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Numerical Correlation Model Between Indentation Parameters and Mechanical Performance of Concrete. Case of Ordinary Concrete, SCC and HPC.

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***Abstract*:** *The direct mechanical characterization of concrete has been limited for a long time to the classical tests, it is a question of subjecting the sample to a crushing test, these tests simulate the mechanical behavior of concrete with respect to the loads, which will be applied to it in the structures, and elements of Civil Engineering. The use of concrete is now expanded to vast areas, the indentation meets more and more a need to represent the behavior of a concrete against the impacts and punctures. In this work we are interested in obtaining a numerical correlation model, allowing to predict the mechanical characteristics of concrete, based on the indentation parameters. The proposed model has been deduced on the basis of the characterization of three families of concrete: ordinary concrete, self-compacting concrete (SCC), and high performance concrete (HPC). The result obtained allows the prediction of the mechanical behavior of concrete, knowing only the indentation parameters. The advantage of this approach is to valorize the indentation approach in the field of Civil Engineering.*

Keywords: *Concrete, Mechanical behavior, Indentation, Numerical correlation, Model.*

1. Introduction

This work consists in the study of the influence of the indentation parameters on the mechanical performances of concretes: ordinary concrete (OC), self-compacting concrete (SCC), and high performance concrete (HPC). We start with the formulation of three classes of concrete, with the characterization of rheological and mechanical properties in the fresh and hardened state. The objective is to propose a model that can estimate the performance of concrete knowing the indentation parameters, the advantage is to predict the mechanical behavior without going through the conventional tests to estimate the properties in the hardened state.

The mechanical characteristics of the concrete were evaluated by indentation tests. This test allows to measure the indentation depth, the resistance to indentation of the indentor, it is only the hardness of the concrete which prevents the penetration of the latter in the heart of the tested concrete.

For a long time, the mechanical characterization of concrete was limited [5] to classical tests, which sometimes require a long time and are far from representing the real conditions of use of concrete, especially in the industrial field. We are currently witnessing the use of new and more significant means to simulate the mechanical response of materials in situations closer to reality. It has been demonstrated that the instrumented indentation technique can be very useful for the determination of fracture parameters [2] and [6].

2. Formulation of Concretes

The concretes have been formulated using local constituents, all the conditions of the standards of use of the components have been verified. For each concrete, the appropriate ratio Water / Cement or Water / Binder : W/C (or W/B) is chosen. For the study of the formulation of the ordinary concrete (noted: OC), we used the Dreux-Gorisse method. The characteristics of the OC in the fresh state show a concrete of firm to plastic character. The target strength of the OC at 28 days of age is 30 to 35 MPa. The result of the composition of one m^3 of concrete, deduced from this method is exposed in table II.1. The formula of the SCC was deduced from a method based on the global approach of the properties of the concrete. The result of the formulation is shown in Table II.1. This formulation was validated by the three fresh state tests of the SCC: Spreading, Sieve Stability, and L-box test. The HPC design, with a target strength of about 60 MPa is [8] shown in Table II.1. These three concretes encompass a range of the most commonly used concretes in general construction.

TABLE II.I: Results of concrete formulation per m^3..

Class of concrete					
OC		SCC		HPC	
Component	Quantity	Component	Quantity	Component	Quantity
Cement (Kg)	380	Cement (Kg)	355	Cement (Kg)	420
Water (Litre)	212	Water (Litre)	180	Water (Litre)	142
Sand (Kg)	815	Sand (Kg)	800	Sand (Kg)	728
Gravel (Kg)	1240	Gravel (Kg)	820	Gravel (Kg)	1055
E/C = 0,558		Fine limestone (Kg)	125	Silica fume (Kg)	37
		Superplasticizer (Kg)	07	Superplasticizer (Kg)	06
		E/B = 0,375		E/B = 0,311	

3. Indentation Test

After studying the fresh state properties of the different concretes obtained, the hardened specimens, at the age of 28 days, will be cut into small size samples, with lapping and polishing (Figure III.1).

Fig.III. 1 : Cutting of the specimens with lapping and polishing.

The principle of the instrumented indentation test consists in applying a load [6] and [9] on an indenter of known shape (ball, cone or pyramid) on the surface of the material to be tested (figure III.2). Under the action of the indentation load, the indenter sinks into the material producing elastic and plastic deformations in the contact zone. When the loading is removed, a residual indentation remains.

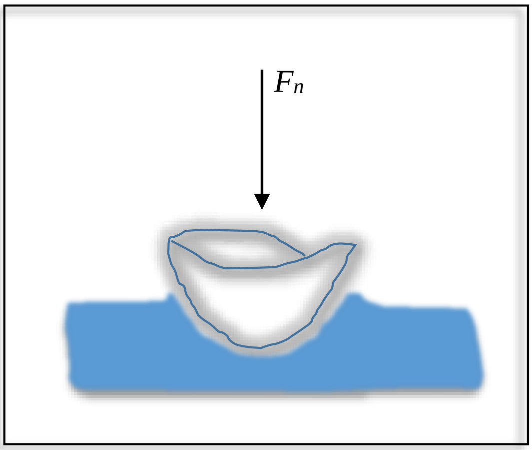

Fig. III.2: Schematic diagram of the indentation test.

The hardness is defined by the following relationship:

$$H = P / A .$$

Where:

H: The hardness expressed in MPa.
P : The load expressed in Newton (N).
A : The area of the cavity expressed in mm^2.

The tests on the studied concretes were carried out in accordance with the standard [1], on an instrumented apparatus (Figure III.3), at the laboratories of the University of Setif. The instrumented indentation [8] is a technique used to determine the hardness and modulus of elasticity of materials as a function of certain parameters such as load, temperature and time. The loads applied to measure the toughness of concrete are variable depending on the type of concrete.

Fig. III.3: Instrumented indentation equipment.

4. Correlation Models

A correlation model [8] is defined here as a mathematical relationship linking two parameters, one representing a characteristic of indentation or formulation of a concrete, and the other defining a quantity of mechanical behavior, the objective is to characterize mechanically a concrete through an indentation test by using directly the model, without going through the mechanical approach.

Using the indentation technique on concrete [8], several theoretical models have been proposed in recent years by the scientific community. As an example, the research proposed by GRAIRIA S. [6], who studied a wide range of different classes of OC and SCC. He proposed models giving the mechanical characteristics of concretes obtained by indentation tets as a function of the formulation parameters (E/B). The study also presents a comparison with previous works, he also concluded [2] that the fracture toughness increased by 26.43% when the water/binder ratio was changed from 0.41 to 0.33. It is observed through this research [10], that the mechanical characteristics: KIC and GIC decrease while the E/B ratio increases. This is due to the reduction in the brittleness of concrete with higher E/B ratios.

Another study on ultra-high performance concrete (UHPC) [11] showed by indentation tests that the modulus of elasticity of concrete is related to the volume of air contained in the cementitious matrix. They consider UHPC to be a four-phase composite material.

In spite of the diversity of the studies and models presented, this axis of research remains far from being approached in an irrevocable way, this is due to the complexity of the subject on the one hand, and to the novelty of the equipment adapted to the tests on concretes on the other hand.

In this study, we want to estimate the influence of the indentation parameters on the mechanical behavior of the studied concretes.

5. Results and Interpretation

Through several cases of study concerning the families of concretes: OC, SCC, and HPC, the following main results were found (Figures; V.1 and V.2).

In this section, we present a correlation study between the different parameters in order to characterize the mechanical properties of the different concretes by the indentation tests.

The strength of the concretes was determined by the traditional crushing tests; the modulus of elasticity by the indentation tests, the relation between the two parameters gives the following results (Figure V.1).

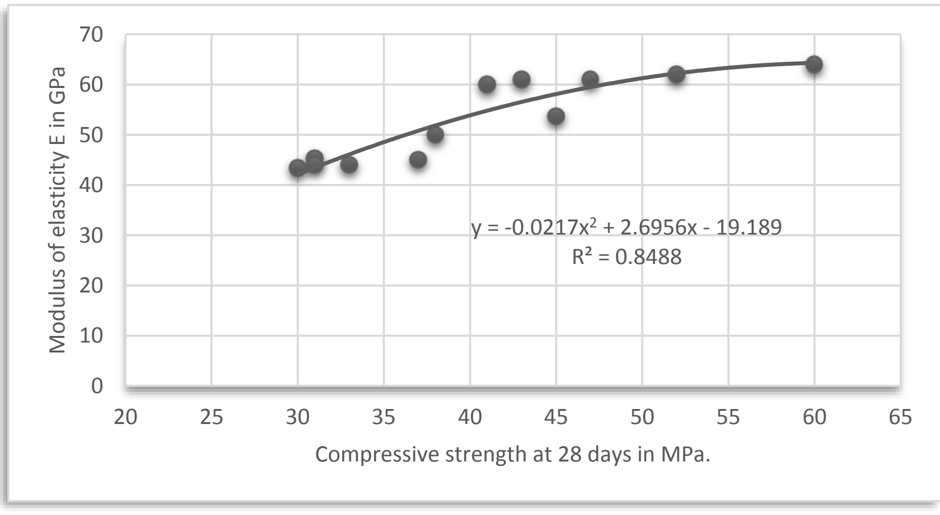

Fig. V.1: Modulus of elasticity E as a function of of the compressive strength of concrete.

As for the different loads applied at the time of the indentation test, several values of the modulus of elasticity are displayed, the graph (Figure V.2) gives the results obtained.

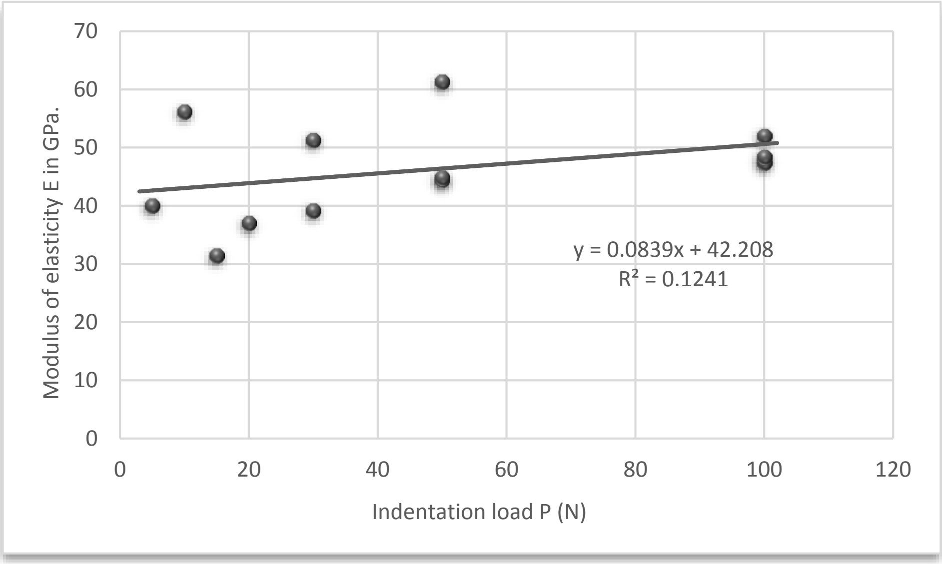

Fig. V.2: Influence of the indentation load P on the modulus E.

Figure V.1 shows the relationship between the compressive strength of concrete determined by the classical crushing tests, and the modulus E determined by indentation test. This function shows that if the strength of the concrete increases, the E-modulus also increases according to a non-linear law of polynomial form, the correlation is very satisfactory (the coefficient of determination $R^2 = 0.8488$). This non-linear behavior explains that other parameters may interact to give this response.

The strength of the concrete of the studied classes varies from 30 to 60 MPa, which gives a variation of the modulus E between 42 and 64 GPa, this interval corresponds with a good approximation to the limits determined by previous studies.

It can be stated that this model presents a more realistic approach giving the mechanical behavior of three classes of concrete at the same time.

Figure V.2 illustrates the mechanical behavior of the concretes (modulus E) as a function of the level of indentation loading P, we can see a dispersion of the results (R^2 = is fable), with a straight ascending trend, the trend curve is purely linear. A better approximation is thought to be obtained by increasing the number of study points. This study focused on the results obtained from the responses between two limits forming a range of values. Despite the scattered results, the following preliminary conclusions can be made:

- ✓ If the load P increases, the value of E increases.
- ✓ With a dense cloud of test points, one can construct a spindle representing this function.
- ✓ Through this plot, we can identify the level of loading P that can give a reliable result of the elastic modulus E.

6. Conclusion

In conclusion, the proposed correlation models (figures V.1 and V.2) present a satisfactory approach for the direct estimation of the mechanical properties of concrete. It should be noted that the studied classes of concretes, can represent most of the families of concretes used in Civil Engineering, which gives these models a more general character.

7. Références

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