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Optimization of the Mechanical Formulation of Typha Concrete

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Abstract*: In order to address energy efficiency issues in the building sector, we conducted this study which focuses on the optimization of the mechanical characteristics of Typha concrete for its use in load-bearing structures of buildings. The fact that buildings are very energy-intensive makes it essential to develop new forms of construction based on bioclimatic architecture and the valorization of certain materials considered as waste in construction. To achieve these objectives, wehave targeted the use of Typha Australis thanks to its great availability and high thermalinsulation capacity. Thus, starting from the composition of a control concrete determined bythe DreuxGorisse formulation method with a characteristic compressive strength of 20 MPaat 28 days, Typha S1 series concretes are formulated with the substitution of sand up to 40, 50,and 60% of Typha. In order to increase the mechanical strength of Typha S1 series concretes,the cement class and G/S ratio are increased for the second S2 series.At the end of this research, the results obtained show that some of these concretes withdifferent proportions of Typha have good mechanical performance, which depends on theirstructural use.

***Keywords*: Load bearing structure, Mechanical resistance, Typha concrete, Typha Australis**

I. INTRODUCTION

In Senegal, the residential sector consumes 47.8% of energy production [1]. To mitigate this significant proportion, the valorization of new materials, especially low-cost renewable or local materials, is being implemented. These include Typha-based materials such as hemp [2], millet pods [3], pumice [4], etc. Typha, with its high insulating power due to its porosity [5], considerably reduces the thermal conductivity of the frames when it is integrated in a cementitious matrix [6-7]. However, these studies make it possible to use these bio-based materials as fillers in the non-load-bearing part of the building. Thus, the object of this study is to integrate the Typha in the load-bearing structure of buildings while having a compromise between mechanical strength and thermal conductivity.

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II. MATERIALS AND METHODS

A. Used materials

Cement: Two types of Portland composite cement CEMII/B of 32.5 MPa strength class for the formulation of the S1 sample series and 42.5 MPa class for the S2 series were used.

Aggregates: The sand used, comes from Gouloumbou, located at 30 km from Tambacounda. Its properties below, table I, classify it as clean, spread and well graded sand.

Table- I: Sand Characteristics

Coefficient of curvature (NF P 18-540)	C_c= 1.34
Uniformity coefficient (NF P 18-540)	C_u = 4.13
Fineness Module(NF P 18-540)	M_f = 2.39
Sand equivalent (NF P 18-598)	ES_{vue}> 85 ES_{piston}> 80
Apparent density (NF P 18-554,555)	ρ_{app} = 1,62 g/cm³
Absolute density(NF P 18-554,555)	ρ_s = 2,54 g/cm³
Specificweight (NF P 18-554,555)	γ_s = 2,6 g/cm³

The table II summarizes the densities of the 3/8 and 8/16 basalt aggregates used:

Table- II: Density of basalt aggregates

Designation	Apparent density	Absolute density
Basalt 3/8	ρ_{app} = 1,43 g/cm³	ρ_s = 2,86 g/cm³
Basalt 8/16	ρ_{app} = 1,43 g/cm	ρ_s = 2,86 g/cm³

The granulometric analysis of these various aggregates makes it possible to draw the granulometric graphs shown in Fig. 1 below:

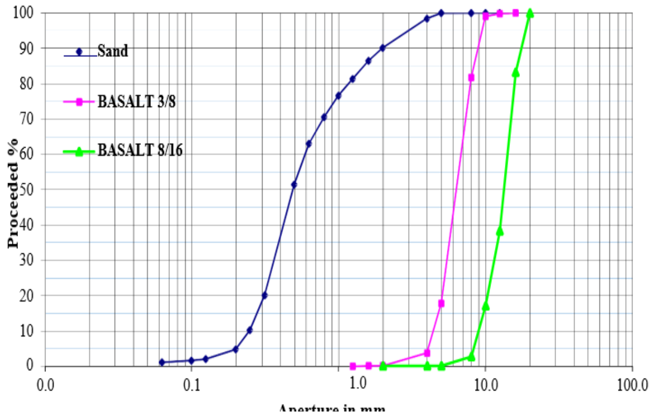

Fig. 1.Aggregate sieve analysis

Water:Potable water is used for mixing concrete.
Typha:Typha, also known as "Barakh" in Senegal, cattail abroad, is an invasive aquatic plant of the reed family that can reach up to 3.5 m in height. It is found in brackish water and in certainregions with stagnant water.

It currently occupies more than 3 million hectares with apotential of 520,000 t/year of dry matter [8], a proliferation rate of 15 %/year [9] and a densityof 18t/ha [10]. Its invasion constitutes a real brake on the economy and causes manyenvironmental and social problems. Indeed, Typha is a real scourge, which the State has triedthrough very expensive programs to fight and control its proliferation but without success.Thus, other programs to valorize Typha are being developed in other sectors such as energy asbiomass, handicrafts, Industry and construction with the creation of new efficient materialsfor thermal insulation such as hemp.

The Typha used for the formulation is dried and then chopped before being ground in a mill.

The percentages of passageways obtained during the sieve size analysis are shown in graph 2:

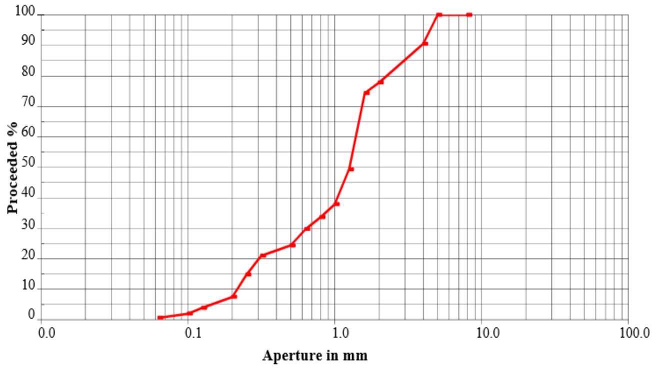

Fig. 2.Typha sieve analysis

B. Formulation method

The determination of the different proportions of the mixture will be done by the method of DreuxGorisse [11], using the Bolomey formula (1):

$$f_c=G^* C_E \left(\frac{C}{E}-0,5\right)(1)$$

Two series of samples S1 and S2 are used for a desired strength after 28 days for thereference concrete greater than or equal to 25MPa and a slump of 7cm for a plastic concrete.On this basis, Typha concrete is obtained by substituting a determined percentage of sandwith Typha.

The two formulations differ in their G/S ratio which goes from 1.83 for the first series to 2 for the second series and in the strength class of the cement of 32.5 MPa for series 1 replaced bya cement of 42.5 MPa for series 2 in order to increase the mechanical strength of the concrete [12]. After calculation, the determined amount of sand is substituted by 40, 50 and 60%Typha. The mass quantities required for the composition of one cubic meter of concrete aregiven in Table III for the S1 series and Table IV for the S2 series.

Table- III: Mass composition of S1 series concretes for 1m³

	Cement (kg)	Sand (kg)	Basalt 3/8 (kg)	Basalt 8/16 (kg)	Typha (kg)	Water (kg)
Control concrete	350	680	329	917	0	197
Concrete with 40% Typha	350	408	329	917	6.17	197
Concrete with 50% Typha	350	340	329	917	7.71	197
Concrete with 60% Typha	350	272	329	917	9.25	197

Table- IV: Mass composition of S2 series concretes for 1m³

	Cement (kg)	Sand (kg)	Basalt 3/8 (kg)	Basalt 8/16 (kg)	Typha (kg)	Water (kg)
Control concrete	350	680	360	1000	0	185
Concrete with 40% Typha	350	408	360	1000	6.17	185
Concrete with 50% Typha	350	340	360	1000	7.71	185
Concrete with 60% Typha	350	272	360	1000	9.25	185

For each formulation, 6 cylindrical specimens with a diameter of 16 cm and a height of 32 cm are made for the purposes of compression tests of half of the specimens at 7 days and theother half at 28 days according to the NF P 18-404 standard. Fig. 3 shows the samplesafter preparation, fig. 4 shows the samples 24 hours after removal from the mould andFig. 5 shows them immersed in water for curing.

Fig. 3.Prepared specimens

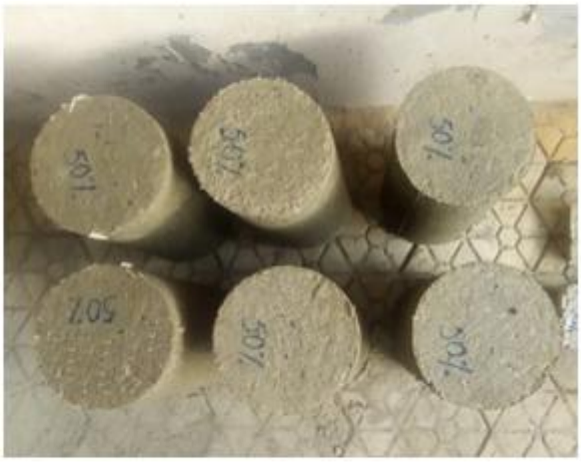

Fig. 4.Demolded specimens (*Example concrete 50% Typha*)

Fig. 5.Sample immersion

The specimens are soaked 24 hours before the determination of the mechanical resistance at 7and 28 days by the FORDIA type mechanical press as shown in Fig. 6 below:

Fig. 6.Mechanical press

III. RESULTS

The determination of the densities in the fresh state, at 7 and 28 days before crushing allows the following curves to be drawn from Fig. 7 from Table V for the S1 series and Fig. 8 from Table VI for the S2 series for the reference concrete and concretes with Typha:

Table- V: Density of S1 series samples

Age (days)		0	7	28
Control concrete	ρ_1 (kg/m³)	2479.02	2384.99	2416.85
	ρ_2 (kg/m³)	2471.25	2402.87	2420.74
	ρ_3 (kg/m³)	-	2382.66	2423.07
	ρ_{moy}(kg/m³)	**2375.14**	**2390.17**	**2420.22**
Concrete with 40% Typha	ρ_1 (kg/m³)	2362.46	2384.22	2385.77
	ρ_2 (kg/m³)	2440.17	2335.26	2378.00
	ρ_3 (kg/m³)	-	2354.68	2381.11
	ρ_{moy}(kg/m³)	**2401.31**	**2358.05**	**2381.62**
Concrete with 50% Typha	ρ_1 (kg/m³)	2370.23	2333.70	2346.91
	ρ_2 (kg/m³)	2362.46	2325.15	2340.70
	ρ_3 (kg/m³)	-	2301.06	2347.69
	ρ_{moy}(kg/m³)	**2366.34**	**2319.97**	**2345.10**
Concrete with 60% Typha	ρ_1 (kg/m³)	2331.37	2256.77	2276.97
	ρ_2 (kg/m³)	2284.74	2262.21	2269.20
	ρ_3 (kg/m³)	-	2207.81	2266.09
	ρ_{moy}(kg/m³)	**2308.06**	**2242.26**	**2270.75**

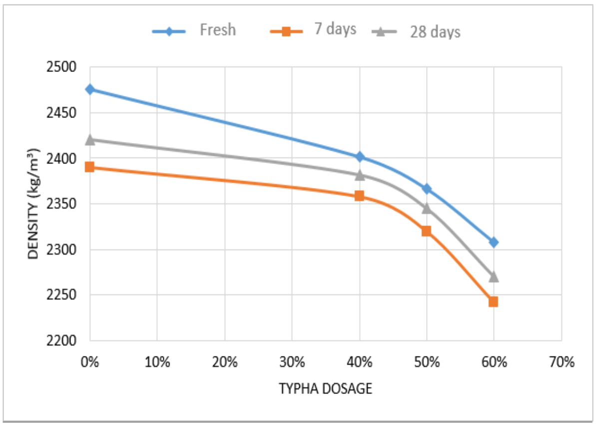

Fig. 7.Evolution of densities of the S1 series

Table- VI: Density of S2 series samples

Age (days)		0	7	28
Control concrete	ρ_1 (kg/m³)	2578.11	2471.25	2504.67
	ρ_2 (kg/m³)	2562.18	2453.38	2489.13
	ρ_3 (kg/m³)	2570.72	2479.80	2481.36
	ρ_{moy}(kg/m³)	**2570.34**	**2468.14**	**2491.72**
Concrete with 40% Typha	ρ_1 (kg/m³)	2429.68	2395.09	2402.87
	ρ_2 (kg/m³)	2400.53	2396.65	2424.63
	ρ_3 (kg/m³)	2447.16	2409.86	2406.75
	ρ_{moy}(kg/m³)	**2425.79**	**2400.53**	**2411.41**
Concrete with 50% Typha	ρ_1 (kg/m³)	2377.61	2343.03	2363.23
	ρ_2 (kg/m³)	2394.32	2330.59	2352.35
	ρ_3 (kg/m³)	2416.08	2374.89	2341.47
	ρ_{moy}(kg/m³)	**2396.00**	**2349.50**	**2352.35**
Concrete with 60% Typha	ρ_1 (kg/m³)	2389.65	2350.80	2357.02
	ρ_2 (kg/m³)	2395.48	2331.37	2353.13
	ρ_3 (kg/m³)	2367.90	2306.50	2350.80
	ρ_{moy}(kg/m³)	**2384.34**	**2329.56**	**2353.65**

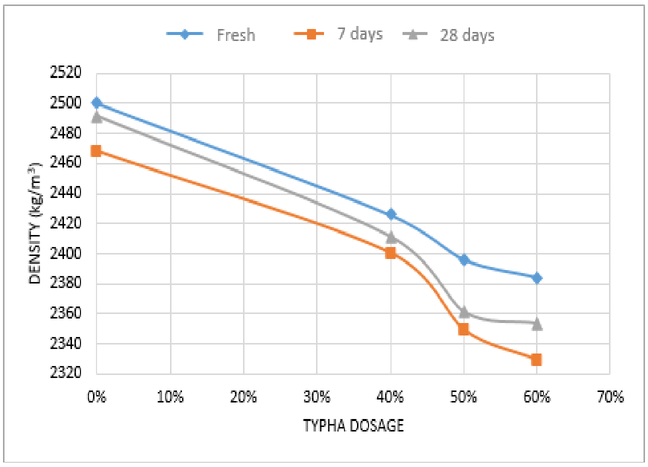

Fig. 8.Evolution of densities of the S2 series

After determining the densities, the breaking force determined by compression is related to the cross-section of the specimens in order to determine the compressive stresses at 7 and 28 days. Table VII lists the stresses for the four formulation categories of the S1 series which are shown in Fig. 9. The compressive results for the S2 series are grouped in Table VIII below and shown in Fig. 10.

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Table- VII: Compression stresses of S1 series samples

Age (days)		7	28
Control concrete	σ_{c1} (MPa)	14.41	24.98
	σ_{c2} (MPa)	14.19	25.41
	σ_{c3} (MPa)	13.69	25.59
	σ_{cmoy}(MPa)	**14.10**	**25.33**
Concrete with 40% Typha	σ_{c1} (MPa)	11.77	23.47
	σ_{c2} (MPa)	12.51	23.00
	σ_{c3} (MPa)	13.28	23.11
	σ_{cmoy}(MPa)	**12.52**	**23.19**
Concrete with 50% Typha	σ_{c1} (MPa)	12.85	22.90
	σ_{c2} (MPa)	12.35	22.76
	σ_{c3} (MPa)	10.88	23.02
	σ_{cmoy}(MPa)	**12.03**	**22.89**
Concrete with 60% Typha	σ_{c1} (MPa)	10.30	18.28
	σ_{c2} (MPa)	10.16	17.97
	σ_{c3} (MPa)	9.63	17.78
	σ_{cmoy}(MPa)	**10.03**	**18.01**

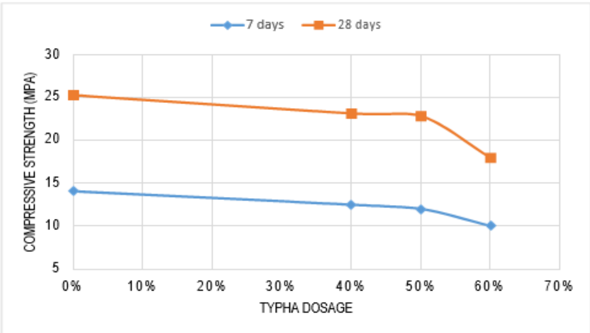

Fig. 9.Evolution of the mechanical resistance of S1 series sample

Table- VIII: Compression stresses of S2 series samples

Age (days)		7	28
Control concrete	σ_{c1} (MPa)	16.35	28.11
	σ_{c2} (MPa)	16.00	27.29
	σ_{c3} (MPa)	14.04	26.97
	σ_{cmoy}(MPa)	**16.46**	**27.46**
Concrete with 40% Typha	σ_{c1} (MPa)	14.95	25.08
	σ_{c2} (MPa)	15.40	26.45
	σ_{c3} (MPa)	15.74	25.79
	σ_{cmoy}(MPa)	**15.36**	**25.77**
Concrete with 50% Typha	σ_{c1} (MPa)	14.39	24.94
	σ_{c2} (MPa)	13.83	24.36
	σ_{c3} (MPa)	15.04	24.11
	σ_{cmoy}(MPa)	**14.42**	**24.47**
Concrete with 60% Typha	σ_{c1} (MPa)	12.92	22.30
	σ_{c2} (MPa)	12.65	21.87
	σ_{c3} (MPa)	12.42	21.48
	σ_{cmoy}(MPa)	**12.66**	**21.88**

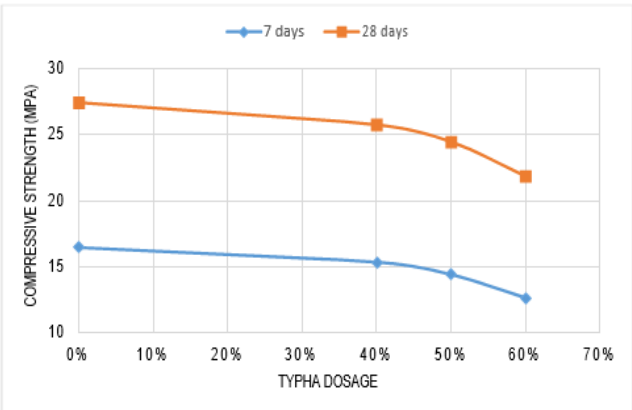

Fig. 10. Evolution of the mechanical resistance of S2 series sample

IV. DISCUSSION

The results of the experimental measurements showed that the density of the concretesdecreases with the percentage of addition of Typha. This is explained by the fact that thedensity of Typha is lower than the density of substituted sand. Nevertheless, these concretescannot be considered as light concretes because their density remains higher than 2000 kg/m^3(NF EN 206-1, Eurocode 2 - 1992). They then remain lightweight concretes with normaldensity.

In addition, the compressive strength of concretes with Typha decreases in an inverselyproportional way with the amount of Typha added. The strength decreases compared to the reference concrete by about 8 to 29% for the S1 series and 6 to 20% for the S2 series. Thissmall drop in strength for the S2 series compared to the S1 series is explained by the increasein the G/S ratio and the cement class.

The Typha concretes obtained can be used for the dimensioning of the load-bearing structure of a building depending on their use and the resistance classes of C20/25 or C25/30 accordingto the exposure class of the NF EN 206-1 standard. In fact, for the S1 series, concretes with 40% Typha allow to have a compression strength at 28 days of 23.19 MPa and a resistance of22.89 MPa for concretes with 50% Typha. For the S2 series, the 40, 50, and 60% Typhaconcrete formulations provide compressive strengths of 25.77 MPa, 24.47 MPa, and 21.88MPa respectively. Therefore, they can be used in load-bearing parts of buildings with desiredminimum strengths of 20 MPa at 28 days.

V. CONCLUSION

Typha Australis is locally available in large quantities, with a relatively low operating costand ease of implementation. This work allowed us to valorize it in concrete as a building material. Its valorization in a cementitious matrix, with a progressive reduction of the quantity of sand to the detriment of Typha Australis, allows concrete to be lightened while keeping a normal density (higher than 2000 kg/m^3). The mechanical compressive strengths also obtained are all higher than 20 MPa for the 40 and 50% Typha concretes of the S1 series and for all Typha concretes of the S2 series. In short, all these Typha concretes can be used to dimension the load-bearing parts of buildings according to their uses and exposure classes.

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