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Original Article

Experimental Analysis of Rubberized Concrete Under Compression Test

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Abstract - *The presence of end-of-life tires in nature can cause several environmental problems. Their reuse as a sustainable additive for the production of concrete represents a path for both the protection of the environment and may be improvement of some characteristics of concrete for special uses. The goal of this study is to contribute to the development of the research on rubberized concrete. Thus, the use of rubber crumbs as a partial replacement of fine and coarse natural aggregates was investigated while attempting to minimize significant losses in compressive strength and improve certain specific concrete properties, such as improved impact resistance, increased energy absorption and enhanced sound insulation. This will make rubberized concrete applicable on a wide scale, for instance, in the construction of noise barriers alongside highways, the development of resilient pavements in urban areas and the reinforcement of structures experiencing dynamic loading. Two families with the same design strength were defined based on the loading speed (Family 1,* v_1 *=0.25MPa/s and Family 2,* v_2*=0.6MPa/s). Each family has 4 groups depending on the percentage of rubber crumbs introduced by volume. Groups 1, 2, 3 and 4 had 0%, 10%, 20% and 30% of rubber crumbs, respectively. The results showed that as the percentage of rubber increased, a decrease was noticed in compressive strength and reached 30 to 38% for 20 and 30% rubber crumbs replacement of fine and coarse natural aggregates. Moreover, the Modulus of elasticity decreased slightly while the compressive failure strain was noticed to increase by 30% for rubber crumbs replacement. The results of compressive strength and failure strain were practically the same for the two distinct loading speeds, while changing the loading speed slightly influenced the modulus of elasticity.*

Keywords - *Rubber, Rubberized concrete, Compressive strength, Compressive failure strain, Modulus of elasticity.*

1. Introduction

The increasing use of vehicles in numerous countries can be the source of a lot of environmental problems. Other than the emission of air pollutants, the introduction of wastes such as tires at their end of life in nature, for example, can be a very serious problem. In the construction field, the idea of the introduction of many types of waste for the production of environmental concrete is a genius one. In this context, many researchers are interested in replacing natural aggregates with rubber particles derived from end-of-life tires. Numerous researches have been conducted to determine the effect of rubber particles on the properties of concrete. While increasing the percentage of rubber introduced in the case of two mixtures investigated by Walid and al. [1] with two distinct design resistances, the workability of concrete at its fresh state seems not to be influenced significantly by a percentage of rubber going up to 20%. The compressive strength reduced progressively, but the reduction remained acceptable up to 20% rubber introduction. A decrease in the modulus of elasticity was also noticed. The failure modes comparison has shown that the introduction of rubber crumbs can improve the deformability of the mixture, as specimens with rubberized concrete presented a more ductile failure. Furthermore, the workability was not significantly affected, with a percentage of up to 20% of crumb rubber introduced, while the density of hardened concrete decreased [2]. Replacing fine aggregates with rubber crumbs led to a reduction in slump, compressive strength, modulus of elasticity and unit weight. As the rubber crumbs content increased, strain increased while maximum stress decreased, in addition, an improvement in compressive toughness was observed [3]. Fine aggregate replacement by rubber particles with varying and uniform sizes [4] led to a general decrease in the workability of different mixtures. A slump reduction was also observed when rubber particle size decreased, and for the aggregates with variable size and continuous grading, the slump was better than that of rubber particles of uniform size. A compressive strength decrease was generally observed. Nevertheless, a modest increase in strength was noticed as the rubber aggregate size decreased. Meanwhile, the variable size with continuous grading of the rubber aggregates, led to similar results to those of the finer size rubber particles. The fresh density of concrete decreased. In the case of high-strength concrete, partial replacement [5] of fine aggregates by volume with 0%, 10%, 20%, and 30% of rubber crumbs did not significantly impact the workability of fresh concrete. However, it resulted in a decline in compressive strength as rubber content increased, reaching a decrease up to 47.83% at 30%. Replacement. In addition, a slight decrease in density was observed. Bulk density [6] also decreased as the proportion of rubber crumbs increased.

Replacing fine aggregates with rubber crumbs at weights of 0%, 10%, 15% and 20% resulted in reduced slump and unit weight, along with decreased compressive strength and modulus of elasticity as the rubber content increased [7]. However, it also led to an increase in compressive strain. Notably, toughness increased with the proportion of rubber up to 10% but declined when the percentage exceeded 10% [7].

A study by A. Sofia [8] revealed that introducing rubber led to a reduction in compressive strength and modulus of elasticity. Other researchers attributed the strength decrease to the rapid appearance of cracks, accelerated failure of the rubber-cement matrix, and insufficient adhesion between rubber and cement paste [9]. In lightweight aggregate concrete, replacing natural fine aggregates with varying percentages (0% to 100%) of rubber seems to decrease slump, dry unit weight, compressive strength and static modulus of elasticity [10].

A decrease in concrete workability, compressive strength and hardened concrete density was observed for higher rubber content, it seems that the global volume of rubber replacement affects the strength more than the type of rubber (fine or coarse) [11]. The workability was not much influenced by rubber introduction up to 10%, while with rubber percentage beyond 10%, workability was severely reduced. Increasing rubber content reduces the strength, except that the degradation recorded [12] for a replacement of up to 15% was very limited for a mixture with a constant slump.

Karunarathna et al. [13] noticed that replacing natural aggregates with rubber particles reduces both slump, compressive strength and modulus of elasticity. However, rubberized concrete containing 0% to 20% crumb rubber showed significant resistance in aggressive environments, making it suitable for application in areas prone to acid attack [14].

Fauzan et al. [15] studied the effect of crumb rubber as a partial replacement for coarse aggregate associated with incorporation of cementitious materials such as fly ash, silica fume and slag on concrete. It was found that optimal combinations of these materials maintained acceptable mechanical properties while enhancing the sustainability and durability of the concrete. Furthermore, the combination with steel fibers [16] led to an improvement in the tensile and flexural strengths.

Otherwise, the replacement of fine aggregates with treated crumb rubber in high-strength concrete, particularly at lower replacement levels with smaller particle sizes, contributes to sustainable construction practices without significantly compromising material performance. Other studies highlighted rubberized concrete advantages, including shock resistance, cracking resistance [15], lower heat conductivity [18,19] and noise reduction [20,21], making it suitable for dynamic and impact loading applications.

2. Research Significance

Despite the advantages of rubberized concrete cited above, studies found that increasing rubber crumb content decreased compressive strength significantly, with fine aggregate replacements causing a more considerable reduction than coarse aggregate replacements. Trying to avoid severe strength loss and find a balance between the strength, durability and flexibility of rubberized concrete, this study presents an experimental investigation into the use of crumb rubber as a partial replacement for fine and coarse aggregate in concrete. Based on existing research [1-11], the partial substitution by volume of fine and coarse natural aggregates will be at a maximum of 30% of rubber crumb.

3. Experimental Investigation

3.1. Materials

The cement used is CEM II/B-M (S-LL) 42.5R SR EN 197-1:2011 type Structo Plus® from HOLCIM. The natural aggregates were classified into three groups based on their dimensions (0-4mm, 4-8mm, 8-16mm). A local supplier provided rubber crumbs, and the cut of end-of-life tires obtained them. They were divided into two groups, 0-4mm and 4-8mm, based on their dimensions, and they were cleaned from any foreign element resulting from the manufacturing process. The water chosen for this research is tap water.

3.2. Characteristics of the Samples

In this research, two families (named Family 1 and Family 2) of samples are taken into consideration; each family contain four groups. Group 1 is the reference group with no rubber crumbs (0%). The replacement percentage of fine and coarse natural aggregates with rubber crumbs for Group 2, Group 3 and Group 4 is 10%, 20% and 30%, respectively. At the minimum, three samples were prepared from each group of the two families.

In the experimentation, the target concrete is class C30/37. The water/cement report was maintained constant (W/C=0.43) for all the mixtures of different groups. The molds used were cylinders of identical dimensions (diameter 100mm* height 200mm) [22].

Table 1. Mix proportions

	Group 1	Group 2	Group 3	Group 4
Cement [kg/m3]	489			
Water [kg/m3]	210			
W/C	0.43			
Regular aggregates [kg/m3]				
0-4mm	582	523.80	465.60	407.40
4-8mm	388	310.40	232.80	155.20
8-16mm	646.7	646.70	646.70	646.70
Rubber aggregates [kg/m3]				
0-4mm	0	10.95	21.90	32.85
4-8mm	0	14.60	29.20	43.80
8-16mm	0	0.00	0.00	0.00
Additives [kg/m3]	4.89			

Fig. 1 Rubber crumbs 0-4mm, Rubber crumbs 4-8mm

Fig. 2 Samples vibration

3.3. Mixture Preparation

In a dry environment, natural aggregates and rubber crumbs were mixed for one minute; subsequently, the cement was introduced and mixed for an additional minute.Liquids (water + additives) were afterward added little by little. Mixing was carried out until a homogenous mixture was obtained, trying to eliminate voids and increase adhesion between rubber and cement paste. Prior to concrete casting, formwork oil was applied to the internal surfaces of all the cylinders. Afterwards, the cylinders were filled and compacted in two layers on a vibrating table; this process helps eliminate voids in specimens of concrete and ensures the proper distribution of aggregates in the samples in Figure 2. Cylinders have been stripped 24h after their casting, spotted with their identifiers (Number, Group and Casting Date) and left to dry in standard laboratory conditions.

Fig. 3 Compression test

3.4. Test Methodology

At 28 days of age, compression and modulus of elasticity tests were conducted on rubberized concrete cylinders following standards SR EN 12390-3/2009, SR EN 12390-13/2013 and NM 10.1.051/2008 [23, 24, 17], using a universal machine WAW-600E with 600kN of capacity Figure 3 with two distinct loading speeds for the two different families of samples. The loading speeds maintained constant during the whole tests for both families, are in the range of 0.2MPa/s to 1.0MPa/s. For Family 1, the loading speed is v_1= 0.25MPa/s, while for Family 2, the value is v_2=0.6MPa/s. Results were obtained using a measurement acquisition system.

4. Test Results

4.1. Compressive Strength

4.1.1. Family 1: v_1=0.25 MPa/s

The compressive strength $f_{c,28}$ values of the four groups of Family 1 (v_1=0.25 MPa/s) are summarized in Table 2.

Table 2. Compressive strength variation [MPa] - Family 1 (v_1=0.25 MPa/s)

	Group 1	Group 2	Group 3	Group 4
$f_{c,28}$ [MPa]	32.00	24.57	22.05	19.40
StDev	2.89	1.02	2.41	2.34
Average+1StDev	34.89	25.59	24.46	21.74
Average-1StDev	29.12	23.55	19.63	17.06

Note : StDev is the standard deviation

4.1.2. Family 2: v_2=0.6MPa/s

The compressive strength values of the four groups of Family 2 (v_2=0.6 MPa/s) are summarized in Table 3.

4.2. Compressive Failure Strain

4.2.1. Family 1: v_1=0.25 MPa/s

The compressive failure strain values of the four groups of Family 1 (v_1=0.25 MPa/s) are summarized in Table 4.

4.2.2. Family 2: v_2=0.6 MPa/s

The compressive failure strain values of the four groups of Family 2 (v_2=0.6 MPa/s) are summarized in Table 5.

4.3. Modulus of Elasticity

4.3.1. Family 1: v_1=0.25 MPa/s

The Modulus of Elasticity values of the four groups of Family 1 (v_1=0.25 MPa/s) are summarized in Table 6.

4.3.2. Family 2: v_2=0.6 MPa/s

The Modulus of Elasticity values of the four groups of Family 2 (v_2=0.6 MPa/s) are summarized in Table 7.

Table 3. Compressive strength variation [MPa] - Family 2 (v_2=0.6 MPa/s)

	Group 1	Group 2	Group 3	Group 4
$f_{c,28}$ [MPa]	29.28	26.16	20.81	18.02
StDev	1.11	0.96	0.54	1.35
Average+1StDev	30.39	27.12	21.34	19.37
Average-1StDev	28.17	25.20	20.27	16.66

Table 4. Compressive failure strain variation (%) - Family 1 (v_1=0.25 MPa/s)

	Group 1	Group 2	Group 3	Group 4
ε (‰)	2.74	2.97	2.61	3.74
StDev	0.53	0.89	0.49	0.39
Average+1StDev	3.27	3.86	3.10	4.12
Average-1StDev	2.21	2.08	2.13	3.35

Table 5. Compressive failure strain variation (%) - Family 2 (v_2=0.6 MPa/s)

	Group 1	Group 2	Group 3	Group 4
ε (‰)	2.73	2.85	2.60	3.30
StDev	0.46	0.10	0.21	0.46
Average + 1StDev	3.19	2.95	2.81	3.75
Average - 1StDev	2.27	2.76	2.38	2.84

Table 6. Modulus of Elasticity variation [MPa] - Family 1 (v1=0.25 MPa/s)

	Group 1	Group 2	Group 3	Group 4
E [MPa]	29182	28834	27643	27613
StDev	2843	2077	3452	1050
Average + 1StDev	32025	30911	31095	28662
Average - 1StDev	26339	26757	24191	26563

Table 7. Modulus of Elasticity variation [MPa] - Family 2 (v_2=0.6 MPa/s)

	Group 1	Group 2	Group 3	Group 4
E [MPa]	30783	25409	25258	24704
StDev	4147	141	7457	1380
Average + 1StDev	34930	25551	32716	26084
Average - 1StDev	26635	25268	17801	23324

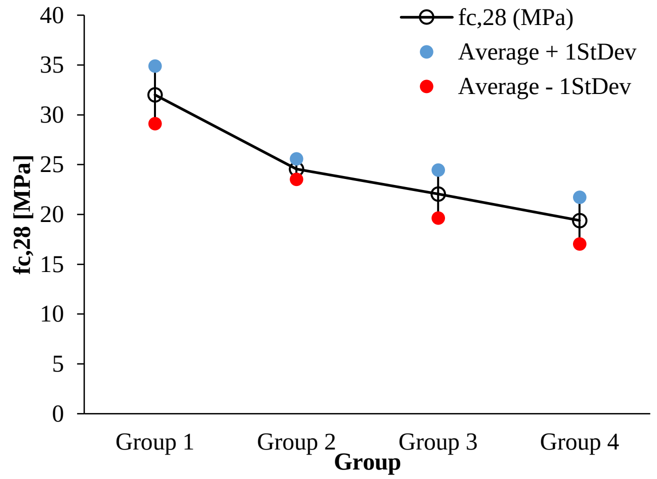

Fig. 4 Compressive strength variation curve according to the percentage of rubber crumbs introduced for samples of Family 1 (v_1=0.25 MPa/s)

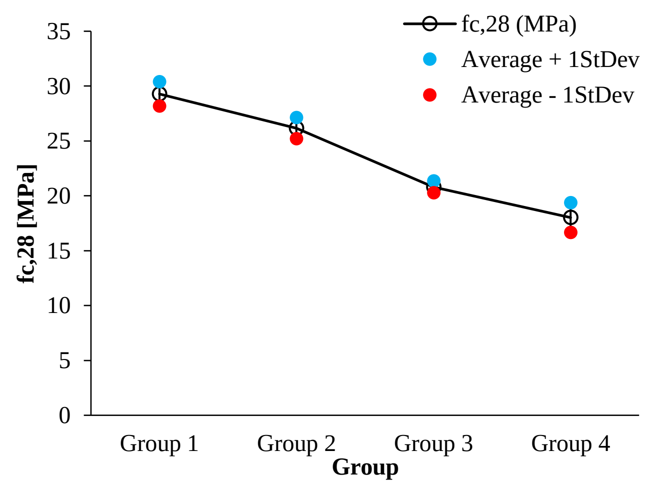

Fig. 5 Compressive strength variation curve according to the percentage of rubber crumbs introduced for samples of Family 2 (v_2=0.6 MPa/s)

5. Discussions of Results

5.1. Compressive Strength

5.1.1. Family 1: v_1=0.25 MPa/s

The maximum value observed for the reference group is 32 MPa. A drop of strength up to 23%, 31% and 39% compared to that of the reference group was observed for Groups 2, 3 and 4 respectively. The minimum value of 19.4MPa was recorded for Group 4 with a replacement percentage of naturally fine and coarse aggregates with rubber crumbs of 30% in Figure 4.

5.1.2. Family 2: v_2=0.6MPa/s

The maximum strength value of 29.3MPa was observed for the reference group. Subsequently, strength reductions of 11%, 29% and 38% were observed for Groups 2, 3 and 4, respectively, compared to the reference group. The minimum strength of 18MPa was observed for group 4, which utilized a replacement percentage of 30% for natural fine and coarse aggregates with rubber crumbs in Figure 5.

5.1.3. Comparison between Family 1 (v_1=0.25 MPa/s) and Family 2 (v_2=0.6 MPa/s)

The compressive strength values of Family 1 and Family 2 are summarized in Table 8 and Figure 6. The averages of strengths recorded are 30.6MPa, 25.4MPa, 21.4MPa and 18.7MPa for Groups 1, 2, 3 and 4, respectively.

Table 8. Compressive strength variation Family 1 and Family 2

$f_{c,28}$ [MPa]	Group 1	Group 2	Group 3	Group 4
Family 1	32.00	24.57	22.05	19.40
Family 2	29.28	26.16	20.81	18.02
Average	30.64	25.37	21.43	18.71

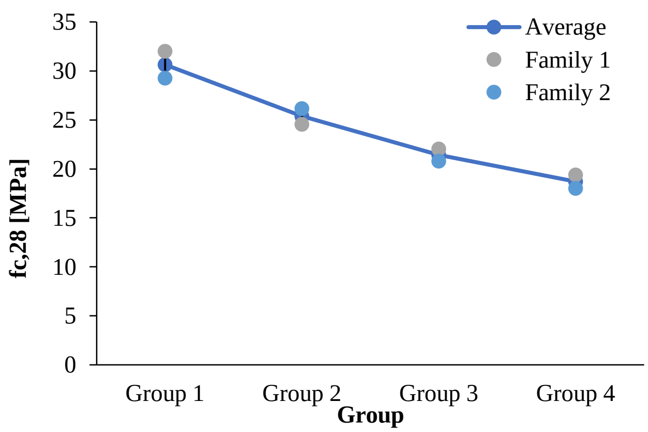

Fig. 6 Comparative curve of the compressive strength variation according to the percentage of rubber crumbs introduced for samples of Family 1 (v_1=0.25 MPa/s) and Family 2 (v_2=0.6 MPa/s)

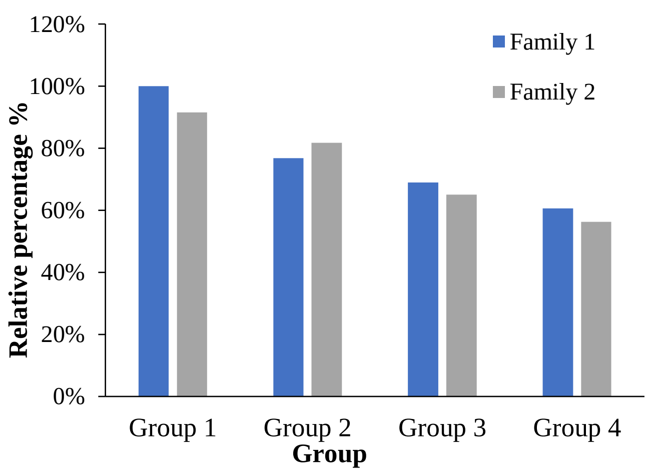

Fig. 7 Compressive strength variations normalized to the reference group of Family 1 (v_1=0.25 MPa/s)

Figure 7 shows the compressive strength variation in percentage normalized to the reference group of Family 1. A slight reduction of compressive strength was recorded for the different groups (except for Group 2) of Family 2 compared to their respective rivals of Family 1. This means that loading speed change has no significant influence on compressive strength.

5.2. Compressive Failure Strain

5.2.1. Family 1: v_1=0.25 MPa/s

The maximum failure strain value of 3.74‰ is observed for group 4, and the minimum value of 2.61‰ is observed for Group 3.

5.2.2. Family 2: v_2=0.6MPa/s

The maximum failure strain value of 3.30‰ is observed for Group 4, and the minimum value of 2.60‰ is observed for Group 3.

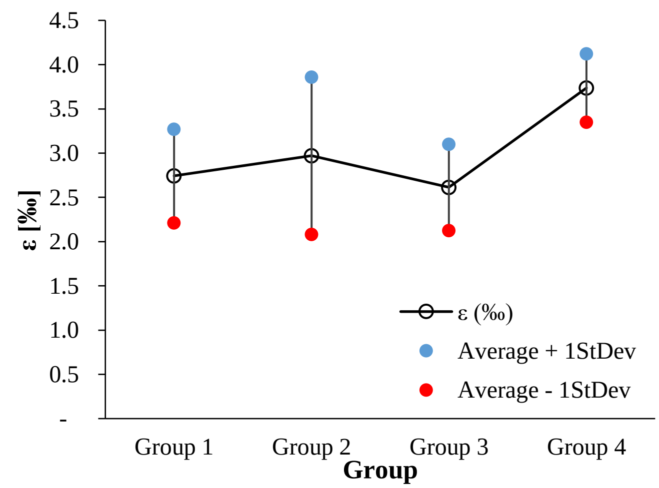

Fig. 8 Compressive failure strain variation curve according to the percentage of rubber crumbs introduced for samples of Family 1 (v_1=0.25 MPa/s)

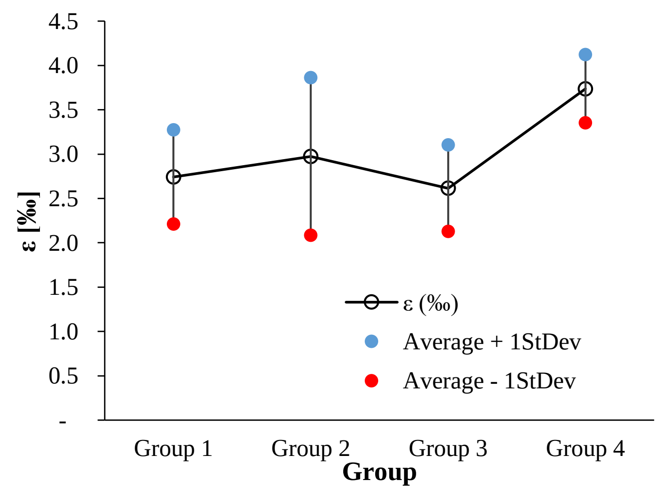

Fig. 9 Compressive failure strain variation curve according to the percentage of rubber crumbs introduced for samples of Family 2 (v_2=0.6 MPa/s)

Table 9. Compressive failure strain variation Family 1 and Family 2

ε [‰]	Group 1	Group 2	Group 3	Group 4
Family 1	2.74	2.97	2.61	3.74
Family 2	2.73	2.85	2.60	3.30
Average	2.73	2.91	2.61	3.52

5.2.3. Comparison between Family 1 (v_1=0.25 MPa/s) and Family 2 (v_2=0.6 MPa/s)

A comparison of compressive failure strain values of Family 1 and Family 2 is summarized in Table 9 and Figure 10. The failure strain's average values recorded are 2.73‰, 2.91‰, 2.61‰ and 3.52‰ for Groups 1, 2, 3 and 4, respectively. Figure 11 shows the compressive failure strain variation in percentage normalized to the reference group of Family 1. A slight reduction of the compressive failure strain was recorded for Group 1, Group 2, Group 3 and Group 4 of Family 2 compared to their respective rivals of Family 1. This means that loading speed change has no significant influence on the compressive failure strain.

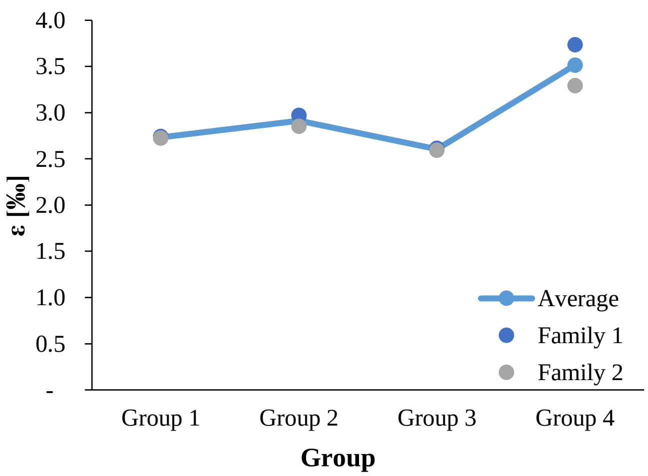

Fig. 10 Comparative curve of compressive failure strain variation according to the percentage of rubber crumbs introduced for samples of Family 1 (v_1=0.25 MPa/s) and Family 2 (v_2=0.6 MPa/s)

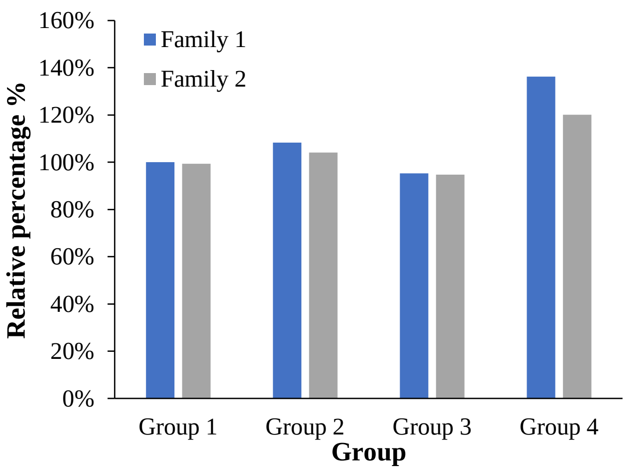

Fig. 11 Compressive failure strain variations normalized to the reference group of Family 1 (v_1=0.25 MPa/s)

5.3. Modulus of Elasticity

5.3.1. Family 1: v_1=0.25 MPa/s

The maximum Modulus of Elasticity value of 29182 MPa is observed for Group 1, and the minimum value of 27613 MPa is observed for Group 4.

5.3.2. Family 2: v_2=0.6MPa/s

The maximum Modulus of Elasticity value of 30783 MPa is observed for Group 1, and the minimum value of 24704 MPa is observed for Group 4.

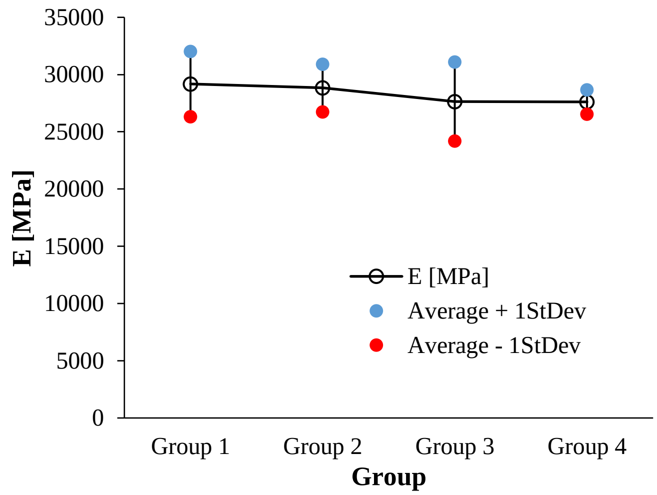

Fig. 12 Modulus of Elasticity variation curve according to the percentage of rubber crumbs introduced for samples of Family 1 (v_1=0.25 MPa/s)

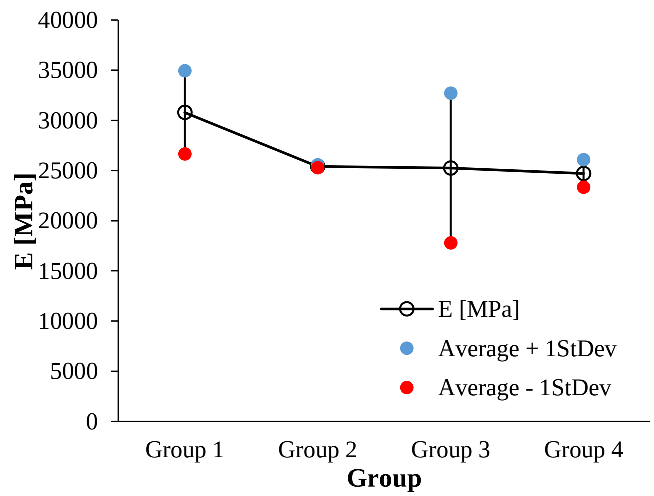

Fig. 13 Modulus of Elasticity variation curve according to the percentage of rubber crumbs introduced for samples of Family 2 (v_2=0.6 MPz/s)

Table 10. Modulus of Elasticity variation Family 1 and Family 2

E [MPa]	Group 1	Group 2	Group 3	Group 4
Family 1	29182	28834	27643	27613
Family 2	30783	25409	25258	24704
Average	29982	27122	26451	26158

5.3.3. Comparison between Family 1 (v_1=0.25 MPa/s) and Family 2 (v_2=0.6 MPa/s)

A comparison of the modulus of elasticity values of Family 1 and Family 2 is summarized in Table 10 and Figure 14. The Modulus of Elasticity's average values recorded are 29982 MPa, 27122 MPa, 26451 MPa and 26158 MPa for Groups 1, 2, 3 and 4, respectively.

Figure 15 depicts the percentage variation in modulus of elasticity normalized to the reference group of Family 1. A minor decrease in the modulus of elasticity was recorded for Groups 2, 3 and 4 of Family 2 compared to their respective rivals of Family 1. This indicates that changes in loading speed have a minimal impact on the modulus of elasticity

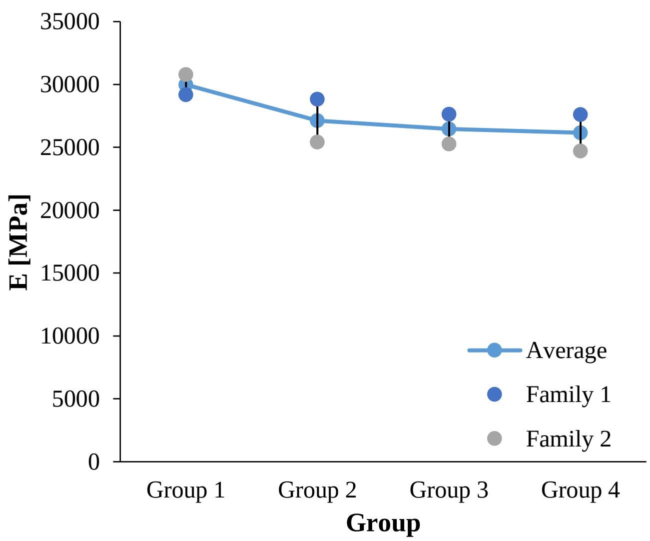

Fig. 14 Comparative curve of Modulus of Elasticity variation according to the percentage of rubber crumbs introduced for samples of Family 1 (v_1=0.25 MPa/s) and Family 2 (v_2=0.6 MPa/s)

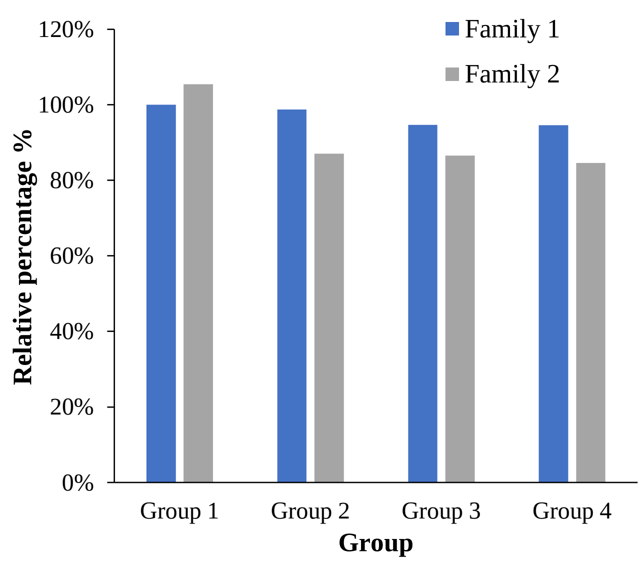

Fig. 15 Modulus of Elasticity variations normalized to the reference group of Family 1 (v_1=0.25 MPa/s)

6. Conclusion

The experimental investigations on the impact of rubber crumbs on compressive strength, compressive failure strain and modulus of elasticity under two distinct loading speeds, v_1=0.25 MPa/s and v_2=0.6 MPa/s, are reported in this article. Based on these experiments, the following conclusions can be drawn:

- The compressive strength decreases as the introduced rubber crumbs percentage increases for the two distinct loading speeds v_1=0.25 MPa/s and v_2=0.6 MPa/s. The compressive strength drop can be explained by several reasons. In fact, natural aggregates represent the solid material in the concrete mix. Therefore, their substitution with rubber crumbs, which is a soft material, reduces the compressive strength. Furthermore, compared to natural aggregates [10, 18, 19] and sand particles [7], rubber crumbs adhere less to cement.
- The compressive failure strain increases slightly as introduced rubber crumbs percentage increases, which is in line with other research [1, 3, 7]. This slight increase was observed for the two distinct loading speeds, v_1=0.25 MPa/s and v_2=0.6 MPa/s.
- The modulus of elasticity decreases slightly as introduced rubber crumbs percentage increases, which is in line with other research [1, 7, 8, 10, 13]. This slight increase was observed for the two distinct loading speeds, v_1=0.25 MPa/s and v_2=0.6 MPa/s. The reduction in modulus of elasticity can be attributed to the lower modulus of rubber crumbs compared to natural aggregates.
- Tests at different loading speeds (v_1=0.25 MPa/s and v_2=0.6 MPa/s) led to practically the same results of compressive strengths and compressive failure strain, while the loading speed had a slight influence on the modulus of elasticity.

The primary goal of using rubberized concrete is to reduce waste and the conservation of natural resources. Many researchers studied the effects of different sizes and replacement percentages of rubber particles on the concrete's mechanical and physical properties. Recommendations suggest limiting rubber aggregate replacement to 20% of total aggregates to avoid severe strength loss. A percentage of 20% replacement of coarse aggregates [15] leads to a 46% loss of compressive strength, and it reaches almost 41% with the addition of fly ash or silica fume.

In this study, the reduction of compressive strength is found to be 30 and 38%, respectively, with 20 and 30% rubber crumb replacement of fine and coarse aggregates without cementitious materials addition. This means that the chosen mix proportion is adequate.Despite reduced compressive strength, rubberized concrete appears to improve many properties such as ductility, energy absorption, impact resistance, lower thermal conductivity and noise reduction, making it suitable for dynamic and impact load applications.

Thus, subsequent research will study the behavior of this concrete in bending, tensile strength and impact resistance, as well as its thermal and acoustic behaviour.

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