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COMPARATIVE ASSESSMENT OF FRP'S AND STEEL BARS APPLIED ON THE REINFORCEMENT OF CONCRETE STRUCTURES

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ABSTRACT

Nowadays the sustainability of construction and the need for more sustainable construction solutions is one big concern in the construction field. This way, many times the FRP reinforcing materials are seen and sold as more sustainable and ecological options, when compared with steel or other metal based materials. This fact is essentially due to their non carbon dioxide corrosion characteristics that ensure longer service life and light-weight combined with high strength (Waldron, 2004). But the application of FRP bars for concrete reinforcement is a very specific application that deals with very different requirements and conditions. Due to that, the sustainability has to be assessed through the whole range of structural applications by specific tools, able to evaluate the real sustainability such as the Life Cycle Assessment (LCA) tools (Franzoni, 2011).

To address this issue, a comparative study has been performed , among different concrete reinforcing materials such as steel, Glass fiber-reinforced Polymer (GFRP), Aramid fiber-reinforced polymer (AFRP) and Carbon Fiber-reinforced Polymer(CFRP) and for two different structural applications: beam and slab. Therefore, the objective of this work is to compare the LCA of concrete structural elements, under the same ultimate and service load conditions, reinforced by steel and different FRPs.

Keywords: sustainability, FRP reinforced concrete structure, life-cycle assessment.

INTRODUCTION

The corrosion of steel rebars, in the reinforced concrete structures, is one of the most important causes of structural degradation nowadays. Therefore, this phenomena is reducing the service life of concrete structures, increasing the risk of collapse and causing big economical losses in the maintenance and repair of affected structures. An existing solution to avoid the corrosion problem of concrete reinforcements is to substitute the steel rebars with fiber reinforced polymer rods, composed of different fibers such as carbon, glass or aramid fibers and impregnated with vinylester and epoxy resins (Bank, 2006). That's why many times FRPs are sold as more sustainable and ecological options, not taking in account all the differences between behaviours, which implicate different design methodologies and design codes, causing very different reinforcing ratios and structural sections. But the sustainability is not directly assessed by specific tools, able to evaluate the real sustainability such as the Life Cycle Assessment (LCA) tools. In this work a comparative study has been carried out among different concrete reinforcing materials: steel, GFRP, AFRP and CFRP and for two different structural applications: beam and slab. For each structural application, a specific set of design conditions was taken in account: concrete elements reinforced with steel were designed based on Eurocode 2, while the FRP reinforced elements were designed using ACI 440.1R-06. The designing process took in account the ultimate and the serviceability limit states (limitation of the deflection).

RESULTS AND CONCLUSIONS

The chosen structural elements were: a slab with 4,5 m of distance between supports, pinned at the ends and, the considered beam was the beam responsible for supporting the analyzed slab, with distance between supports of 5,0 m. This analysis considered the life cycle of the concrete structures from the production of raw materials until the demolition and recycling of materials. The evaluation methods where: Cumulative Energy Demand (CED) and CML 2 baseline (2000).

Table 1 - Summary table of material quantities considered for each element and the LCA

Element	Rebar		Cross Section dimension (m)	LCA environmental impacts categories						Embodied energy	
	Type	weight (kg)		ADP kg Sb Eq	GWP Kg CO2 Eq	ODP (x10^{-5}) Kg CFC^{-11} Eq	AP Kg SO_2 Eq	POCP Kg C_2H_4 Eq	EP Kg PO_4 Eq	ENR MJ Eq	ER MJ Eq
Slab	Steel	108,09	0,24x5,0	4,59	1580	5,53	3,01	0,18	0,53	10070	702
	GFRP	18,18	0,40x5,0	10,80	3190	18,90	7,67	0,29	1,35	24980	1134
	AFRP	4,99	0,39x5,0	7,81	2750	26,50	5,65	0,21	0,97	22470	1058
	CFRP	6,86	0,38x5,0	8,47	2760	31,90	6,05	0,22	1,05	19390	1039
Beam	Steel	57,7	0,30x0,30	33,00	15300	49,40	24,90	0,90	3,95	77500	6651
	GFRP	18,73	0,55x0,30	5,02	896	9,27	3,41	0,13	0,64	11500	198
	AFRP	8,49	0,55x0,30	2,81	571	27,30	1,86	0,08	0,34	13790	131
	CFRP	7,24	0,55x0,30	2,87	520	23,50	1,90	0,07	0,36	6317	127

Table 1 shows that in all cases where FRP bars were used, the height of the cross section is more than those where steel bars were used., This aspect is mainly due to two reasons: the conservative factors applied to the strength of FRP bars due to lack of ductility and the lower Young´s modulus of FRPs when compared with steel, causing higher deformations. This difference increases the use of concrete in order to achieve a stiffer section, but increasing the environmental impact factors.

Analysing the slab element it can be said that the traditional steel solution has always a lower environmental impact and less consumption of energy. In the beam element, in all environmental factors FRPs have better performance than steel and even less energy is consumed. This is mainly explained by the fact that the beam element is more loaded than the slab. So the most demanding design case for beam is the ultimate limit state while in the slab element, which is less loaded, the most demanding design case is the serviceability limit states.This is explained by the inherent mechanical properties of the materials: FRP bars have higher tensile strength than steel but lower stiffness. So FRPs can fit more easily in the requirements of ultimate limit states than the serviceability limit states.

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