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Repeatability of the rebound surface hardness of concrete with alteration of concrete parameters

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HIGHLIGHTS

- Concrete type directly affects the response of the repeatability of the rebound index.
- Ultra-high strength concrete has the lowest coefficient of variation for rebound hammer test.
- Main concrete parameters influencing the response of the Schmidt hammer are examined.
- Carbonation dramatically influences the repeatability of the rebound index.
- EN 13791 basic curve underestimates the mean compressive strength values.

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ABSTRACT

Diagnostic of concrete structure properties is essential towards assessing the properties of the evaluated element. Since the Schmidt hammer is categorized as an economic and effective non-destructive testing tool, an extensive investigation is applied on several hundred of concrete specimens produced from several types, in order to assess the compressive strength and understand the limitations and boundaries of rebound hardness. From normally vibrated concrete to ultra-high strength concrete, water-binder ratio, water-powder ratio, supplementary cementitious materials and admixtures are relatively affecting the response of rebound index of the Schmidt hammer in terms of repeatability for compressive strength prediction. Additional porosity measurements were performed to enhance this statement.

1. Introduction

The evaluation of existing concrete structures is preferably carried out using non-destructive testing (NDT) methods. The Schmidt hammer is classified as one of the most commonly used techniques. Several empirical relationships have been created based on regression analysis, between applied rebound index and actual compressive strength of tested element, in order to predict the actual compressive strength [1,3]. Strength prediction accuracy strongly depends on the correlation between the strength of concrete and the amount of measure in-situ tests. Hence, the validation of such methodology remains a key issue questioning the reliability of the results. A number of earlier studies tried to understand the uncertainty of this testing method by evaluating the concrete itself. The literature provides a connection between rebound index coefficient of variation (COV) and concrete parameters, such as water-cement ratio of the concrete, age of the concrete, the applied cement type for the concrete, the testing conditions and others [2–8]. Over the last decade, several concrete types were created, as well as diagnostic applications, that are not limited only to normally vibrate concrete (NVC). Due to the high paste content and rheological properties, High performance self-compacting concrete (HPSCC) microstructure was considered to be more unified, dense and interconnected [11,12,14]. Therefore, the variability of the rebound hardness index in HPSCC usually brings into question the effectiveness of the Schmidt hammer. In this study, however, the attention is turned on the variation of the rebound index as an effect of several parameters influencing concrete properties. Over the last 20 years, several trials and models have been developed to study the dependence of the mechanical behavior of NVC on the microstructure of the cement paste. In this effort the "degree of sensitivity concept" has been used, which is based on the pore structure of cement paste [10].

HPSCC, with a growing interest in application, is considered more adequate in terms of homogeneity and sensitivity than

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NVC. Sensitivity represents the degree of dependence of the concrete on its pore structure and related properties. Earlier studies on NVC and high strength concrete, showed that the latter has better behavior with regard to its sensitivity [9,10].

In order to assess the characteristic compressive strength of concrete, mean and standard deviation are calculated based on the strength points of the tested specimen, fitting a type of probability distribution (that is certainly not always a normal distribution).

The COV contributes to a better understanding of the margin of variability and dispersion of material properties, as well as their standard deviation. Referring to fib bulletin 1999, Fig. 1 shows the COV of concrete mean compressive strengths ranged between 20 and 70 MPa [13].

To perform the present study, concrete types and compositions should be selected properly in order to obtain an objective comparative evaluation. Therefore, the parameters related to the powder, binders, admixtures and fillers have to be considered with respect to the repeatability of the rebound index. The term repeatability considers the inherent scatter with the NDT method and is often noted as a within test variation. For the characterization of repeatability either the standard deviation or the COV of repeated tests by the same operator on the same material can be suitable. The repeatability for the Schmidt rebound hammer test was found to be appropriately described by the within-test COV, rather than the within-test standard deviation [15].

Fig. 2 illustrates the COV parameter regarding the mean rebound index. The repeatability of the Schmidt rebound hammer analyzed in terms of the COV can range between 10 and 12% of within-test COV. Hence, additional studies are essential for more data relevant to the Schmidt hammer.

Input and output are the key terms to understand the behavior of Schmidt hammer towards the tested material. The outcomes of this process depend on what kind of input data is involved. Input in this case is defined as the following: type and constituent of material, quality control and exposures which influence the material properties and the type of Schmidt hammer used. In this research program, several variables and constant parameters were selected in order to evaluate the limitations and boundary conditions of the rebound index of N-type Schmidt hammer on a series of NVC, HPSCC and ultra-high strength concrete (UHSC).

This paper aims to evaluate the effect of powder, binder contents, supplementary cementitious materials (SCMs) and admixtures on the COV of the rebound index. Further porosity and durability measurements were performed to enrich this investigation.

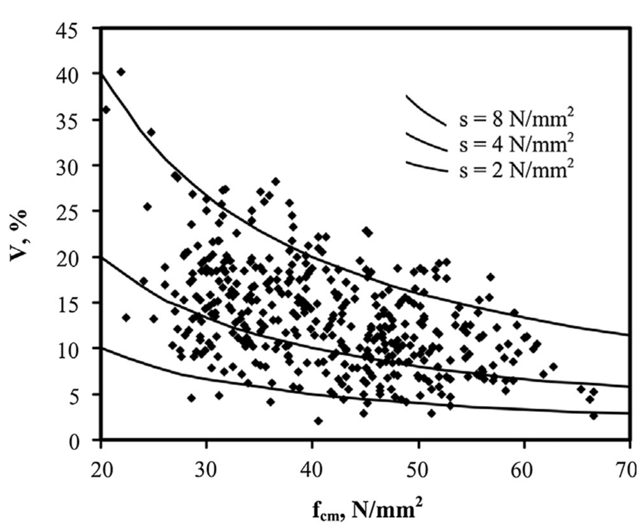

Fig. 1. Coefficient of variation (V_R) as a function of the mean compressive strength (f_{cm}) [13].

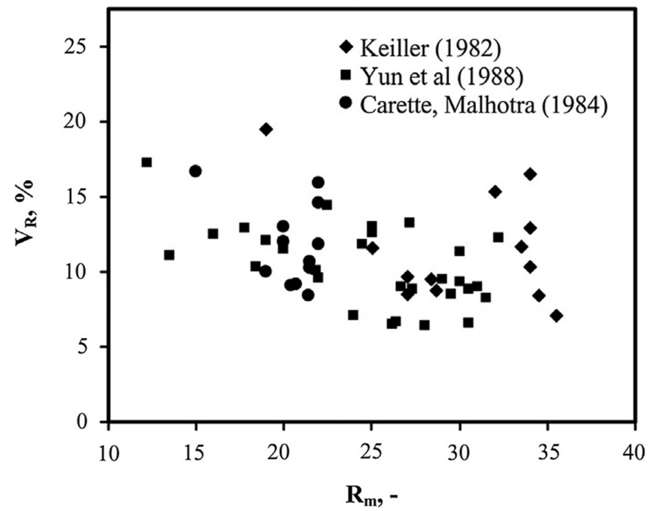

Fig. 2. Coefficient of variation (V_R) as a function of the mean rebound index (R_m) [15].

2. Research objectives

The paper focuses on the response of Schmidt hammer rebound index towards different measured parameters in order to understand the limitations of such NDT method. Concrete is a composite material, that has been lately developing with the use of SCMs. Therefore, many types of concrete are produced and classified as NVC, HPSCC and UHSC. Since these classifications are designated based on the provided materials inside the mixture, the paper intends to show a compressive analysis on the repeatability of the surface hardness with respect to the influence of such a selection of parameters. For this purpose, the response of the Schmidt hammer rebound index COV is arranged according to the selected parameter and its relevant conditions.

3. Experimental procedures

In order to investigate the relation between the repeatability of the rebound index represented by the COV and the concrete parameters represented by water-binder ratio (w/b), water-powder ratio (w/p), SCMs, and admixtures, several concrete batches were designed and placed. A wide range of NVC, HPSCC and UHSC series was produced after which the evaluation of the rebound index of the Schmidt hammer and related properties could be completed.

3.1. Materials and mixtures

The applied cements were supplied by the local Producer, "LAFARGE", based on European standards EN 197-1:2011 [16], CEM II A-S 42.5 RS, CEM III A-N 32.5 MSR and CEM III A-R 32.5 MSR.

Metakaolin (MK) and silica fume (SF) served as the SCMs implemented independently in the mixtures.

Quartz sand and gravel collected from the "Danube" were used for the preparation of HPSCC and NVC with relative maximum aggregate size (D_{max}) of 16 mm. Three nominal grading fractions according to European Standard EN 12620:2002+A1:2008 [17] were used: sand 0/4 mm, small gravel 4/8 mm and medium gravel 8/16 mm. In case of UHSC, natural quartz sand was used as