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# Reliability of pull-off test for steel fiber reinforced self-compacting concrete

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ABSTRACT

This study investigates the applicability of pull-off test in more detail to prepare appropriate outlines for assessing the in-situ quality of steel fiber reinforced self-compacting concrete (SFRSCC) in order to minimize uncertainties involved. For this purpose, an extensive experimental program was conducted including different cement contents of 400 and 500 kg/m$^3$, two maximum aggregate sizes of 10 and 20 mm along with steel fiber contents of 0, 30, 50 and 80 kg/m$^3$. In this study, the water/cement ratio was kept constant at 0.45 for all mixes. 50 mm diameter aluminum and steel discs with thicknesses of 10, 20 and 30 mm along with 70 mm diameter aluminum and steel discs with thicknesses of 10 and 30 mm were supplied. Moreover, to examine the effect of partial core depth on pull-off strength, three different depths of 10, 30 and 50 mm for 50 mm diameter discs and two different depths of 20 and 50 mm for 70 mm diameter discs were chosen. The material and proportions of discs, partial coring and steel fiber content are shown to be particularly significant in pull-off test results for SFRSCC. Also, it is recommended that a specific calibration curve must be developed for each SFR and plain concretes with particular attention to disc characteristics for interpretation and comparisons of results to make a realistic assessment.



## 1. Introduction

Concrete differs from other construction materials since it can be made from an infinite combination of suitable materials and that its final properties are dependent on the treatment after it arrives at the job site. Self-compacting concrete (SCC) consists of the same components as conventional concrete i.e. cement, water, aggregates, admixtures, and mineral additions, but the final composition of the mixture and its fresh characteristics are different. This difference is caused by containing larger quantities of mineral fillers such as Limestone Powder (LP) or fly ash as well as higher quantities of high-range water-reducing admixtures (HRWRA), and reducing the maximum size of the aggregate.

It is well documented that the fibers added to concrete can substantially improve many of its engineering properties. Steel fiber reinforced self-compacting concrete (SFRSCC) provides the benefits of the self-compacting concrete (SCC) technology with the advantages of the fiber addition to a brittle cementitious matrix [1–4]. In fact, the elimination of vibration to consolidate in SCC enhanced the stability of SCC matrix. This may cause in a randomly uniform dispersion of the fibers within structural elements which is not affected by the downward settlement and segregation of the fibers [1].

Nowadays, SFRSCC is utilized in various areas including road pavements, sidewalks, bridges, lining of tunnel, segments, slabs [3] and also for many repair situations. Applications can range from strengthening existing

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structures to replacement of degraded concrete especially where it is difficult or even impossible to vibrate [1].

Because of attractive properties of SFRSCC, its usage continuously increased during the last decades. So, there is indisputable reason why in-situ testing of SFR concrete is more significant. The major motivation comes from industry which is interested in quality management systems, i.e. during production of concrete and construction of concrete elements, the achieved quality in the sense of deviation from an ordered quality and in the sense of scatter of material properties should be known. Moreover, there has always been a need for test methods to measure the in-situ concrete properties for evaluation of the existing conditions. Furthermore, it must be borne in mind that the data generated through laboratory experiments can differ substantially from field data due to a variety of causes, including non-uniformity of material and differences in compaction, casting, curing and general workmanship, which may have a significant effect on future characteristics [5].

Core tests provide the good reliable in-situ strength assessment but also cause the most damage and are slow and expensive [5]. It would be desirable to have a test method that can be readily applied to existing construction which has a stable correlation.

Ideally, these methods should be non-destructive or partially destructive so that they do not significant impair the function of the structure and permit re-testing at the same locations to evaluate changes in properties with time. History suggests that methods which measure some static strength property, i.e. partially destructive, are likely to be the best selections [6].

The pull-off method is one of a group of partially destructive techniques has been developed to measure the in-situ tensile strength of concrete by applying a direct tensile force to a disc which is glued to the concrete. This may be converted to compressive strength using a calibration appropriate to the concrete with considering the affecting factors to arrive a reliable estimate of the in-place strength.

The method may also be useful for measuring bonding of surface repairs with the use of partial coring into the base material. This test simple and quick to perform and no pre-planning is required to avoid reinforcement [7–11].

In comparative studies, it was reported that the pull-off test was more reliable than other methods such as the BRE internal fracture test and (slightly more than) Windsor probe test [9] and is comparable to the pull-out tests using specific correlations [12]. By developing the specific correlations for the concrete under investigation, this method could be successfully applied with strength estimation accuracies generally of the order of ±10% based on the average of six no. tests [12].

The principal properties of SFRSCC are influenced by a great number of parameters. In fact, not only the content and type of cement, aggregate content and its maximum size, but also the type, the length, diameter, aspect ratio and fiber content play important roles. In addition, practical parameters including disc material, disc diameter and thickness as well as effects of partial coring may possibly contribute to the measured values of pull-off test. These observations were demonstrated by Bungey and Madandoust [7] from extensive laboratory experimental studies conducted on lightweight and normal weight vibrated concretes, supported by finite element analysis. It is also claimed that factors such as age, natural aggregate type and size, air entrainment, compressive stress and curing have only marginal influences upon this [5,8,9].

The purpose of the present study is to attempt to shed light on the following topics based on an extensive experimental program with particular reference to the concrete strength:

(1) Evaluation of pull-off test in more detail to probe the applicability for in-situ quality control of SFRSCC in order to minimize uncertainties relating to the properties of SCC and caused by steel fibers.
(2) Assessment of influencing parameters on the test results and practical limitations, reliability and accuracy.

## 2. Experimental framework

### 2.1. Materials

Typical commercial Type II Portland cement that complies with the requirements of specification ASTM C150 [13] was used as testing cement with specific gravity of 3.15 and Blain specific surface area 3165 $cm^2/g$. The fine aggregate was washed river sand with fineness modulus of 2.92 and specific gravity of 2.65. The coarse aggregates were natural crashed gravel with maximum sizes of 10 and 20 mm and specific gravity of 2.65.

Concrete with high fluidity generally requires a high dosage of superplasticizer. In a pure Portland cement concrete, bleeding often occurs under high superplasticizer dosages. In general, two techniques such as usage of mineral admixtures or viscosity modifying agent have been used to solve this problem [14,15]. The first technique was chosen in this investigation. A locally available very fine limestone powder (<150 mm) with specific gravity of 2.7 was used as a mineral viscosity enhancing admixture to maintain sufficient yield value and viscosity of the fresh state. The mixing water was local tap water. Novel polycarboxylic ether based high-range water-reducing admixture (HRWRA) with density between $1.13 \pm 0.01$ $g/cm^3$ (at 25 °C) was used to enhance the flowability of the mixtures. Also, Hooked-end and low carbon steel fibers with a length of 50-mm, diameter of 0.8-mm, aspect ratio of 62.5 and density of 7.85 $g/cm^3$ were added into the mixes. As expected, regardless of the cement content, HRWRA demand to retain slump flow in a desired range gradually raised with the increase of fibers content and maximum nominal aggregate size (see Table 1). The superplasticizer dosages were adjusted in order to keep the slump flow diameters for all mixtures within the range of $650 \pm 50$ mm.

After mixing, workability properties of SCC mixes were evaluated through the measurement of slump flow diameter, slump flow time to reach a concrete 50-cm spread circle ($T_{50}$) and J-ring test according to the procedure recommended by EFNARC [16] as well as Visual Stability