Mechanical behavior of fiber reinforced compacted concrete with incorporation of reclaimed asphalt pavement

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ABSTRACT: A composite material "Steel fiber reinforced compacted concrete (FRCC©) mixed with reclaimed asphalt pavement (RAP) materials" is investigated for road structure. It is intended to use this composite for heavy traffic road below the surface layer made with asphalt concrete. Monitoring of pavement structure behavior and experimental studies in laboratory are both conducted. First, the new innovative material combining cement concrete, fiber and RAP is presented. It is a compacted concrete with a low cement content compared to a standard cement concrete. Fibers are used in FRCC© to minimize crack width and RAP is added to preserve material and respect sustainable development. Four mixes have been placed on site. Different fibers and RAP contents are used in FRCC©. These structures are also compared with a reference structure composed of classical granular material treated with road hydraulic binders. In order to select the formulations used on site, experimental investigations are performed in laboratory. A total of nine different combinations were tested. In the laboratory, a traditional characterization for design is conducted. This part, made at EIFFAGE Travaux Publics laboratory, includes the following tests: compressive strength, tensile strength, tensile splitting strength, Proctor and immediate bearing ratio (IPI). The first results and analyses from lab investigations are presented in this paper.

KEY WORDS: Roller Compacted Concrete, Pavement, Steel Fiber, FRCC©, Reclaimed Asphalt Pavement.

1 INTRODUCTION

This research is a part of a French National Research Agency (ANR) project named "Recyroute". This 2.3 million-euro project intends to propose a new high performance and long-lasting pavement using "Steel fiber reinforced roller compacted concrete" (FRCC©) road base layer including reclaimed asphalt pavement (RAP). Pavement design, material properties characterization and road structure calculation are part of the developments to be conducted among the involved teams: EIFFAGE Travaux Public, École Nationale des Travaux Publics de l'État (ENTPE), Laboratoire Central des Ponts et Chaussées (LCPC), Laboratoire Régional de l'Ouest Parisien, Chaussée Technique et Innovation (CTI), Paris City and Autoroutes Paris Rhin Rhône (toll highways company, EIFFAGE subsidiary). Both *in situ* and laboratory studies are performed.

The first step of the program is to design and select the material formulation to be used on experimental sites. Some standard tests were then performed in order to define classical mechanical parameters of FRCC© materials to be placed as road base layer. These parameters were used for the pavement design. Chosen wearing course is a thin bituminous concrete layer (classical BBTM from French design guide LCPC-SETRA 1997).

FRCC© (Ficheroulle and Henin 2004) is a roller compacted concrete with steel fiber developed by CTI company. FRCC© is composed of:

- Hydraulic binder content : between 180 to 400kg/m³ of concrete,
- Water content : from 90 to 150 l/m³ of concrete,
- Fibers content : between 25 to 60 kg/m³ of concrete and,
- Plasticizer admixture content : between 0.3% to 1.8% in mass of the hydraulic binder

The new aspect introduced in the program is the analysis of the use of different RAP contents (between 0% and 80% of the aggregate mass).

The following sections present the tested materials, the standard tests campaign, the obtained results and discussions.

2 MATERIALS

The FRRC© components are presented in this section, as well as the material design. The hydraulic binder content is fixed at 12% in mass of granular part. It corresponds to about 280kg/m³ of concrete when used with natural aggregate only. The chosen hydraulic binder (Ligex FPL2) is composed of 52% clinker, 21% fly ash, 6% slag and 21% limestone. The plasticizer admixture is fixed at 0.5% in mass of hydraulic binder. Three different fiber contents are investigated: 0 kg/m^3, 20 kg/m^3 and 30 kg/m^3 of concrete. The chosen steel fibers are 6cm long and 0.75mm diameter (Dramix 80/60 BN from Beckaert Company, Figure 1). Fibers are added during the final mix process and are not considered for concrete design.

Figure1: Dramix 80/60 BN fibers used in FRCC© materials

As mentioned previously, the innovative aspect is the use of RAP as an aggregate. Three RAP contents materials are studied. The contents are fixed: 0%, 40% and 80% by weight of the aggregate (respectively 0%, 36% and 70% of aggregates+ hydraulic binder mass). The obtained materials are named F0%, F40% and F80% (see Table 2). Considering combination of fiber and RAP contents, 8 different FRRC© formulations are studied (see section 3 and Table 3).

A material developed by EIFFAGE Travaux Publics (ERTALH) is used as reference to evaluate the properties of the FRCC© materials. This reference material is made with the same Ligex FPL2 hydraulic binder (the content of which being fixed at 5% by weight of the aggregate) and contains 70% of the same RAP (in mass of aggregates + hydraulic binder).

Table 1 presents the properties of RAP used for FRCC© and ERTALH. RAP bitumen content was obtained following the standard NF EN 12697-3. A penetration test, as well as a ring and ball temperature test were done according to standard NF EN 1426 and NF EN 1427 on the bitumen extracted by distillation (NF EN 12697-3). Grading curves of all used aggregates (alluvial sand 0/4 Gurgy, crushed sand 0/6 Crain, crushed gravels 6/14 Crain and RAP) are presented in Figure 2.

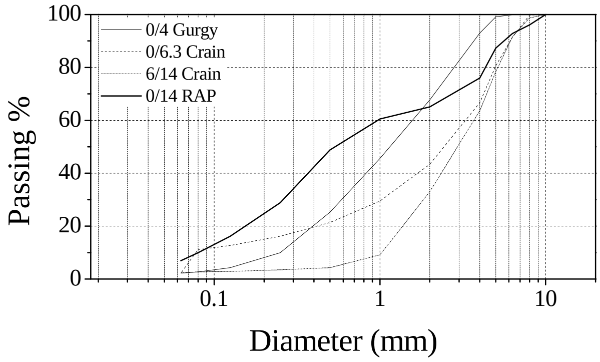
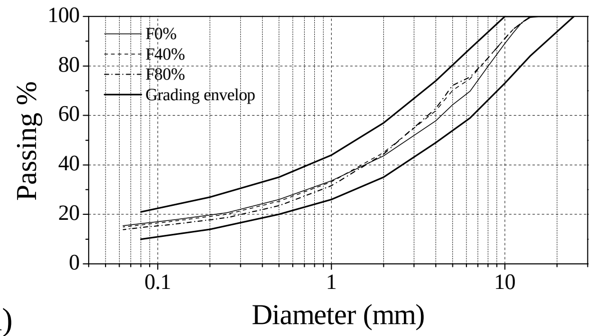


Figure2: Grading curves of aggregates used in FRCC© and ERTALH materials

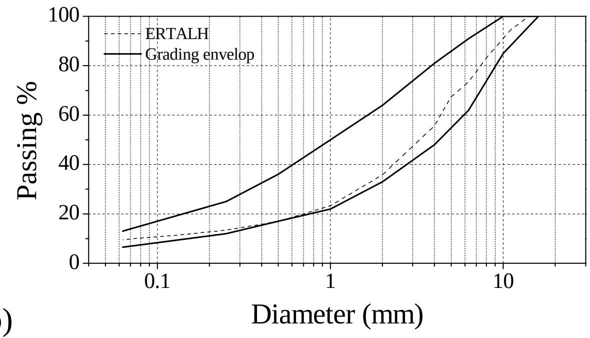
Table 1: Properties of used Reclaimed Asphalt Pavement

Aggregates	Bitumen		
Size (mm)	Content (%) NF EN 12697-3	Penetration at 25°C (1/10 mm) NF EN 1426	Ring & Ball temperature (°C) NF EN 1427
0-14	3.51	12	69.4

To obtain FRCC© and ERTALH final design the following procedure is used. First the cement content and grading envelop (Figure 3) are fixed. Cement content is fixed at 12% in mass for FRCC© materials and at 5% for ERTALH mix. Then the aggregate fractions are adjusted to give a grading curve inside the grading envelop specification. Figure 3 shows the selected grading envelops and grading curves of all mixes. The water content is then determined from the modified Proctor test (NF EN 13286-2) and immediate bearing ratio (IPI) test (NF P 94-078) on materials without steel fiber. Figure 4 presents Proctor and IPI curve and the selected water content of each mixes. Finally Table 2 gives the mix proportions (without fiber) of the tested materials.



a)



b)

Figure3: Grading curves and grading envelops for a) FRCC© b) ERTALH®

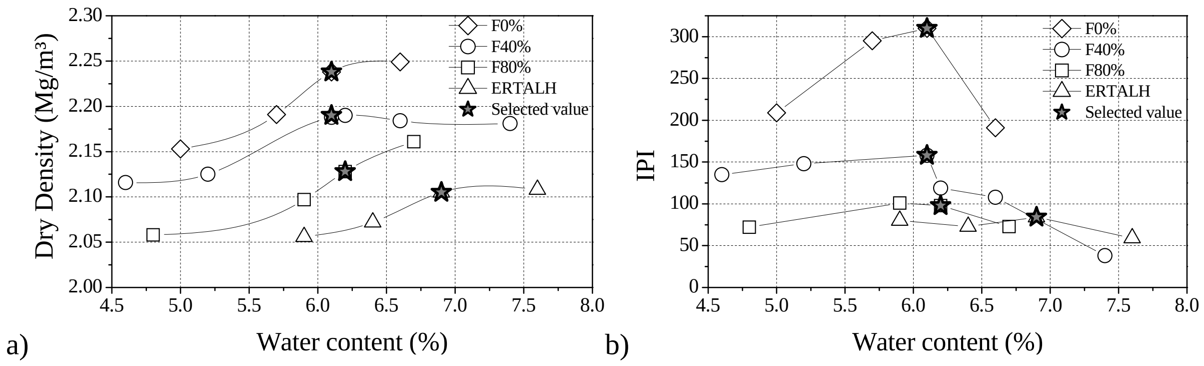


Figure4: a) Proctor and b) IPI curves and selected water content values of each mixes

Table 2: Mixes component (without fiber)

	F0%	F40%	F80%	ERTALH
Alluvial sand 0/4 Gurgy	23.0%	20.0%	18.0%	0.0%
Crushed sand 0/6.3 Crain	35.0%	20.0%	0.0%	25.0%
Crushed gravel 6/14 Crain	30.0%	12.0%	0.0%	0.0%
RAP (0/10 Yonne enrobés)	0.0%	36.0%	70.0%	70.0%
Hydraulic binder (FPL2)	12.0%	12.0%	12.0%	5.0%
Total	100.0%	100.0%	100.0%	100.0%
Additive[1] (Sika)	0.06%	0.06%	0.06%	None
Water content[2]	6.1%	6.2%	6.2%	6.9%
Bitumen content (%) from RAP	0.0	1.26	2.46	2.46
Dry Density	2.240	2.190	2.128	2.105
water/cement ratio	0.508	0.516	0.516	1.380

[1] by weight of concrete
[2] by weight of aggregates

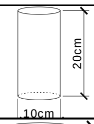
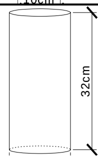
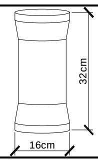
3 CLASSICAL STANDARD TEST CAMPAIGN

Experimental campaign was performed with standard tests at EIFFAGE Travaux Publics central laboratory in Ciry-Salsogne. The reference material ERTALH and eight FRCC© with different combinations of steel fibers and RAP content were tested. The nine different materials are listed in Table 3 where Fx% (yy) means FRCC© having x% RAP content of the aggregates mass and yy fibers content in kg/m³ of concrete.

Samples were molded using vibrocompression method (NF EN 13286-52) and stored in constant relative humidity (90% RH) and temperature (20°C) room.

Four different standard tests were carried out: compressive strength (Rc), compressive modulus (Ec), tensile splitting strength (Rit) and direct tensile strength (Rt). The same specimens were used for Ec and Rit. The tests were performed at different curing periods. As mentioned in Table 3, the curing time was slightly longer than forecasted for 3 specimens. Table 3 shows the specimen size, the determined parameters and the performed tests for each considered materials.

Table 3: Experimental campaign (at least 3 replicates for each condition)

TESTS		Name	Curing period (days)	F0%	F0%(20)	F0%(30)	F40%	F40%(20)	F80%	F80%(20)	F80%(30)	ERTALH
	Compressive Strength Rc (NF EN 13286-41)	Rc1	1	●			●		●			●
		Rc7	7	●			●		●			●
		Rc28	28	●	●	●	●	●	●	●[2]	●	●
	Compressive Modulus Ec (NF EN 13286-43)	Ec28	28	●[1]	●	●	●	●			●	●
		Ec63	63	●	●	●	●	●	●	●	●	●
	Tensile Splitting Strength Rit (NF EN 13286-42)	Rit28	28	●[1]	●	●	●	●			●	●
		Rit63	63	●	●	●	●	●	●	●	●	●
	Tensile Strength Rt (NF EN 13286-40)	Rt28	28	●	●	●		●		●	●	
		Rt63	63				●		●			●[3]

[1] curing time 30 days; [2] curing time 35 days; [3] curing time 66 days

4 RESULTS AND DISCUSSIONS

Results of performed tests (Table 3) are presented in sections 4.1 to 4.4. Each data point represents the average of three specimens and the error bar is the standard deviation. Section 4.5 gives a comparison between different types of test results.

4.1 Compressive strength (Rc)

The compressive strength test was made according to the standard NF EN 13285-41. Figure 5a shows the compressive strength of each material at different curing times. As no clear influence of the fiber content appears, the same data are transposed into Figure 5b, considering four groups of materials (ERTALH, F0%, F40% and F80%) without distinguishing the fiber content.

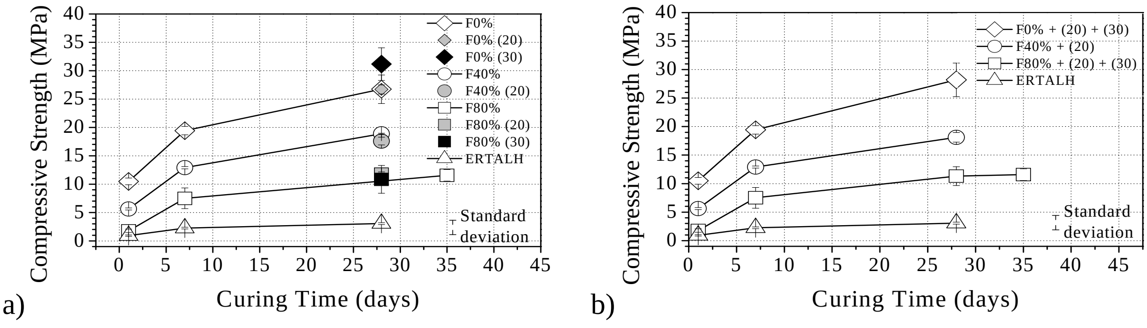


Figure5: Compressive strength at different curing times a) All mixes separately b) Grouped by RAP content

In Figure 5, the influence of the RAP content appears clearly for FRCC mixes. Regardless of the curing time, compressive strength decreases considerably when increasing the RAP content. This result is obtained by other authors (Kolias, 1996 and Mathias, 2004). Compressive strength results for 28 days are also presented as a function of RAP content at

Figure 6b. Considering F80% and ERTHAL materials, which have the same RAP contents and respectively 12% and 5% cement contents, it can be noted that the cement content has an obvious effect on the compressive strength. At 7 and 28 days, FRCC 80% is much stronger than ERTALH. Figure 6a shows the compressive strength ratio between Rc_d and Rc_{28}. It appears that normalized compressive strength evolution is the same at any RAP (and fiber) content.

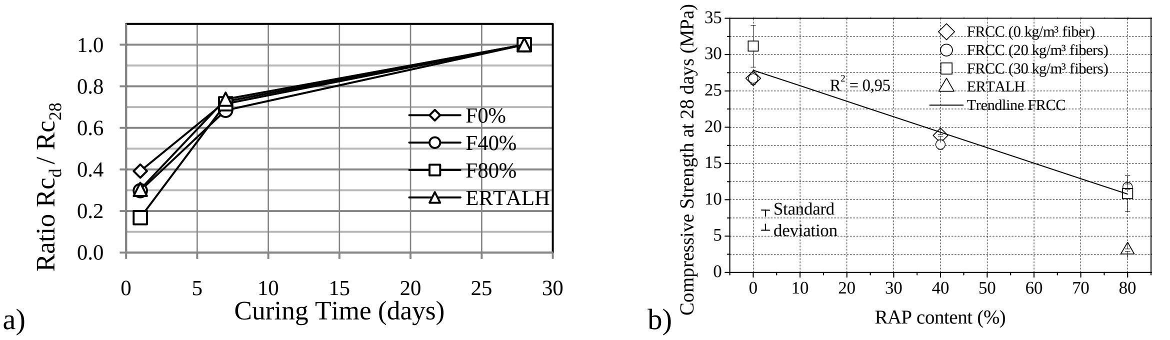


Figure6: Compressive strength a) ratio of specimen without fiber (Rc_d/Rc_{28}) at different curing times b) of different RAP contents at 28 days

4.2 Compressive modulus (Ec)

The compressive modulus test was made according to the standard NF EN 13286-43. Figure 7 presents the compressive modulus as a function of the curing times. Figure 7a shows all data, and Figure 7b represents the same data when considering four groups of materials (ERTALH, F0%, F40% and F80%) without considering the fiber contents. Figure 8 shows the ratio between compressive modulus at 28 and 63 days. The average ratio is 0.9.

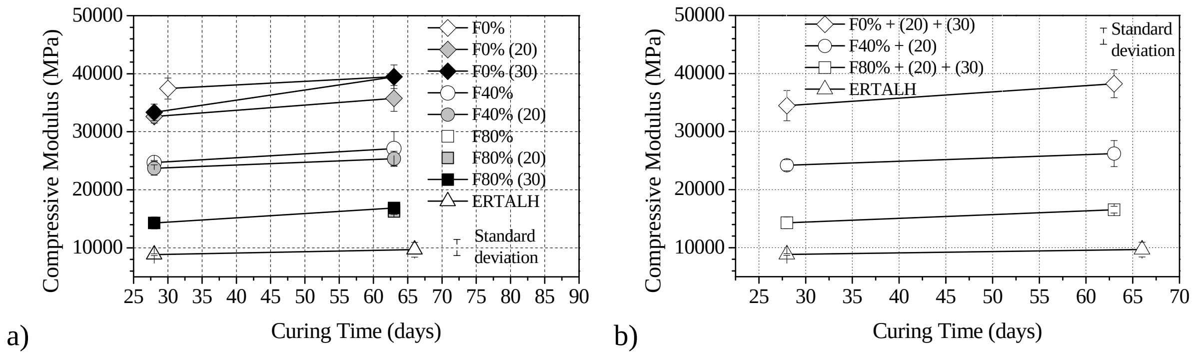


Figure7: Compressive modulus at different curing times a) All mixes separately b) Grouped by RAP content

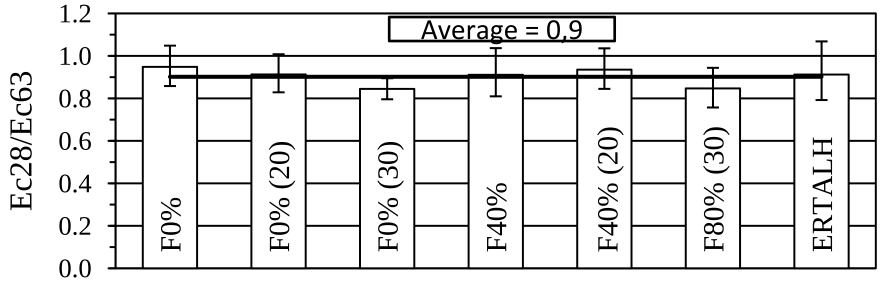


Figure8: Compressive modulus ratio Ec28/Ec63

The same conclusion as for the compressive strength can be formulated: incorporating RAP in FRCC decreases the compressive modulus. The cement content affects the compressive modulus. It decreases at the same time as the cement content does. The fiber content has no significant influence on the modulus (Figure 7a). In addition, the evolution of Ec between 28 and 63 days is low.

4.3 Tensile splitting strength (Rit)

The tensile splitting strength test was made according to the standard NF EN 13286-42 with the same specimens tested as the compressive modulus. Figure 9a presents the evolution of the tensile splitting strength of each material at different curing times, and Figure 9b groups FRCC by RAP content. In Figure 9b), all values for F0% are grouped at 28 days, despite distinct curing times (28 and 30 days). Figure 10 shows the tensile splitting strength ratio. The average ratio is 0.81.

The same conclusion as for Rc and Ec can be drawn for tensile splitting strength: Rit decreases with incorporation of RAP, but the scattering is higher (Figure 9a) than for Rc and Ec. There is no effect of fiber content. The evolution between 28 and 63 days is more important than for compressive strength (Figure 10).

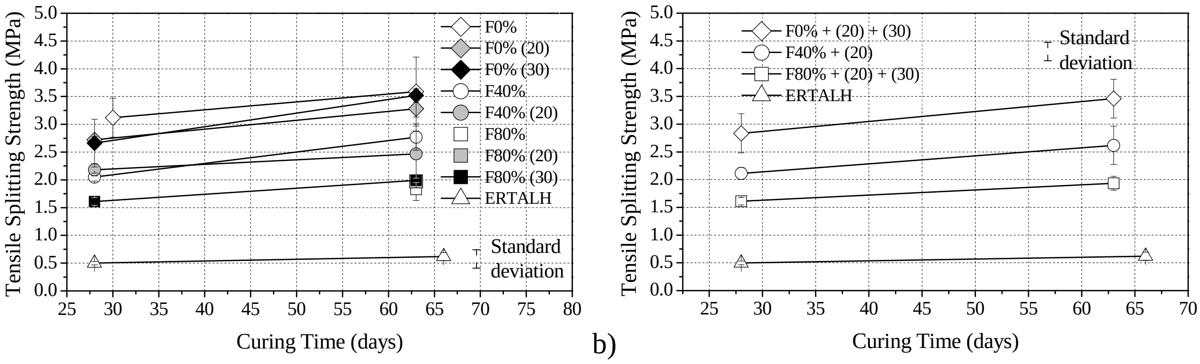


Figure9: Tensile splitting strength a) All mixes separately b) Grouped by RAP content

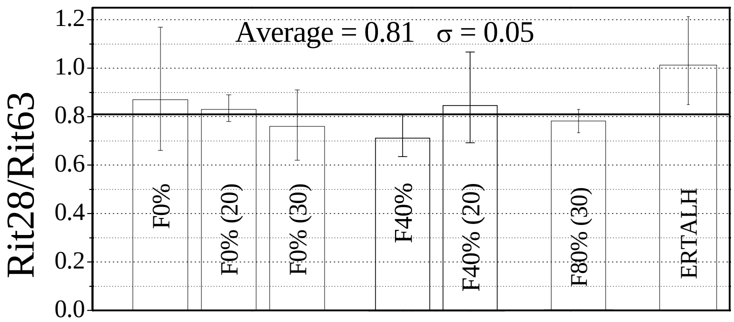


Figure10: Tensile splitting strength ratio (Rit28/Rit63)

4.4 Tensile strength (Rt)

This section presents results from tensile strength tests. The tensile strength test was made according to the standard NF EN 13286-40. Figure 11 shows results and standard deviations of all available data. RAP and cement contents have the same effect on Rt values as that presented for the three other parameters (Rc, Ec Rit). The few results for tensile strength don’t allow us to obtain either strength evolution at different curing times or effect of fiber content.

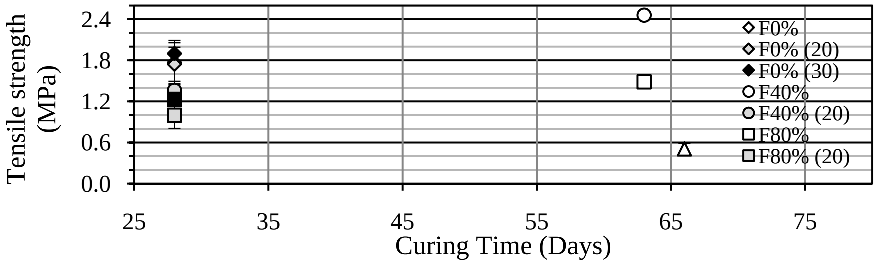


Figure11: Tensile strength at different curing times

4.5 Comparison between different tests

In this section different types of results are compared. When designing road base layer in roller compacted concrete according the French design guide, the tensile strength and the elastic modulus are needed. The French design guide proposes different ratios that can approximate tensile strength and elastic modulus from tensile splitting strength. For roller compacted concrete, these values are 0.8 for Rt-Rit ratio and 12000 for Ec-Rit ratio both at 360 days. In order to know these ratios for FRCC and ERTALH mix, tensile splitting strength is compared to tensile strength and compressive modulus. Then, compressive strength is compared to Rt and Ec at 28 days.

4.5.1 Comparison between Rt and Rit

Figure 12 shows the Rt-Rit ratio for all available data at 28 and 63 days. It seems to have a slighter influence of RAP and fiber (Figure 12a) at 28 days. For F0%, adding fibers increases the Rt-Rit ratio. At equal fiber content for F0% and F40% at 20kg/m³ or F0% and F80% at 30kg/m³ the incorporation of RAP increases the Rt-Rit ratio. As a first approximation and considering error ranges, all formula can be linked by a common value of 0.7. At 63 days, there is no influence of cement content (Figure 12b). The ratio at 28 days is lower than the French design guide ratio at 360 days. At 60 days, it has the same value (LCPC-SERTA 1997).

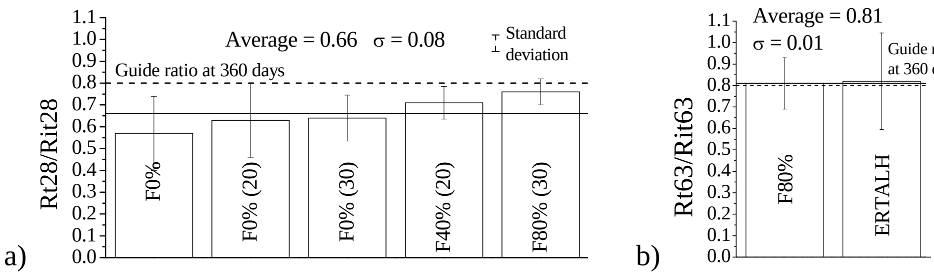


Figure12: Ratio between Rt-Rit a) 28 days b) 63 days and indication of French design guide ratio at 360 days

4.5.2 Comparison between Ec and Rit

Figure 13 shows the Ec-Rit ratio for all available data at different curing times. The cement content has a significant effect on Ec-Rit ratio. The ratio increase when decreasing the cement content. Because the evident difference between the ratio Ec-Rit of FRCC and ERTALH, ERTALH is separated from FRCC. The average for FRCC is given for 28 and 63 days. There is no influence of fiber. A small effect of the RAP content is observed. The ratio slightly decreases when incorporating RAP in FRCC©. The French design method proposes a 12000 ratio at 360 days (LCPC-SETRA 1997). The lower level of the ratio found at 28 and 63 days shows that the actual guide value at 360 days is not valid for FRCC. Ec-Rit ratio at 360 days is needed before given a conclusion for ERTALH.

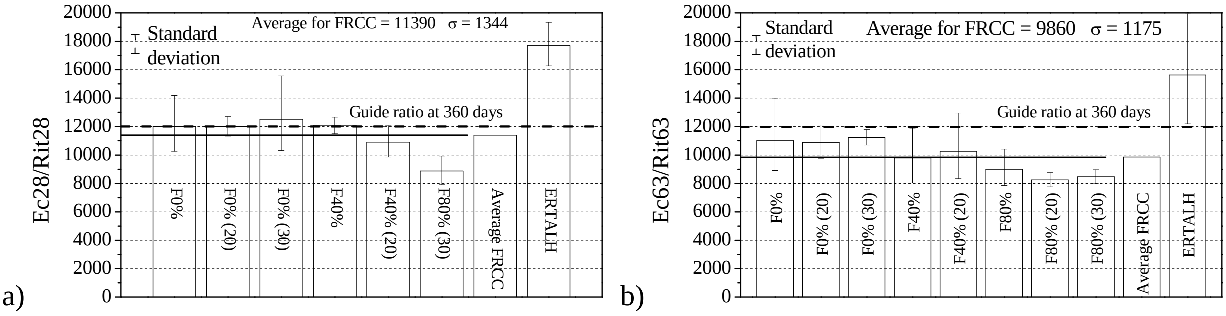


Figure13**:** Ec-Rit ratio of all mixes and French design guide ratio at 360 days a) 28 days b) 63 days

4.5.3 Comparison between Rc and Rt

Figure 14 shows the Rc-Rt ratio for all available data at 28 days. Previously, the same effect of the RAP content is seen on Rc and Rt. The strength decreases with incorporation of RAP. The RAP content has also an effect on the Rc-Rt ratio. This ratio decreases by increasing the RAP content. The decrease of the ratio when increasing the RAP content shows a more significantly effect of RAP content on Rc than Rt. No fiber effect is observed.

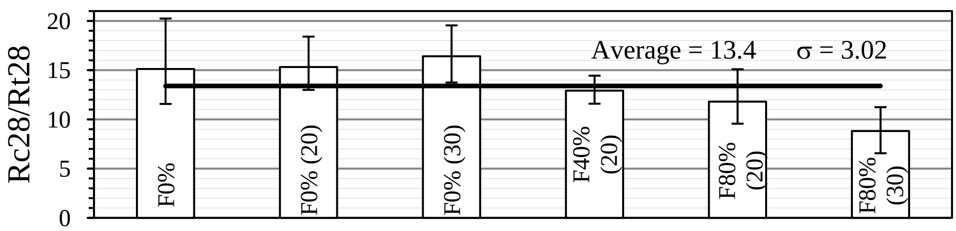


Figure14: Ratio between compressive strength and direct tensile strength at 28 days for FRCC materials

4.5.4 Comparison between Ec and Rc

Figure 15 shows the Ec-Rc ratio at 28 days for all available data. Cement content has a significant effect on Ec-Rc ratio. Less the cement content is, higher is the ratio. Because of this difference, an average value for FRCC is calculated and added to figure 15. The RAP and fiber contents don’t significantly affect the Ec-Rc ratio.

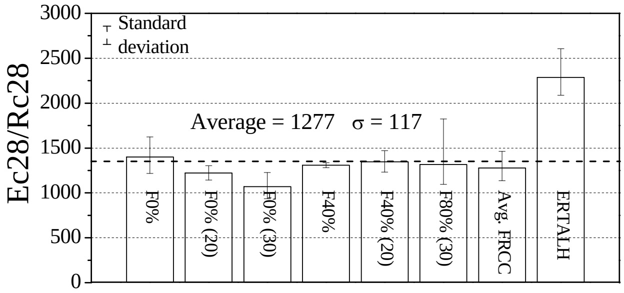


Figure15: Ratio between compressive modulus and the compressive strength at 28 days

5 CONCLUSIONS

Results on compressive modulus Ec, tensile and compressive strength (Rt, Rit, Rc) on FRCC© (with and without RAP) and ERTALH are presented. RAP content has an effect on the strength and the compressive modulus of FRCC© mixes. The higher the RAP content is, the weaker all three strengths and the modulus become. There is no influence of the fibers for the considered tests. Fiber plays a role only when the anchor of the fiber is in action. A further testing investigation after the first crack is required to view the influence of fibers after cracking. At equal RAP content (80%), there is a hydraulic binder content effect. With a rising of cement content, the strength and the modulus of the specimen are both increased. The increase of RAP content influences the strength, according to the temperature (which has to be taken into consideration).

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