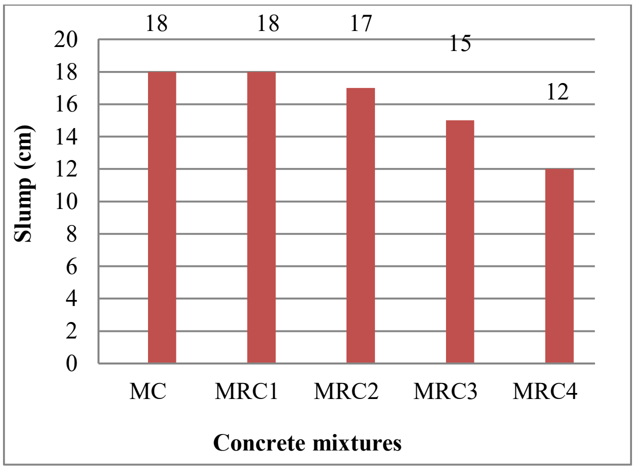

Fig. 3. Slump values of concrete mixtures

4.2. Fresh density

Figure 4 shows the fresh density values of concrete mixtures. As shown, the density of concrete gradually decreases by increasing the RTR rate.

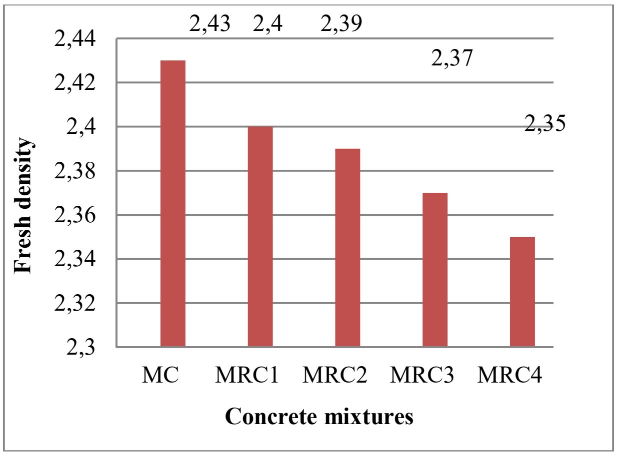

Fig. 4. Fresh density values of concrete mixtures

The MRC4 mixture has density lesser by 3.30% when compared to the control concrete (MC). This tendency concord with that obtained by (Gesoglu et al 2014, Pelisser et al 2011). It was ascribed to the lower density of RTR compared with the other aggregates. The lightening of the concrete by the incorporation of RTR constitutes a solution which allows reducing the dead load of structures (Asuktar et al 2017) and ensuring thermal insulation (Fraile-Garcia et al 2018). It is also suitable for some construction elements and architectural applications (Pavements, roads barriers, walls) (Asuktar et al 2017, siddique et al 2004).

4.3. Air content

As reported in figure 5, the air content value of concrete increases with increasing RTR proportion. A 110% increase in air content is observed when 4% of RTR is used. This trend was showed by (Ling et al 2010, Siddique et al 2004), it was explained by the non-polar nature of the RTR grains which traps air bubbles and leads to increase the air content of concrete.

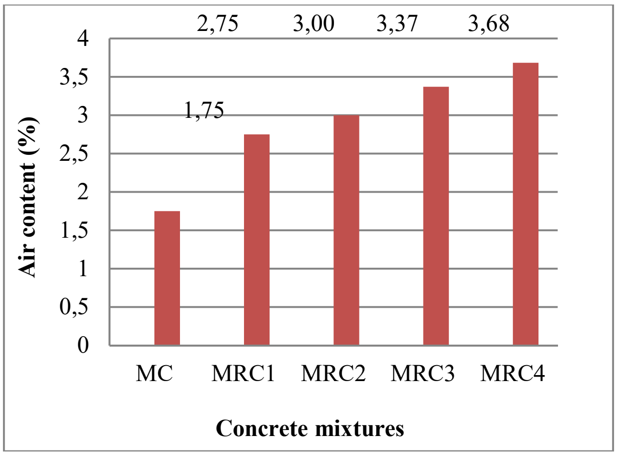

Fig. 5. Air content values of concrete mixtures

It was noted that the increase of the air content in presence of RTR can significantly improve the freeze-thaw resistance of concrete (Zhu et al 2012).

4.4. Compressive strength

Figure 6 illustrates the effect of RTR content on compressive strength of concrete mixtures. It indicates that the addition of RTR gradually reduces the compressive strength of concrete. The compressive strength is reduced by 19% and 25% at 7 and 28 days respectively when 4% of RTR is used. This reduction is attributed to the adhesion lack of the RTR with the cement paste and lower hardness of RTR in comparison with the other constituents (Gangian et al 2009). Additionally, the increase of the air content in the presence of RTR (figure 5) leads to reduce the compressive strength of concrete. It can be seen also that with 1% of RTR content, the compressive strength decreases by 6% only.

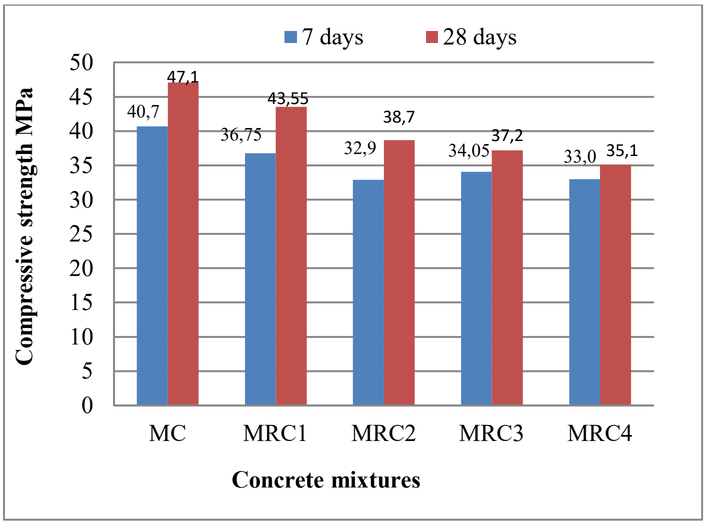

Fig. 6. Compressive strength values of concrete mixtures

4.5. Flexural strength

In figure 7, it can be seen that MC have flexural strength greater than that of the other specimens (MRC).

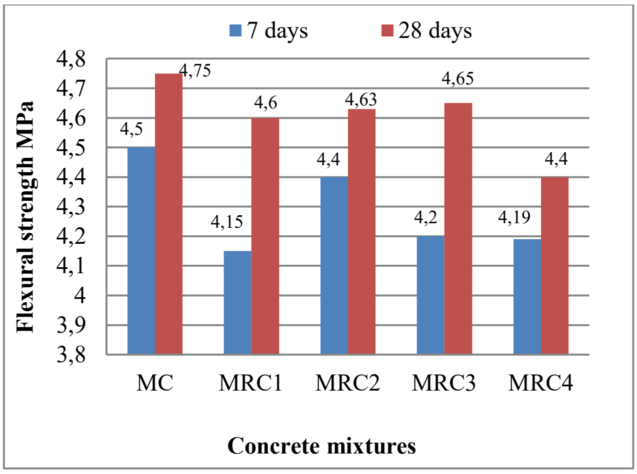

Fig. 7. Compressive strength values of concrete mixtures

The flexural strength at 28 days drops from 4.75 MPa to 4.40 MPa when the RTR content increases from 0% to 4%, i.e. a loss by 7%. (Bisht et al 2017, Su et al 2015) were explained the reduction of the flexural strength by the weak adhesion between the RTR and the cement paste which leads to the rapid propagation of cracks within the specimens.

Figure 8 shows the relationship between the flexural and compressive strength at 28 days for all concrete mixtures. As shown, there is a linear relationship between the flexural and compressive strength with lower correlation coefficient R^2 equal to 0.546. This lower correlation is probably attributed to the dispersion of results of the flexural strength test due to non-uniform distribution of tensile strength.

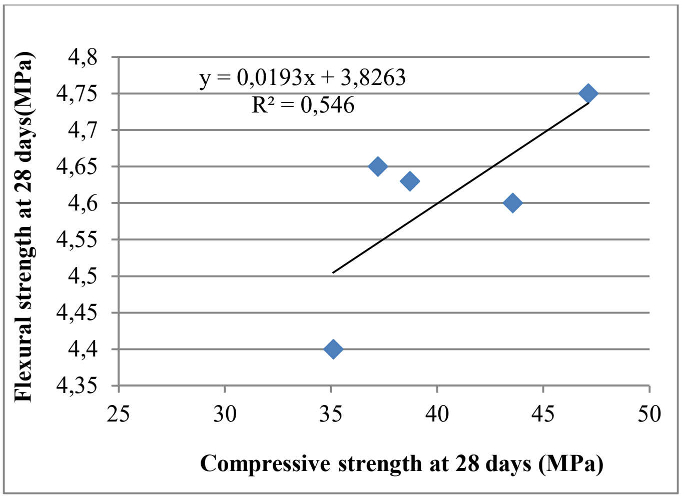

Fig. 8. Relationship between Compressive strength and flexural strength

4.6. Pulse velocity

The ultrasonic pulse velocity variations of concretes mixtures at 28 days are illustrated in figure 9. The ultrasonic pulse velocity decreases with increase of RTR content. The pulse velocity decrease is more pronounced when the RTR content exceed 1%. When the RTR content increases from 1% to 4% the pulse velocity decreases by 1.10% and 10.11% respectively. Similar trend was showed by (Jalal et al 2019b, Jalal et al 2020), it was explained by the lower density of RTR which reduces the pulse velocity. It was explained also by the weak adhesion between RTR and cement paste and generation of micro cracks which lead to increase the concrete porosity and slow down the pulse velocity (Si et al 2018). Yung et al (2013) added that concretes containing coarse aggregates of RTR have a greater pulse velocity than those containing fine aggregates of RTR. It should be noted that according to ASTM C597 which considers the concrete to be of good quality when the ultrasonic pulse velocity ranges from 3500 to 4500 m/s, all concrete mixtures are classified to have good quality.

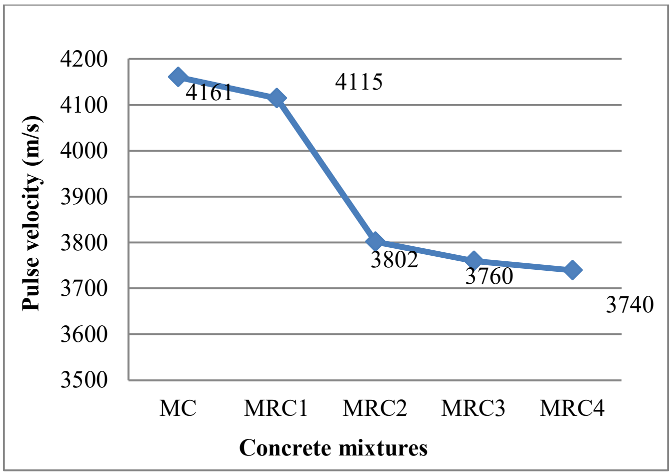

Fig. 9. Pulse velocity values of concrete mixtures

Figure 10 shows the relationship between the ultrasonic pulse velocity and compressive strength at 28 days for all concrete mixtures. As shown, there is a good linear relationship between the compressive strength and pulse velocity with correlation coefficient R^2 equal to 0.94. This indicates that the compressive strength is predominantly influenced by the RTR content.

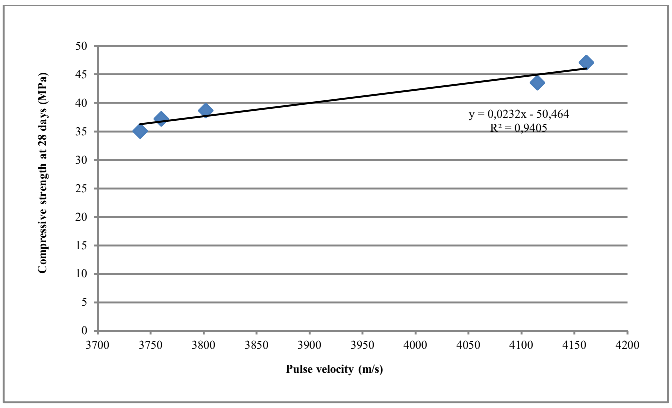

Fig. 10. Relationship between Compressive strength and pulse velocity

4.7. Water absorption

Figure 11 reports the absorption values of concrete mixtures.

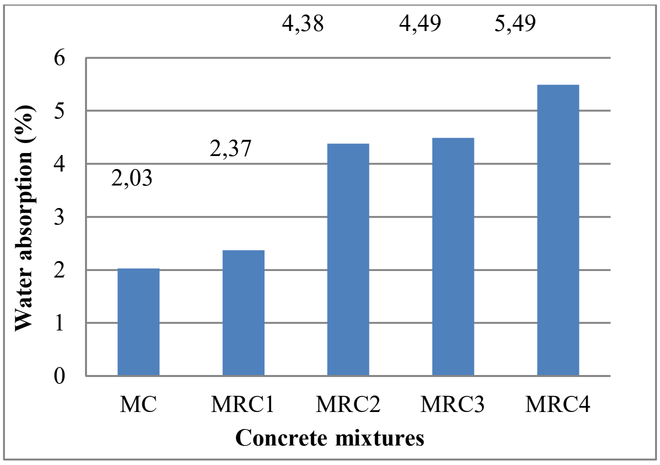

Fig. 11. Water absorption values of concrete mixtures

A gradual increase of absorption values with increasing RTR content is showed. The absorption values increase by 16.74% and 170.44% when the RTR rate increases by 2% and 4% respectively. It should also be mentioned that the absorption increase is more significant when the RTR content exceeds 1%. This trend can be explained by the increase in internal porosity due to the bonding lack between cement paste and RTR which facilitates the penetration of water into specimens (Ganjian et al 2009).

A linear relationship between the ultrasonic pulse velocity and water absorption was illustrated in Figure 12. It is clear that there is a good correlation between the variations of pulse velocity and water absorption with higher correlation coefficient R^2.

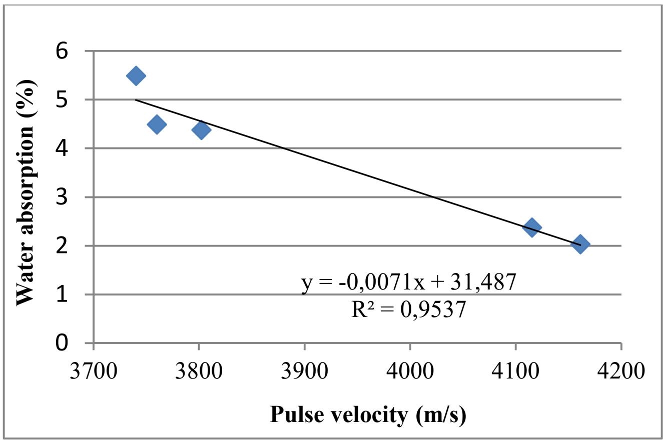

Fig. 12. Relationship between water absorption and pulse velocity

Figure 13 presents a linear relationship between the compressive strength and water absorption. As presented, the highest correlation coefficient R^2 was obtained for the compressive strength - water absorption relationship. The good correlations between the pulse velocity, compressive strength, and water absorption indicates that the weak bonding of RTR with cement paste and the RTR content are the predominant factors that govern the variation of these properties.

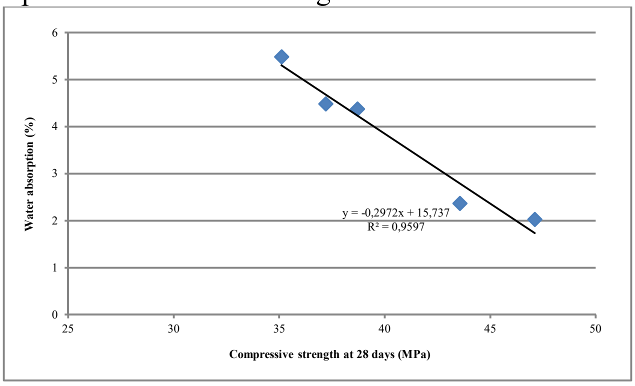

Fig. 13. Relationship between water absorption and compressive strength

4.7. Dynamic elastic modulus

The dynamic elastic modulus of concrete mixtures was evaluated using the following formula:

$$E = 10^5 \times V^2 \times (\Delta/g) \quad (4.1)$$

Where E is the dynamic elastic modulus (GPa), V is ultrasonic pulse velocity (m/s), Δ is bulk density of concrete (kg/m^3) and g is gravity acceleration (m/s^2). Figure 14 illustrates the effect of RTR content on dynamic elastic modulus of concrete mixtures. The dynamic elastic modulus gradually decreases with increasing in RTR content. The elastic modulus drops by 21.87% when RTR content increases by 4%. It is also showed that the drops in elastic modulus values are insignificant when the RTR rate does not exceed 1%. The highest elastic modulus is obtained from MC mixture which has the highest compressive strength. Similar trend was observed by (Li et al 2014, Atahan et al 2012) and it was attributed to the decrease in compressive strength of rubberized concrete.

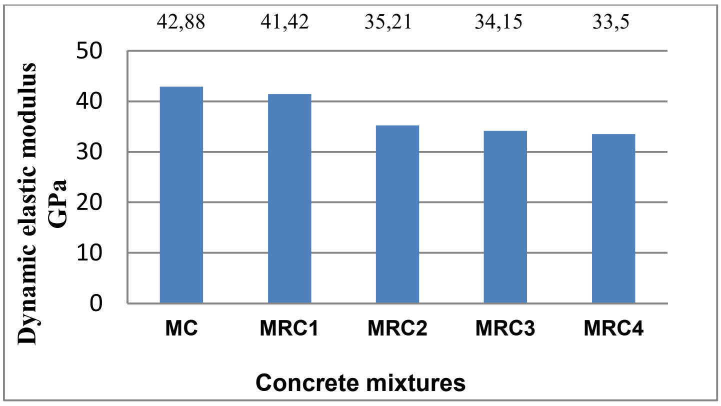

Fig. 14. Dynamic elastic modulus values of concrete mixtures

5. CONCLUSIONS

This paper investigated the effect of combined use of recycled tires rubber and marble waste as fine aggregates on fresh and hardened properties of concrete. The recycled tire rubber was used by volumetric substitution of aggregates. The following conclusions can be drawn:

- The addition of MWS delays the reduction of rubberized concrete properties.
- The workability of concrete containing MWS decreases with increasing RTR content. The decrease of workability remains insignificant when RTR content does not exceed 2%.
- The decrease in workability of concrete was accompanied by a decrease in density and increase in the air content.
- The increase of RTR content reduces the compressive and flexural strength of concrete containing MWS. The reduction of compressive strength is more pronounced when RTR content exceeds 1%.
- The use of RTR in the formulation of concrete significantly increases the ability of concrete to absorb water.
- With low substitution rates, the pulse velocity test indicated that concretes were considered to have good quality.
- There are good relationships between the compressive strength, ultrasonic pulse velocity and water absorption of concrete containing RTR and MWS with correlation coefficients greater than 0.94 .

It can be noted that the combined use of RTR and MWS in production of concrete presents promising ecological and economical interests. From the obtained results, the concrete containing RTR and MWS can be applied in the fabrication of (sealing element, dividing walls, cleanliness concrete…) when the mechanical strengths are not required. It should be also noted that the combined utilization of RTR and MWS in concrete composition leads to produce green concrete.

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