

Analysis of dynamic fracture properties of High-Performance

Victor Rey-de-Pedraza^{1*}, David Cendón¹, Rafael Sancho¹ and Francisco Gálvez¹

¹Departamento de Ciencia de los Materiales, ETSI Caminos, Canales y Puertos, Universidad Politécnica de Madrid, C/ Profesor Aranguren s/n, 28040 Madrid, España

Abstract. Concrete product research has experimented a deep change during the last decades in the search of novel products with improved mechanical properties. Conventional concrete (CC) is now being replaced by new high-performance-concrete (HPC) mixes, with compressive strengths ranging from 80 to 200 MPa, offering great chemical resistance and improved durability. The use of these HPC mixes has been extended to a wide diversity of applications, from civil to military structures, allowing the development of new designs by increasing the compressive properties with a notorious self-weight decrease. As opposite to the improved quasi-static behaviour, HPC may be more susceptible to certain dynamic actions as compared to conventional mixes. Research in the dynamic behaviour of these new mixes is needed in order to ensure resilient structural designs. In the present paper, a compared analysis of the dynamic response of HPC mixes versus conventional concrete is carried. Using a Modified Hopkinson Bar, spalling tests are performed over cylindrical concrete specimens. Results on the dynamic tensile strength are compared for CC and HPC.

1 Introduction

Concrete has been traditionally the preferred material for every type of infrastructure, mainly thanks to the evolution of its mechanical properties throughout the last decades. In this sense, the most critical factor for the development of high-performing concretes has been the progressive reduction on the water/cement (w/c) ratio [1] and the introduction of superplasticizers and silica fume in the recipes [2] which derived into progressive increment of the compressive strengths.

In the particular case of HPC mixes, the experimental insight into the dynamic mechanical response has not been carried as compared to CC mixes. Only few research works have tried to define the dynamic behaviour of HPC and very few references have been found dealing with pure HPC mixes as most of the works performed around HPC include fibres into the dosage. Works by B. Riisgaard [3] in 2007 in compression, Schuler [4] in 2006 devoted to tensile and fracture energy and M. R. Khosravani [5] in 2018 performing indirect tensile tests, bring some results around the dynamic behaviour of novel high-performing concretes.

Corresponding author: v.rey@upm.es

In the present work a comparison of the dynamic tensile strength of two types of concrete mixes has been performed. Dynamic spalling tests using the Hopkinson Bar technique are carried over conventional concrete (CC) and high-performance concrete (HPC) cylindrical specimens.

2 Experimental program

2.1 Concrete manufacturing and characterization

For the experimental campaign, two concrete dosages were manufactured at the Materials Department of the UPM, a conventional concrete (CC) and a high-performance concrete (HPC). Compression and indirect tensile tests were performed to obtain the quasi-static properties of both types of concrete. Results given in Table 1 show the difference in the compressive strength between CC and HPC, with a value of 55 MPa in the first case and 81 MPa in the second one.

Table 1. Quasi-static properties of mixtures (average values (standard deviations in parentheses))

	HPC	CC
Bulk density ρ (kg/mm ³)	2290 (62)	2293 (25)
Maximum aggregate size (mm)	12	12
Dynamic Young Modulus (GPa)	47 (1)	37 (2)
Compressive strength (MPa)	81 (11)	55 (8)
Tensile strength (MPa)	6.1 (0.8)	3.1 (0.3)
Tensile/compression ratio	0.075	0.056

2.2 Dynamic test setup

Spalling tests were performed over concrete cylinders of 450 mm in length and 69 mm in diameter using a modified configuration of the Hopkinson Bar. The complete set-up of the experimental device is shown in Figure 1. A steel projectile with 450 mm length and impact diameter of 22 mm was used with a conical shape developed and justified from previous studies [6]

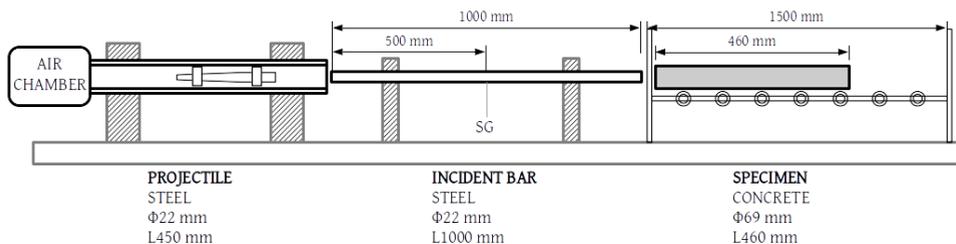


Fig. 1. Experimental scheme

A total of 13 spalling tests were performed over the two concrete mixes. 9 tests corresponded to the CC while 4 were performed over HPC specimens. The experimental methodology for obtaining the dynamic tensile strength is based on the analytical reconstruction of the stress evolution at the specimen's free-end after the reflection of the pulse, which has already been published in [7]. Using the record of the incident compressive pulse in concrete, the pulse reflection at the concrete's free end can be analytically shifted (Figure 2) and the tensile strength derived from the position of the first fracture.

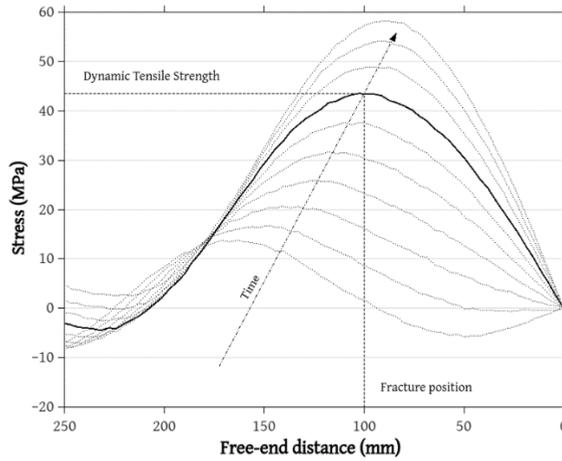


Fig. 2. Stress evolution with time at the free end and determination of the tensile strength

3 Results

3.1 Tensile strength

The estimation of the tensile strength was done identifying the first fracture position from the DIC analysis and matched to the evolution of stresses to estimate the maximum tensile stresses reached by the concrete sample. The compared results for the dynamic tensile strength over the strain rate are shown in Figure 3. In this case, Dynamic Increase Factors are plotted showing, in both cases, a rise in the tensile strength with increasing strain rates. Regarding tensile strength values, results show higher stress ranges for the HPC, with a maximum of 36 MPa versus the 21 MPa reached by CC. The strain rate reached for this

maximum stress differs between mixes, with a CC value of 200 s⁻¹, being twice the corresponding at HPC (100 s⁻¹).

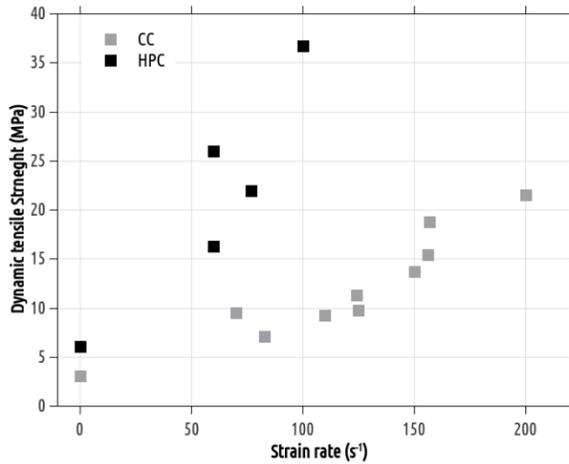


Fig. 3. Comparisson of the dynamic tensile strength for CC and HPC as a function fo the strain rate

Even though primary tensile results show the higher resistance of HPC, the analysis of the obtained DIF's shows a different behaviour of both mixes against dynamic loads. Plotted values in Figure 4 reflect that the tested conventional concrete is capable of developing a better performance in the dynamic regime represented by the higher DIF reached as compared to HPC. A possible explanation for this behaviour could rely in the capacity of CC for developing higher values of strain rate up to fracture thanks to a lower Young Modulus coefficient.

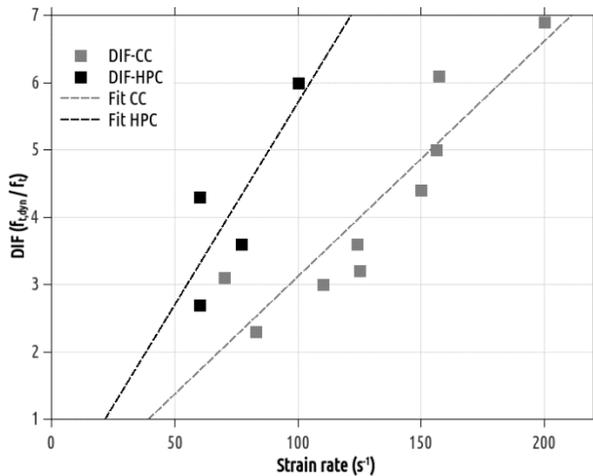


Fig. 4. Comparisson of the DIF for CC and HPC as a function of the strain rate

4 Conclusions

Spalling tests were carried over a High-Performing Concrete (HPC) and the dynamic response compared to a Conventional Concrete (CC) under tensile fracture. The presented results have confirmed the rise in the tensile properties experienced by concrete material under impulsive loads. In a primary analysis, HPC showed higher values for the dynamic tensile strength as expected, however, the obtained DIF over the quasi-static reference revealed the capacity of CC mixes for reaching significant increases in the tensile mechanical properties and so a better performance under dynamic solicitations. This behaviour can be explained through the difference in the elastic properties of both types of concretes. HPC, with a higher Young Modulus, adopts a stiffer response against sudden loads, showing a more brittle behaviour when compared to CC. On the other hand, CC offered a more elastic response, with an improved distribution of the damage among several fractures, as opposite to HPC, where the fracture located in fewer critical sections.

The authors gratefully acknowledge the Ministerio de Ciencia, Innovación y Universidades (MCIU), Agencia Estatal de Investigación (AEI) and Fondo Europeo de Desarrollo Regional (FEDER) for providing financial support for this work under grant PGC2018-097116-A-I00.

References

1. H. Ronneberg and M. Sandvik, *High-Strength Concrete for North Sea Platforms* Concrete International, vol. 12, pp. 29-34, Jan. 1990.
2. H. H. Bache, *Densified cement ultra-fine particle-based materials* Dec. 1981
3. B. Riisgaard, T. Ngo, P. Mendis, C. T. Georgakis, and H. Stang, *Dynamic increase factors for High-Performance Concrete in compression using Split Hopkinson Pressure Bar* p. 4.
4. H. Schuler and H. Hansson, *Fracture behaviour of High Performance Concrete (HPC) investigated with a Hopkinson-Bar* Journal de Physique IV (Proceedings), vol. 134, pp. 1145-1151, Aug. 2006.
5. M. R. Khosravani, M. Silani, and K. Weinberg, *Fracture studies of Ultra-High Performance Concrete using dynamic Brazilian tests* Theoretical and Applied Fracture Mechanics, vol. 93, pp. 302-310, Feb. 2018.
6. F. Galvez Diaz-Rubio, J. Rodriguez Perez, and V. Sanchez Galvez, *The spalling of long bars as a reliable method of measuring the dynamic tensile strength of ceramics* International Journal of Impact Engineering, vol. 27, pp. 161-177, Feb. 2002.
7. V. Rey-De-Pedraza, D. Cendon, V. Sanchez-Galvez, and F. Galvez, *Measurement of fracture properties of concrete at high strain rates* Philosophical Transactions of The Royal Society A Mathematical Physical and Engineering Sciences, vol. 375, p. 20160174, Jan. 2017.