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Rheological and mechanical behavior of High Strength Steel Fiber-River Gravel Self Compacting Concrete

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HIGHLIGHTS

- River gravels (RG) present different properties in comparison with crushed rock aggregates.
- The influence of RG in high strength Steel Fiber Self Compacting Concrete is analyzed.
- The concrete performance is investigated at both fresh and hardened states.
- The presence of RG improves the concrete rheology and reduce its the strain capacity.
- The addition of steel fiber is more beneficial for concrete containing RG than ordinary aggregates.

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ABSTRACT

This study reports the results of a comprehensive experimental campaign aimed at demonstrating the feasibility of using river gravels in substitution of ordinary crushed aggregates for the production of high strength Steel Fiber-River Gravel-Self Compacting Concrete (SFRGSCC). Due to geomorphological reasons, the river gravels represent the most common type of aggregates used in Amazon region for ordinary structural concrete production but only few researches focused on the use of this kind of raw material for the production of high performance cement-based composites. In fact, the river gravels present different intrinsic characteristic in comparison with crushed rocks such as, higher density and elastic modulus, rounded shape with a smoother surface and a more brittle behavior. As a consequence, when embedded in a cement-based matrix they can significantly affect the rheology and mechanical performance of both self-compacting concrete matrices (RGSCC) and Fiber Reinforced Concrete (SFRGSCC).

In this context, the present study firstly analyzes the physical and mechanical properties of the alternative aggregates and then, investigates how the complete replacement of crushed aggregate by river gravel can influence the flowability, segregation potential, yield stress and plastic viscosity of the RGSCC and SFRGSCC in the fresh state as well as the stress-strain behavior under compression, direct tension and bending in the hardened state. The results highlight as the river gravel aggregates shape and surface roughness have relevant effects on the concrete performance as they improve the concrete rheology increasing the concrete flowing and reducing the corresponding yield stress and entrapped air while, on the other hand, reduce the strain capacity of the matrix resulting in a more fragile mechanical response under compression, tension and bending. The addition of steel fiber to the RGSCC resulted being more beneficial than to the reference crushed aggregate SCC. The reinforcement significantly enhanced the RGSCC toughness being this improvement even more pronounced when the samples were submitted to direct tension and bending loads.

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1. Introduction

Concrete is certainly the most widely used construction material in the World [1] and, among its constituents two of them deserve special attention: cement and aggregates. As a matter of

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fact, these components represent the largest volume fraction within the cement based mixtures and, consequently, they are the main responsible for the high CO_2 emissions and consumption of raw materials that can be attribute to the concrete industry [2,3]. In the last decades, considerable progresses, in the view of enhancing the concrete performance and durability, have been done mainly due to the emergence of new chemicals, minerals and the various types of fibrous reinforcement additives [4]. Particularly, these kind of admixtures lead to produce among others, High-Performance Concrete (HPC) [5,6], Self-compacting concrete (SCC) [7,8] and Fiber Reinforced Concrete (FRC) [9,10].

SCC enables compacting process to be performed under its own self-weight, reducing casting duration while, at the same time, increasing productivity [11]. Allied with high performance behavior [12], in its first ages, the three key fresh properties of SCC are: filling capacity, passing ability and segregation resistance [13]. These properties can be achieved by the inclusion of a high amount of fine particles and the use of superplasticizers [14] and are evaluated through rheological characteristics such as yield stress and plastic viscosity [15]. On the other hand, the addition of steel fibers as a disperse reinforcement in cement based materials (leading to produce Fiber-Reinforced Concretes, FRC [16]) improves the post cracking behavior of the matrix at the hardened state and these improvements depend on several parameters such as volume fraction, fiber geometry, orientation and distribution [17] and the characteristics of the matrix but, at the same time, the presence of the fibers can affect the concrete workability [18].

These developments are allowing to design and to produce concrete mixtures meeting required and specific needs while at the same time reducing the construction operations and improving the structural elements durability [19].

In this context, this paper presents the results of a comprehensive experimental campaign performed at the *Sustainable Centre for Construction Materials and Technologies* (NUMATS) of the Federal University of Rio de Janeiro (UFRJ, Brazil) for demonstrating the feasibility of using alternative aggregates for the production of High Strength Self Compacting Fiber Reinforced Concrete (HSSCFRC) [20]. The proposed study herein focuses on the possible use of natural rounded river aggregates derived from rivers of the Amazon region, with the aim of replacing the ordinary crushed aggregates derived from natural rocks. This is mainly motivated by local availability of such aggregate. A particular case is the Amazon region of Brazil where river pebbles are extensively used as coarse aggregates for ordinary concrete production [21]. In fact, the Amazon region is geomorphologically constituted, for the most part, by unconsolidated sediments of its river basins and, therefore, this geological feature leads to a shortage of aggregates derived from rocks crushing [22,23]. Despite this, in the past, the coarse aggregates used in the construction industry in Amazon region were obtained by mechanical crushing of sandstones but, mainly due to the growth in demand, the use of crushed sandstone generated an increase of the environmental degradation and, in addition, the deposits began to be further away from the consumer center. Consequently, also the crushed stone aggregates transportation costs have considerably increased.

The Amazonian's river beds offer a valuable alternative to the crushed aggregates: the so called "river gravels" that are significantly abundant in some regions of Brazil. As a matter of principle, in comparison to the extraction and transportation costs of crushed stone aggregates, the river gravels are less expensive and, consequently, this raw material is more and more used for producing ordinary concrete mixtures in the Amazon region. It is worth to highlights that, in order to avoid environmental degradation of this important river's bed, the Brazilian government is currently applying strict rules in order to manage and promote a rational and adequate use of the river gravels as aggregates [24,25].

The river gravels present, however, different intrinsic characteristic in comparison with crushed rocks and, as consequence, on the resulting concrete performance. In comparison with the ordinary coarse aggregates derived from crushed rocks, the river gravels are generally characterized by lower porosity, higher density and elastic modulus, brittle mechanical behavior, rounded shape and smoother surface [26]. For these reasons, the presence of river gravels embedded in a cement-based matrix can significantly affect the performance of self-compacting and/or High Strength concretes at the fresh and hardened state. In fact, the presence of a denser and rounded compound in a SCC mixtures can lead to bleeding and segregation phenomena at the fresh state. Besides, the presence of a stiffer inclusion with smooth surface may lead to a weaker Interfacial Transition Zone in comparison with crushed aggregates that can affect the fracture mechanisms due to deformation "incompatibility" of river gravels with the surrounding cement paste.

The use of randomly distributed steel fiber to reinforce crushed aggregate-SCC to produce advance cement based composites is quite well established [27] but only a limited number of studies investigated these phenomena on RGSCC [26]. Therefore, the present study aims firstly to analyze the physical and mechanical properties of the alternative aggregates and then, investigates how the combined presence of river gravel aggregates and steel fibers can influence the concrete performance at both fresh and hardened states. Particularly, two types of river gravels and a crushed granite aggregate (employed as a reference) were used for producing high strength concrete mixtures incorporating several amounts of steel fibers (i.e., 0, 0.50, 0.75 and 1.00% of matrix volume). The mixture composition was optimized by using the Compressible Packing Model [28] in order to obtain a optimal granular skeleton that could avoid bleeding and segregation phenomena. The rheological behavior was evaluated through performing the following tests: BTRHEOM rheometer, slump, slump flow, L-box, V-funnel, J-ring in combination with the slump flow, segregation column and entrapped air content. Finally, the stress-strain behavior under compression and direct tension were determined as well as the load-deflection curves under flexural loads and the splitting strength.

2. Materials and methods

2.1. Materials

2.1.1. Binders and admixtures

For the concrete mixtures production Portland cement, fly ash and silica fume, were employed. High Strength Portland cement, composed at least of 95% by clinker, produced by Lafarge in accordance with the national Brazilian standard [29],

Table 1
Chemical and physical properties for the cement, fly ash and silica fume used in the study.

Oxide	Concentration (%)		
	Cement	Fly ash	Silica fume
Na_2O	0.37	0.55	0.34
MgO	2.20	0.79	0.58
Al_2O_3	5.20	27.8	0.12
SiO_2	19.70	58.3	95.10
P_2O_5	0.13	0.10	0.06
SO_3	3.70	0.54	0.08
K_2O	0.30	3.20	0.44
CaO	61.60	1.70	0.34
TiO_2	0.35	1.30	–
MnO	0.23	0.03	0.01
Fe_2O_3	3.30	4.50	0.06
MLC	2.71	0.97	2.75
Specific Mass (g/cm^3)	3.11	2.39	2.29

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