Use of high performance concrete and its impact on structures, costs and

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Abstract. The objective of this work is an analysis of the use of high performance concrete and its impact on the morphology and structure costs and the environment. The use of high performance concrete (HPC) in the construction of buildings and civil engineering works offers advantages in terms of durability, ease of implementation, reduction of deformation and shrinkage, increase the resistance of reinforced concrete structures. The economic benefits of the use of high performance concrete, compared to conventional concrete are illustrated by the reduction of the following costs: the implementation of concrete, the geometric sections of bearing elements of the built space and the maintenance of structures. The consequences of the use of high performance concrete on the urban and the nature, are measured in terms of impact on the Environment. For the same cement production, that is to say the same pollution, the built surfaces in concrete are considerably larger. Potential disadvantages of these high performance concretes, such as the reduction of ductility, fire resistance, and increase of unit costs induced by admixtures, are much lower than the benefits. The generalized use of this type of concrete in many countries has been stimulated by a politic founded on national plans.
Keywords: High performance concrete, impact, morphology, costs, Environment.

1 Introduction

In recent years, the concrete material is used in specific applications where its main characteristic mechanical compressive strength is not the main criterion of choice. In the expression High performance concrete (HPC), the term performance applies, of course, for the compressive strength, but also to all other mechanical and physico-chemical properties of the material: tensile strength, fatigue resistance, abrasion permeability, low or high density, chemical resistance, etc… During the past 10 years, the use of HPC in bridges and other structures has been actively encouraged by the governments of several countries. A classification of high-performance concrete related to the resistance is showed below in Table 1.

Table 1. Classification of high-performance concrete related to the resistance (source : American Concrete Institute).

Compressive strength (Mpa)	50	75	100	125	150
High Performance Class	I	II	III	IV	V

The use of high performance concrete in construction is increasing in worldwide. These developments are summarized in the "High Performance concrete", a state of Art Report (1989-1994) [1] is a valuable summary of the HPC technology.

In Norway, for example, in 1989, the Road Administration of Norway has imposed the obligation to use a concrete with a water / cement ratio less than 0.40 and the use of silica fume on all infrastructure projects [1]. In 1990, the Norwegian Code introduces the concrete with a characteristic 105 MPa [2] for lightweight aggregate structures in cantilever shape and the concrete with characteristic 55 to 70 MPa for structures made with ordinary aggregate (densities of about 1900 to 1950 kg / m3) [2]. After 1988, the concrete must meet the requirements of high strength [2]. The term performance concrete (HPC) is not used in Denmark. The requirements may be high or low, but the performance can be only "yes" or "no." However, the concrete with as such requirements would be described as HPC in the terminology of the United States [3].

The first use of high performance concrete (HPC) in France dates from 1983 with the construction of bridge at Melun driven by the two public agency the LCPC and the SETRA (research agency) [4. Concretes with strength characteristics in a range from 70 to 80 MPa are now common in France, thanks to changes in codes and standards on the use of HPC [4]. According Virlogeux "The development of high-performance concrete is one of the major trends in recent years for concrete construction. A concrete with good compactness allows long life to structures (sustainability) and this allows us to say that it is a high performance concrete" [5].

In the United States, the AASHTO, in 1987 launched a strategic research program to encourage the use of these technologies (SHRP) [7] in collaboration with eight states. Their mission was to promote the implementation of the BHP technology for use in roads and bridges and to share knowledge, benefits, and challenges with States and their customers (AASHTO, 1999). A study published by the FHWA in March 2004 [8] reported that 44 of the 50 states had used HPC in the past 10 years and than the

big majority of these states made changes to their specifications regarding specifications the resistance of concrete to allow an efficient use of HPC. In 1999, the National Council of Bridges (NCBC) and Admistration of Roads (FHWA) have reached an agreement of cooperation to develop and implement ways to improve the using and quality of concrete and bridge systems [9].
In Canada, extreme weather conditions and sustainability issues has led to the conclusion that the impenetrability of concrete cover was of paramount importance, and the development of construction with HPC material as a key element to achieve this goal [9]. A network of centers of excellence in HP, funded by the federal government "Centres of Excellence program," began in 1990. In 1994, the network has become known under name the concrete in Canada, and in 2000, the network's researchers have published more than 400 articles [9].

In Algeria, the exposure conditions of concrete are not so aggressive and use of high performance concrete is not a major constraint, except in the Sahara during the summer period. There are three major climatic regions: the Sahara with very high temperatures differences between night and day and a very dry atmosphere, the highlands characterized by very high temperatures in summer and very cold in winter and finally coastal region with a mild climate. The history of the use of reinforced concrete is linked to that of France. Regarding the post colonial period, it was not until the years 1970-1972 with the beginning of the second three-year plan for the generalized use of concrete, that will must to support the national development policy. For example, the Company CEVICO specializing in the industrial prefabricated construction (located in Arba Blida) product, since early 2007, the prestressed concrete bridges and industrial buildings with an average of 60 to70 Mpa resistance [18], and the public company SAPTA specializing in the construction of bridges made by prestressed concrete beams uses a concrete with resistance of 50 to55 MPa.

The objective of this paper is to illustrate the problems of positive impacts of the generalized use of high performance concretes on the urban environment and to identify the economic, architectural and environmental.

2 Impacts of high performance concrete

There is little published research on the various impacts of the use of high performance concrete.

2.1. On the structures

3.1.1 Building type

The development of high-rise construction has known a revolution. In fifty years, it increased by an average of 300 meters to 800 meters in height in architecture domain. The historical evolution of the height of buildings is shown in Figure 1.. The historical evolution of the height of buildings is shown in Figure 1.

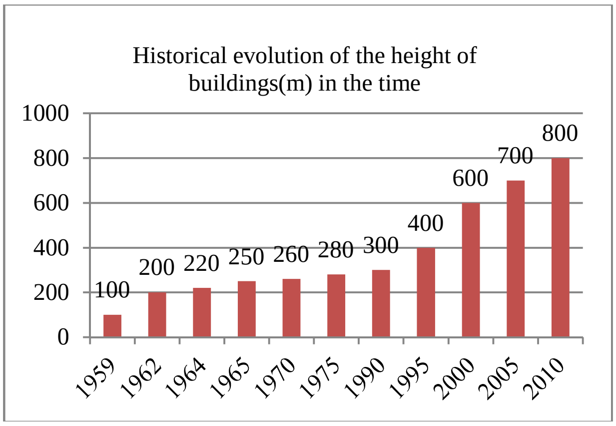

Fig 1. The historical evolution of the height of buildings.

The economic benefits of the use of high performance concrete in the columns of tall buildings have been known from many years. The high strength concrete is the most economical way to transmit a vertical load to the foundations. The four main components of the cost of cubic meter reinforced concrete are the concrete, the rebars, formwork and the casting .
Two other performance criteria give weight to the argument for the use of high strength concrete: the vibrations of wind and traffic require that the modulus of elasticity should be as high as possible to limit the small elastic displacements. In addition, the rapid construction requires early resistance from a young age, a feature that can only be offered by the high strength concrete. The combined effect of these three requirements makes economic and attractive the high strength concrete. Several simulations realized by the Robot Millennium software on two types of buildings, one 6-storey and one 14-storey have give significant differences in terms of volume of concrete compared to results obtained on ordinary concrete. Figures 2, 3 and 4 below illustrate the differences expressed as a percentage in terms of quantities and costs between the high-strength concrete and ordinary concrete.

3.1.2 Briges type

In 1993, the Federal Highway Administration (FHWA) has launched a national program to spread the use of high strength concrete in bridge construction. Applications include bridge decks, beams and pillars. Nine bridges were made under the national program at the end of 1998. In addition, a number of other states have used this type of concrete funded by their own programs. The use of prestressed concrete beams with high resistance allows to obtain greater distances on the spans. A number of studies on the economics of the use of prestressed concrete precast beams for bridges with high compressive resistance have been published in the United States. These studies are agreed on the following conclusions:
- Compressive Strength at time of transfer of the preload tension is acceptable.
- For beam sections (according to AASHTO), the maximum interval of spans have increased between 20 and 45 percent when the concrete strength increased from

41 to 96 MPa.
- The weight of the bridge deck had little influence on the maximum range of beams of high strength.
The availability of HPC allows longer spans, fewer lines of beams and shallow sections of beams .

2.2 On the costs

The costs of high performance concrete are influenced by several. Therefore, developing a cost estimation model requires a greater understanding of the relationship between these factors. Traditional methods of cost estimation are mainly based on spreadsheets, database management systems [19] and statistics [20], [21]. These methods are not suitable for non-linear and multi-dimensional approach for the cost analysis. The development of empirical or semi-empirical methods made by simulations models (Singh, 1994, 1994), or practice with database of statistics to estimate the cost of building structures is extremely difficult because of interactions between the various parameters. Application of neural network is a relatively new approach in the field of construction, decision-making and construction estimate costs [22] and [23]. Table 2 shows an example of high performance concrete composition and Costs of materials used in Algeria. Figure 2 shows the quantitative differences in concrete volume for same load and same safety factor for colunms between the ordinary concrete and the high concrete according to strenght R (Mpa). For example, simulations calculation made on five and ten-story buildings on behalf of the company CIVECO gave the results shown in figures 3, 4 and 5. Figure 3 shows differences in manufacturing costs of the M3 concrete according to resistance, and figure 4 shows the difference between the costs of the square meter floor built in ordinary concrete and high strength concrete. The figure 5 illustrates percent profit obtained on the floor surface accorging to the compressive strenght (R in MaP).

Table 2. Exemple of high performance concrete composition and Costs of materials used in Algeria (year 2012).

Material	unit cost ($ US / ton)	Composition by cubic meter concrete	Average costs cost ($ US)
Ciment C 52.5	100	480 - 520 kg	50
Silica fumes	400	25 kg	10
super placticizers	1200	10 kg	12
water	20	130 kg	3
Sand	15	750 - 800 kg	11
Gravel	15	950-1000 kg	15
Average :		2300-2400 kg	101 $US

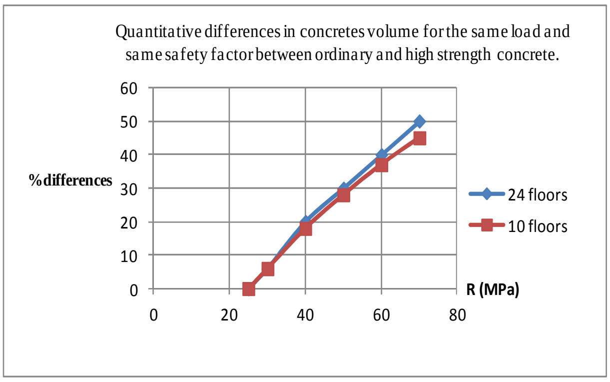

Fig 2. Quantitative differences in concrete volumes for the same load and same safety factor for columns between the ordinary concrete and the high strenght concrete according to R (Mpa).

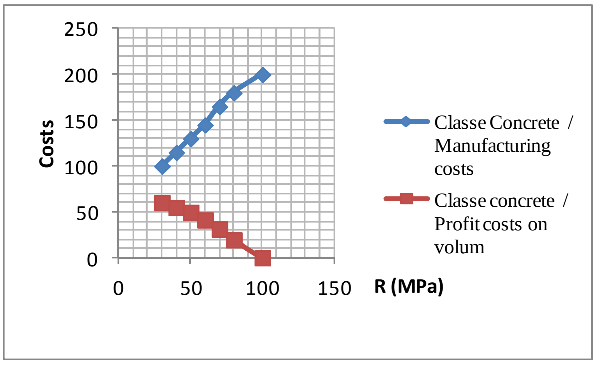

Fig. 3. Evolution of manufacturing costs of the M3 concrete and Profit on volume according to resistance ($ US / M3) .

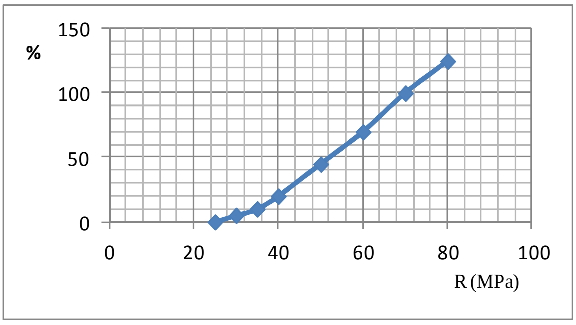

Fig. 4. Differences in manufacturing costs of the M3 concrete according to resistance.

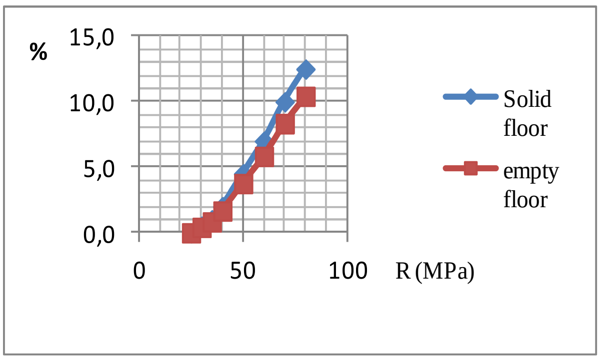

Fig. 5. % profit obtained on the floor surface accorging to the compressive strenght.

2.3 On the Environment

The use of high performance concrete is an economic action to reduce costs and achieve highly beneficial impact on the sustainability of infrastructure, equipment, preservation of land and finally the stabilization of the amount of pollution obtained for producing one ton of cement. Figure 5 shows the energy needed to produce 1 ml column of reinforced concrete to withstand a load of 1,000 tones and Table 6 gives the energy to producing one tone of material for construction (MJ / Tone). These estimates are derived from the results given by Pade et al [24]. Le table 3 shows the Energy cost to producing one tone of material (($ US).

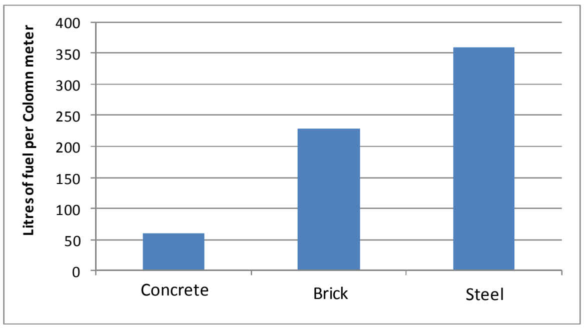

Fig 6. Energy in MJ/Tone to producing one tone of material for construction (source: [25]).

Table 3: Energy cost ($ US) to producing one tone of material (source: [25]).

Concrete	600–800
Cut Wood	500
Multilayers board	4000
Class	15700
Steel	21000
Recycled Steel	11000
Aluminium	164000
Recycled Aluminium	18000
Plastics	81000

With same pollution quantity necessary to produce one ton of ordinary cement, it is possible to increase floor area greater than 30% to 40% of that obtained by ordinary concrete. This is an incitation to vertical evolution of building permitting to preserve the urban land. Thus, for the same amount of concrete, the floor surface increases, which helps to compose and manage urban densities with sustainable development vision. The impact is twofold: increasing urban densities to preserve green space, and stabilization of the pollution generated by the cement industry material.

3 Discussion

In the light of this analysis, it is possible to make the following deductions: the main property for high-performance concrete is still its high strength, other properties are specific to the environmental conditions of the site and to the future function of structure. The difference between the total gross floor area of a building is reduced significantly. A study was carried out by CEVICO company for the feasibility of producing concrete with high performance, was been made in collaboration with many partners. For example, here are two case studies carried out by a French consultancy company for CEVICO compagny in Algeria, about an office building with round columns placed in a frame of 7.20 mx 7.20 m. A comparative study between a height of 10 floors and a height of 24 floors was made using different concrete compositions according formulations gone by Aitcin [25]. Depending on the quality of concrete (strength), economy of volumes on the columns of the ground floor are presented. Table 4 shows the cases corresponding to 10 floors and 24 floors. The figure 7 shows the Costs of manufactured concrete cubic meter according to classe of concrete.

Table 4. Economy on columns volumes according to classe of concrete R for the case corresponding to 10 floors.

Quality of concrete according to résistance classe (Mpa)	% Profit on concrete volume	% Profit on concrete volume
C 30/37		
C 40/50	24	19
C 60/75	49	36
C 80/95	59	51
C 95/105	68	64

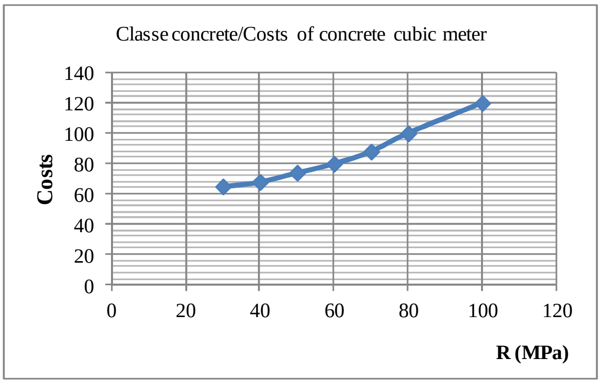

Fig 7. Costs ($ US) of manufactured concrete cubic meter according to classe of concrete R (Mpa).

The profit on the concrete volume cost is of 30 to 65 percent of manufacturing cost. The overcost (Additional cost) generated by the in place of a high strenght concrete, in workability term, is estimated to 15 percent and the overcost of its manufacturing is evaluated of 25 to 60 percent, according to the ordinary concrete cost.

In term of cost, the difference between use of the high strenght concrete and ordinary concrete is negligible. The profit reposes in durability of structures, reduction of urban land use and reduction of polution produced by ciment industry.

The additional costs (Additional costs) generated by the good quality materials and chemical admixtures are largely offset by gains on the realized cubic meter concrete and the final built area.

The table 5 illustrates the overcosts (Additional costs) and profits in the use of the concrete in construction.

Table 5. Economy on columns volumes according to classe of concrete R for the case corresponding to 24 floors.

	(%) Overcosts		(%) Profits		
Concrete according to classe (Mpa)	Manufacturing	in- place	volumes	Rebars	% Total
C 30/37	-	-	-	-	-
C 40/50	20	15	20	20	+5
C 60/75	40	20	40	30	+10
C 80/95	60	20	50	35	+5
C 95/105	80	25	65	40	0

Conclusion

The combinaison of this three factors: rapid growth of the concrete strength during the first age, rapid cycle of formwork and stripping, and durability, gives, to this improved concrete material, the denomination "innovation" in the technology of construction. The widespread use of high performance concrete is dependent on the law of market costs, but also of a sustainable development strategy. The manufacture of high performance concrete requires a significant investment, a competent technical support and a market. It is precisely in the field of technical specifications that the government intervenes to support and oversee the construction industry. Thanks to the prescriptions stipulated in the specifications book, standards and an awareness campaign, the government can to promote the widespread use of building materials adapted to recommendations of sustainable development. A few decades ago, the height for buildings and large spans for bridges was the monopoly of steel material. Today, the new performances of concrete, in terms of resistance and durability, are so high that the high performance concrete is required.

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