Effect of permanent forms of cementitious composites with short sisal fiber on the shear of reinforced concrete beams

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Abstract. Traditional form systems for reinforced concrete structures, produced in steel and wood, have some deficiencies from the point of view of cost, environment and management. The use of permanent form systems for beams, produced with cementitious composites reinforced with short sisal fibers, can bring improvements to the production process and influence the mechanical behavior of the beam when they are subjected to shear efforts. In this work an experimental investigation of the influence of the permanent forms is made when the reinforced concrete beam is subjected to shear forces. 8 beams were produced, 2 of them for control and 6 beams with permanent form. Such forms were produced with 3 composites with short sisal fibers in different levels and different water/binder ratios. The beams were tested by bending at 3 points with asymmetric load and part of the beam was produced without stirrups in order to more easily verify the influence of the form. It was observed that the use of the forms brings improvements in the mechanical behavior, with slightly higher maximum loads, higher energy absorbed and a lower level of opening in the cracks caused by the shear.

Keywords: permanent forms, short sisal fiber, reinforced concrete, beams

1 Introduction

Concrete is the most consumed industrial product in the world according to Ângulo e Figueiredo [1] and this is a consequence of the importance that this material has for humanity. This importance is due to its good resistance to water, ease in producing structural elements of various shapes and sizes, in addition to its low cost and wide availability (MEHTA and MONTEIRO [2]).

The versatility for the production of elements in various forms implies the need to use formwork that must withstand the efforts and keep the concrete in the proper position until it hardens and gains strength as established in the project.

Traditionally, temporary formwork systems in wood and steel have been used, but these systems have some downsides. In the case of steel systems, the costs involved can be a problem, according to Abreu [3] the formwork system can represent between 35% and 60% of the total structures cost.

In the case of temporary wooden formwork systems, in addition to the cost, there may still be a problem the impact on the environment. As the number of reuses of wooden parts is limited, a large amount of wood waste is produced with the structures. According to Amor [4] between 8.3% and 14.58% of the total waste produced by a construction is constituted of wood.

In this sense, a way to avoid these problems is through the use of prefabricated permanent forms that reduce the waste, simplify the production process, bringing benefits from a managerial point of view, but which can impact the mechanical behavior of the structures.

In the context of the production of reinforced concrete beams, Fahmy *et al.* [5] and Fahmy *et al.* [6] used prefabricated formwork made of reinforced mortar in the shape of a "U" and obtained an improvement in the mechanical behavior of the beams when subjected to bending until failure. Other authors, such as Yu, Leung and Cao [7] used composites reinforced with short PVA fibers, also obtaining good results.

As a more sustainable material alternative Leite [8] developed cementitious composites reinforced with short sisal fibers and with these materials produced permanent forms in the shape of a "U" and verified their influence on reinforced concrete beams subject to bending failure at 4 points, noticing that there was an improvement in rigidity and in the strength of the beams, without negatively affecting their properties.

This work aims to advance the investigation of the effect of permanent forms on the behavior of beams. Similar formworks and beams will be produced, but the beams will be analyzed by bending at 3 points, with asymmetrical load, thus showing the effects of shear stresses.

2 Experimental program

2.1 Mix design and material properties

Three cementitious composites reinforced with short sisal fibers were produced, varying the fiber content and the water/binder ratio in order to investigate the effect of the two variables. The unit mix used was 0.45:0.15:0.40:1.0 (cement: silica fume: fly ash: sand), fiber contents were equal to 4% and 6% by mass of binder (cement + silica fume + fly ash) and the water/binder ratios were equal to 0.35 and 0.40. The F4W0.35 composite has 4% fibers and a water/binder ratio equal to 0.35, the F4W0.40 composite has 4% fibers and a water/binder ratio equal to 0.40 and the F6W0.40 composite has 6% fibers and a ratio water/binder equal to 0.40.

The determination of the composites's mixes was made in order to produce composites with a spread of 250 mm with a tolerance of 10 mm according to ABNT [9]. To improve the workability and reduce the segregation of the components, a superplasticizer additive (SP) based on polycarboxylate polymers and a viscosity modifier (VMA) based on cellulose polymers were used.

Cement produced by Mizu of the CPV-ARI RS type was used and has a specific mass equal to 3.08 kg/dm³. The sand used comes from Alagoinhas in the state of Bahia, Brazil and has a specific mass equal to 2.61 kg/dm³, with the fraction passing through the sieve #1.2 mm being used for the composites. Silica fume is produced by the Companhia de Ferro-Ligas da Bahia (FERBASA) with a specific mass equal to 2.21 kg/dm³ and fly ash is supplied by Pozo Fly and has a specific mass equal to 1.93 kg/dm³. These last two materials are characterized as pozzolans and are added to the composites to obtain a calcium hydroxide-free matrix, according to Lima [10]

The sisal fibers used come from the region of Valente, Bahia, Brazil, supplied by the Associação de Desenvolvimento Sustentável e Solidário da Região Sisaleira (APAEB). Before being used, these fibers were washed in hot water to remove impurities, and to reduce their water absorption capacity they went through the hornification process with 5 cycles of saturation, for 3 hours, and drying to 80 ºC, for 16 hours, according to Ferreira et al. [11]. Then, the fibers were untangled, cut to a size equal to 40 mm and stored. The determination of the composites's mixtures and production processes were made according to Leite [8] and for the consumption of the materials per m³ were obtained the values shown in Tab. 1.

Table 1. Material consumption in kg/m³ for composites

Composite	Cem.	Sil.	Fly ash	Fine Aggre.	Water	SP	VMA	Fiber
F4W0.35	375.25	125.08	335.56	833.89	276.71	37.53	0.75	22.24
F4W0.40	360.23	120.08	320.21	800.51	321.54	21.35	1.20	21.35
F6W0.49	353.94	117.98	314.61	786.52	309.23	30.15	1.02	31.47

Note: Cem. = Cement, Sil. = Silica Fume, Fine Aggre. = Fine Aggregate

For the production of concrete, the same cement and fine aggregate as the composites were used. A gravel from Conceição do Jacuípe, Bahia, Brazil was used as a coarse aggregate. This gravel has a maximum dimension of 19 mm, a specific mass of 2.77 kg/dm³ in the condition of saturated with a dry surface and a water absorption content equal to 0.4%. The determination of concrete's mix was made aiming a compressive strength equal to 40 MPa and a slump of 100 mm with a tolerance of 20 mm. The consumption for 1 m³ of this material can be seen in Tab. 2.

Table 2. Material consumption in kg/m³ for concrete

Cement	Fine Aggregate	Coarse Aggregate	Water
459.58	735.33	1011.08	206.81

For the composites, the compressive strength was evaluated according to ABNT [12] with 40 x 40 x 160 mm³ specimens, the tensile strength and residual strength after cracking were evaluated using beams of 150 x 150 x 550 mm³ with notch according to RILEM [13]. The concrete had its compressive strength evaluated according to ABNT [14] and tensile strength evaluated using the Brazilian test according to ABNT [15], both using cylindrical specimens with dimensions equal to 100 mm in diameter and 200 mm in height. The Young's modulus of composites and concrete were evaluated according to ABNT [16] using cylindrical specimens with dimensions equal to 100 mm in diameter and 200 mm in height. Tab. 3 presents the numerical results of the properties obtained, in parentheses the coefficient of variation in percentage is registered.

Table 3. Mechanical properties of the concrete and composites

Material	f_c (MPa)	E_c (MPa)	f_t (MPa)	f_L (kN)	$f_{R,1}$ (kN)	$f_{R,2}$ (kN)	$f_{R,3}$ (kN)	$f_{R,4}$ (kN)
F4W0.35	30.21 (5.39)	24659.48 (10.17)		8.47 (5.73)	7.05 (37.79)	6.79 (33.42)	5.79 (32.59)	5.10 (32.01)
F4W0.40	23.96 (2.70)	19313.38 (15.66)		7.30 (1.80)	7.92 (2.75)	7.97 (2.78)	7.83 (1.94)	5.10 (2.43)
F6W0.40	23.15 (1.97)	12566.75 (18.44)		7.16 (4.89)	12.03 (15.84)	12.09 (15.52)	11.83 (12.27)	8.43 (15.32)
Concrete	47.93 (9.13)	37466.81 (7.49)	2.70 (9.13)					

Note: f_c = Compressive Strength, E_c = Young's Modulus, f_t = Tension Strength, f_L = Load at the first crack, $f_{R,i}$ = Residual load

2.2 Preparation of test specimens

In Fig. 1 the dimensions, in mm, of the formwork section, the production process, and a finished formwork are presented. The production was made using a metal mold and with the bottom of the form facing upwards. The vibration was done externally with an eccentric weighted vibrator.

Figure 1. Production of the permanent forms

In Fig. 2 can be seen the longitudinal steel bars and the stirrups used in the beams.

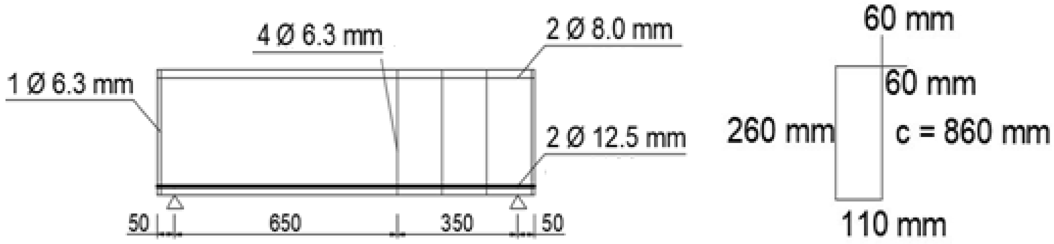

Figure 2. Longitudinal bars and stirrups

External dimensions and reinforcement are the same for all beams. Two control beams and two beams with permanent formwork from each composite were produced. The concrete vibration was made with the use of an immersion vibrator.

2.3 Test setup

The beams were tested by bending at 3 points with the load being applied 650 mm from the left support shown in Fig. 2. The load was applied through a piston associated with a hydraulic pump with a capacity of 250 kN and measured using a load cell of 300 kN capacity. The experiment speed was determined by the load advance being equal to 100 N/s. Vertical displacements were measured using a potentiometric ruler with a 10 mm amplitude located in the load application section, fixed on an aluminum bar positioned at the average height of the beams.

3 Results and discussion

The load-displacement curves obtained for the beams are shown in Fig. 3 using the average values. Two very distinct behaviors were observed, the first one where the beam is in the linear elastic regime and goes to until the critical load, V_{cr}, is reached. In this region, the slope of the curve, called K_{v1}, was calculated.

After cracking has started, there is a strong change in the slope of the curve. The beam supports the increase in loads while the cracks open until the maximum load V_y is reached and there is a sudden rupture. Between the origin and the maximum load is calculated the inclination Kv2 and between the points where V_{cr} and V_y are verified is calculated the slope K_{AB}. The energy absorbed is calculated by the the area under the curve until failure. Such variables were extracted from the graphs and are presented in Tab. 4 in their average values with the coefficient of variation in parentheses.

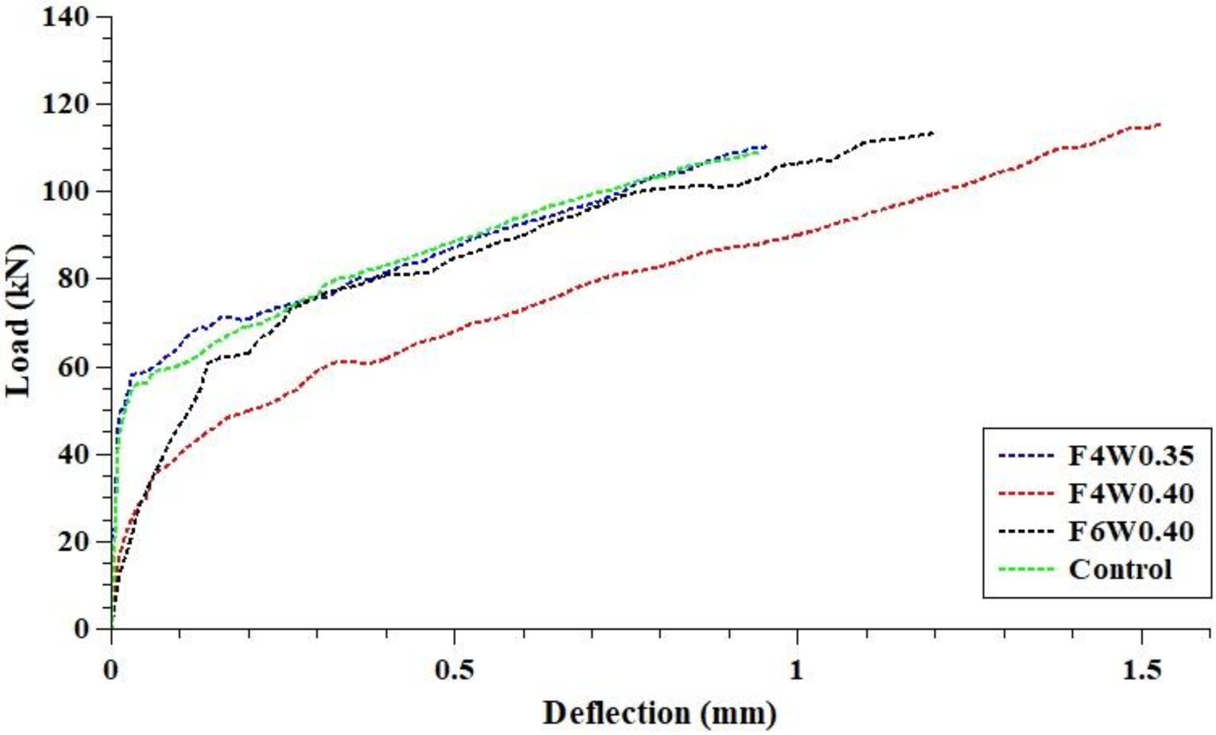

Figure 3. Load-deflection curves

Table 4. Properties of the beams

Property	Control	F4W0.35	F4W0.40	F6W0.40
V_{cr} (kN)	38.23 (16.78)	38.07 (6.62)	31.10 (4.42)	28.35 (0.81)
V_y (kN)	71.28 (6.43)	72.90 (1.26)	75.17 (3.66)	76.46 (2.40)
K_{v1} (kN*m²)	840588.85 (2.48)	2597299.25 (75.55)	313861.42 (59.59)	308717.45 (40.95)
K_{v2} (kN*m²)	48134.05 (9.44)	46768.94 (5.29)	31168.84 (0.98)	40758.11 (3.93)
K_{AB} (kN*m²)	35967.37 (1.67)	34965.26 (4.62)	30449.77 (11.04)	42972.37 (2.22)
Energy (kN*mm)	81.72 (5.40)	87.53 (7.92)	123.83 (1.40)	104.01 (8.51)

Regarding the critical load, V_{cr}, the control beams presented the highest values, indicating that the introduction of permanent forms can reduce the value of this property. Similarly, it can be seen from the curves that there is a tendency for the beams to be less rigid, with greater displacements for the same load level in the linear elastic regime. The phenomenon is due to the replacement of part of the section, approximately 28.44%, by a less resistant and less rigid material, as can be seen in the results of Tab. 3. It can also be seen that among the 3 composites produced, F4W0.35 was the one that caused the less reduction in these variables, being the material with properties, compressive strength and Youngs' Modulus, closer to the concrete.

Regarding the maximum load, V_y, the introduction of the formwork promoted an increase in the property and the composite F6W0.40 is the best in this aspect. The reason for this behavior may be the ability of the forms to resist some portion of efforts when cracked, as a result of the residual loads that the composites present, being the composite F6W0.40 the one with the highest residual stresses.

The analysis of the slopes of the curves reveals a difficulty in evaluating the vertical displacements in the elastic linear region, due to the small displacements. It should also be noted that the F6W0.40 composite was able to increase the stiffness, K_{AB}, of the cracked beams beyond what was observed in the control beams, indicating that the higher fiber content is important in maintaining the stiffness of the cracked beam.

Regarding the energy absorbed by the beams, the introduction of permanent forms made with the 3 composites improved this property due to the greater loads supported by the beams cracked and the greater displacements observed in these beams. The composite F4W0.40 was the best in this aspect because the beams with the forms produced with this composite reached the largest displacements, possibly due to the better transmission capacity of the matrix to the fibers in this composite.

In Fig. 4 are shown the cracks developed in the beams. It can be observed that in the control beam the shear effects were more severe with greater crack opening and concrete disintegration in the lower region of the beam. Among the composites F4W0.35, F4W0.40 and F6W0.40, it is observed that there is a tendency for the crack to be positioned more to the right the greater the value of V_y.

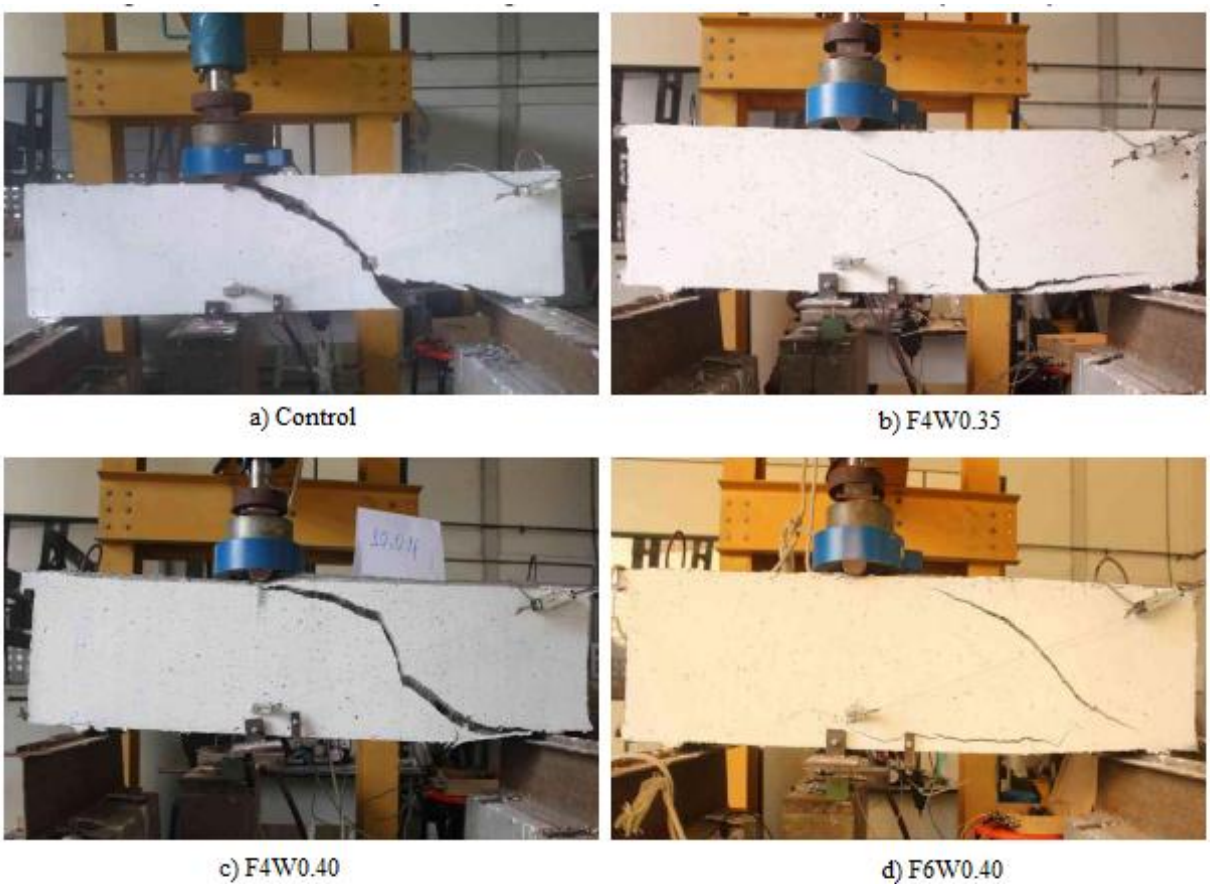

Figure 4. Cracking pattern of the beams

4 Conclusions

From the results obtained throughout this work, it was possible to conclude that the use of permanent formwork can reduce the first crack load of beams as well as the stiffness in the linear elastic regime. However, the maximum load, the stiffness of the cracked beam and the energy absorbed can be increased because of the resistant capacity of the formwork when they are already cracked.

Considering that the composites differed in the water/binder ratio and in the fiber volume, it could be observed that the higher fiber content of the F6W0.40 composite was a more relevant factor for the reduction of stiffness in the linear elastic regime and for the subsequent increase in resistant loads, even though the F4W0.40 composite has shown a greater energy absorption capacity.

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