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Rheometer-4SCC, a portable rheometer for self compating concrete

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Abstract
Rheological measurement is an effective way to monitor quality of self compacting concrete in its fresh state. Currently existing rheo- and viscometers are heavy and expensive and therefore unsuitable to use on building sites as a quality control devices. A new and portable rheometer for self-compacting concrete, Rheometer-4SCC, has now been developed at the Icelandic Building Research Institute (IBRI Rheocenter). The project was also a MS-Project at the faculty of Engineering of University of Iceland. The device has been tested at various on-site and research projects. An overview of the design process is given here.

Introduction
Self-compacting concrete (SCC), also named self-consolidating concrete, has been defined as a concrete that is able to flow and compact under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for any additional compaction [1]. The basic description for SCC was defined for the first time around 1988 at Tokyo University by professor Okamura and his students [2]. Since then interest in high performance concrete like SCC has increased dramatically. The most popular quality test methods for fresh SCC are based on combination of two or more empirical test methods. The interpretation of these test results are not based on scientific calculations but on previous experience of their usage in the field. Rheology measurements are an effective way to monitor quality of high performance concrete in its fresh state like SCC. Currently existing rheometers are heavy and expensive and therefore unsuitable to use on building sites as a quality control devices. It could easily be claimed that one of the most significant limitation of further increased use of high quality concrete like SCC is the apparent lack of established reliable test devices. The main research objectives of this project is to develope a portable version of a concrete rheometer, which is operatable at construction site for quality control of fresh SCC. One of the main requirments for rheometer to be classified as a portable one, is that is has to be lightweighted and easily operateble at construction sites. The European guidelines for egonomics state that portable devices should not exceed 25 kg in weight. Here the development and test process of a new and portable rheometer for self compacting concrete, Rheometer-4SCC, will be covered. Rheometer-4SCC is a portable, low cost and user friendly device for measuring the rheological properties of self compacting concrete at construction sites.

Engineering Design Processes

This chapter covers the design process of Rheometer-4SCC. At the beginning of the design process, an extensive need- and operation analysis was carried out. On the bases of this the first prototype, hereby refered to as prototype 1, was built and tested at IBRI Rheocenter's laboratory and on site at construction sites. Based on the results and experience obtained with the testing of prototype 1 another prototype was constructed, hereby refered to as prototype 2. This prototype has also gone through extensive testing and will be mass produced and marketed as Rheometer-4SCC.

The need analysis was divided into two parts, external needs and internal needs.

- The external needs focus on the needs of the user
- The internal needs focus on the issues the design has to take into consideration during the design process. An example of internal needs is for example the things that the designer has to take into consideration because of mass production of the product [3]

The operation analysis can be divided into four parts, the primary operation of the device, the sub operations of the device, validation boundaries and marginal boundaries.

- The primary operation describes the main operation of which the device is designed to carry out
- The sub operations describe currently available methods to carry out the operation the device is designed to do
- The validation boundaries are the factors which we want to optimize during the design process
- The marginal boundaries are the boundaries which we can not exceed during the design

External needs of Rheometer-4SCC:

- The device has to be as accurate as similar devices currently available on the market
- The device must be simple to operate
- The device must be operable at construction sites
- The device must be light and easily manageable for one person

Internal needs of Rheometer-4SCC:

- In order to fulfil the weight requirements, which state that the weight of each component that the user has to lift or carry do not exceed 25 kg, the material selection of each component must be carefully considered. If possible components made of stainless steel will be replaced with comparable components made of aluminium, plastic or fiber glass. It must be carefully inspected whether such exchange will influence the strength and reliability of the device. The size of the device must be in the range that it can easily be operated by one person
- The usage of standardized components will be as much as possible to minimize production cost
- The device must be usable at construction sites
- The device must be light and easily manageable for one person

- The software for the measuring and data processing must be operable on Windows based PC computers
- The device will be equipped without a built-in computer. Therefore the device must be equipped with a universal PC computer data connection available on most common PC computer for sale today
- Wireless communication between the device and PC computer must be available as optional extra

Primary operation:

F0: Measure the rheology parameters of fresh self compacting concrete by measuring yield value and plastic viscosity of the concrete

Sub operations:

F1: Empirical test methods (slump flow, L-box, V-box, U-box etc.)
F2: Older versions of rheometers
F3: Rheometer-4SCC

Validation boundaries:

Initial capital expenditure
Service life
Weight of device
Processing rate
Controllability
Quality and reliability of test result
Design

Marginal boundaries:

Price
Quality and reliability of test result
Weight of device
Controllabilty
Possibility of marketing
CE marking regulations

Two prototypes were constructed during the development of the device.

The selection of components for prototype 1 can be divided into 3 parts, electronic, casing and metal castings.

The electronic part of the device consists of variable speed drive, motor, PC computer, temperature logging (for semi adiabatic calorimetry) together with appropriateelectronic equipment (switches, power supply, fuses, filter and cables)

Three different type of data communication options (RS-232, ethernet and data processing card) were studied as a possible method to handle the data communication. After going over these three options it was decided to select the RS-232 serial port connection. The main reason for this selection is the stability of the design standard of this communication which means that it is not subjected to frequent changes which would entail reprogramming of the software for the device. Although the maximum data transfer rate for the RS-232 is not high it is sufficient for Rheometer-4SCC.

The second part of the selection of the components was the search for a good casing to store the electronic parts. The aim of the search was to find a casing as small and lightweight as possible but still strong enough to be used as the control-box for Rheometer-4SCC. The casing select for the prototype 1 is constructed out of fiber glass. For easier handling two handles were added to the top of the casing.

The metal castings part consists of the sample bucket, topplate for the sample bucket and the impeller. These units are all constructed out of AISI 304 stainless steel.

Rheometer-4SCC prototype 1 went through an intensive test program at IBRI Rheocenter's laboratory. Prototype 1 has also been tested on-site projects that IBRI Rheocenter has been working on. The first test was carried out at the Kárahnjúkar power plant which is under construction in the eastern part of Iceland and the second test was carried out at bridge repair project in Borgarfjörður which located about 73 kilometer from Reykjavik.

(a) (b)

Figure 1: Rheometer-4SCC prototype 1 on site at the concrete plant in Borgarfjörður (a) and at the bridge over Borgarfjörður (b)

Based on the robustness testing of Prototype 1, a few segments of the device could be modified in order to increase the strength, mobility and controllability of the device. Therefore prototype 2 was built but it was based on the same need- and operation analysis as before. Also the design of the sample bucket was changed and a motorcover designed for the servo motor. As for prototype 1 the selection of components for prototype 2 can be divided into 3 parts, electronic, casing and metal castings.

The electronic part of the device consists of the same variable speed drive and brushless AC servo motor as before together with appropriate electronic equipment (switches, power supply, filter and cables). The main addition in the eleqtronic part was the addition of a wireless communication option via Bluetooth. The reason for why the Bluetooth was selected to handle the wireless communication between the drive and the PC computer is that the Bluetooth is inexpensive, automatic, the maximum data transfer rate is high (although the maximum data transfer rate of the serial port it the limitation here).

The second part of the selection of the components was the search for a good casing to store the electronic parts. The aim of the search was as before to find a casing as small and lightweighted as possible but still strong enough to be used as the control-box for Rheometer-4SCC. The casing which was selected for the prototype 1 turned out to be difficult in handling particulary because the motor was permanently attached to the casing via the motorcables. Three different casings were compared using the Analytical Hierarchy Process (AHP) decision making system. The three casing compared are:

- Fiber glass box manufactured by Himel (used in prototype 1)
- Stainless steel box manufactured by Eldon
- Plastic case manufactured by Pelican

The five points of the items that were compared to get the results are:

- Weight
- Price
- Design
- Mobility
- Strength

Each point of the casings were given grades according to the methods of the AHP and the result calculated. The results recommend the usage of the plastic case manufactured by Pelican for the prototype 2 of the Rheometer-4SCC. According to the AHP the stainless steel box is the least desirable option. The Pelican casing is an indestructible and rigid case manufactured from high grade polypropylene. The case is equipped with 5 cm hard rubber transport wheels, a retractable extension handle and multiple fold down carrying handles for better mobility and easier handling.

The metal castings part consists of the sample bucket, topplate for the sample bucket and the impeller as before. The impeller and the topplate are of the same design as for prototype 1 and are constructed out of AISI 304 stainless steel. The items were all designed in SolidWorks.

Three prototypes of the sample buckets were made. Two of which were made of epoxy reinforced gypsum in a 3D printer. The third prototype was casted out of aluminium. For the material selection for the third prototype, three possible materials were examined. Plastic, aluminium or other types of metals. The aluminium was the only realistic option because of the budget for this project because of the lowest construction cost of the molds, but the metal casting parts are made by aluminium sand casting.

Both the sample bucket and the motor cover are casted by sand casting. Sand casting is by far the most widely used casting process, accounting for a significant majority of the total tonnage cast. Nearly all casting alloys can be sand casted, indeed it is one of the few processes that can be used for metals with high melting temperatures, such as steel, nickels and titaniums. It versatility permits the casting of parts ranging in size from small to very large and in production quantities from one to millions [4].

Figure 2: Rheometer-4SCC sample bucket, CAD drawing (a), the final product castedout of aluminium (b), the outside of the mold (c) and the inside of the mold (d)

The sample bucket was casted by Málmsteypan Hella, which is an Icelandic die cast plant which will be in charge of the mass production of the bucket. The material used for the casting is aluminium with about 10 percent of silicon. This compound was select with regard to it's good casting ability and strength. In order to prevent aluminium contamination in the concrete the inside of the sample bucket is coated with rubber lining.

Figure 3: Rheometer-4SCC prototype 2

Conclusion

Two prototypes were constructed during the design process. Prototype 2 was based on test result obtained in the robustness testing of prototype 1. The design of the device was also optimized in during the design and construction of prototype 2. The weight of the control box is 24.3 kg and the weight of any of the accessories of the device that the user has to lift do not exceed 25 kg. This was one of the presumptions in the need analysis of the device. The device is mainly assembled of standardized items but the sample bucket and motor cover are custom built. The device has been tested in the laboratory and at construction sites and these test have been successful. The device is controlled with a Windows based software and the communication between the drive and the computer are via RS-232 serial port. A serial to Bluetooth wireless connection is available as an option. The result of the robustness testing of prototype 2 demonstrated the abilities of the device to be used as an on site quality control tool. The device is easy to handle and control for one person. The possibilities of marketing are good since this is the first lightweight portable rheometer at a manageable weight and price.

The product of the design process of Rheometer-4SCC is a portable, low cost and user friendly device for measuring the rheological properties of self compacting concrete. Rheometer-4SCC will go into production and will be marketed as a portable rheometer for quality control at construction sites and in the laboratory.

References

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