Rheological measurements on building materials

Development of Concrete Rheometers
-
an overview

Dr. Helena Keller
Schleibinger Geräte Teubert u. Greim GmbH
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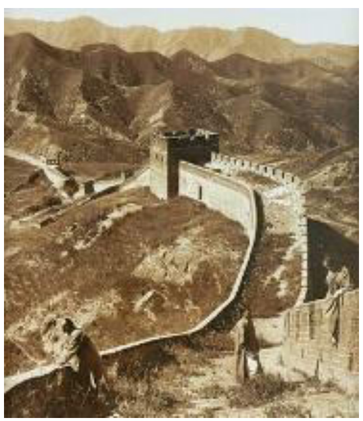
Timeline of concrete and cement history

3000 BC

700 BC

0



3000 BC – Egyptian Pyramids
The Egyptians were using early forms of concrete over 5000 years ago to build pyramids. They mixed mud and straw to form bricks and used gypsum and lime to make mortars.

770 - 476 BC – China´s Great Wall
The northern Chinese used a form of limestone mortar containing of glutinous, sticky rice.

300 BC – 500 AD – Roman Architecture
The Romans used a material that is remarkably close to the modern cement. They also used animal products as an early form of admixtures.

https://www.concretenetwork.com/concrete-history/
www.wikipedia.org

Timeline of concrete and cement history

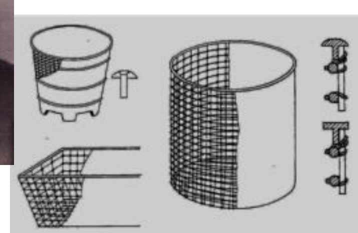
1800


A.D. 1824 . . . . N° 5022.

Artificial Stone.

ASPDIN'S SPECIFICATION.

TO ALL TO WHOM THESE PRESENTS SHALL COME, I, Joseph Aspdin, of Leeds, in the County of York, Bricklayer, send greeting.



1850

1900

1824 – Portland Cement invented
Patent nr. BP 5022, „ An Improvement of the Modes of Producing an Artificial Stone“, Joseph Aspdin, 21 October 1824

1836 – Strength Testing
The first test of tensile and compressive strength took place in Germany.

1845 – first precast concrete parts
Concrete stairs are manufactured in Germany.

1849 – reinforced concrete was born
Joseph Monier, French gardener, copied this principle from nature and reinforced the pots with iron wires („Moniereisen“).

https://www.concretenetwork.com/concrete-history/
www.wikipedia.org / Giatec Scientific

Timeline of concrete and cement history

1850

1900

1920

1850 – start of Portland Cement production in Buxtehude, Germany

1878 – Portland Cement is standardized
Introduction of the standard for Portland Cement by the State of Prussia with a ministerial decree.

1879 – commercial use for reinforced concrete in Germany
Wayss & Freytag greatly contributed to the advancement of Monier´s system of reinforcing and established it as a well-developed scientific technology.

1882 – blast furnace slag for Portland Cement
G. Prüssing added granulated blast furnace slag to the Portland Cement.

1890 – invention of prestressed concrete
German engineer C.F.W. Döhring patented the invention of prestressed concrete. First modern prestressed concrete bridge was built 1948 in West Germany (Kanalhafenbrücke, Heilbronn).

https://www.concretenetwork.com/concrete-history/ www.wikipedia.org / www.beton.org /
D. Bühler, Museum aus gegossenem Stein, Betonbaugeschichte im Deutschen Museum, 2015

Timeline of concrete and cement history

1850

1889 – Alvord Lake Bridge
Was built in San Francisco, CA. This is the first reinforced concrete bridge, and it still exists today.

1891 – concrete street
The first concrete street in America was built in Bellefontaine, Ohio. It still exists today. The concrete used for this street tested at about 8,000 psi, which is about twice the strength of modern concrete used in residential construction.

1900

1903 – concrete buildings
Started with Ingalls Building in Cincinnati, Ohio and first concrete homes in Union, New Jersey in 1908 by Thomas Edison.

1950

https://www.concretenetwork.com/concrete-history/
www.wikipedia.org / www.beton.org /
https://www.atlasobscura.com/places/thomas-edisons-concrete-houses

Timeline of concrete and cement history

1900

1950

1970

1906-1910 – Iron Portland Cement is standardized
National Association of Cement Users (NACU)
„Standard No.1“

1913 – ready mix
The first load of ready mix was delivered in Baltimore, Maryland.

1925 – introduction of DIN 1045 to DIN 1048
Standards Committee of German Industry
(Normenausschuss der Deutschen Industrie (NADI)).

1930 – air entraining agents
were used for the first time in concrete to resist against damage from freezing and thawing.

1938 – Concrete Overlay
John Crossfield add latex to Portland cement, aggregate, and other materials to make a covering for ship desks.

https://www.concretenetwork.com/concrete-history/
www.wikipedia.org / www.beton.org

Timeline of concrete and cement history

1900

1930 – Thin Shell Technique
Development of new way of building with reinforced concrete (e.g. Eduardo Torroja, Pier Luigi Nervi, Felix Candela…)

1954 – ready-mixed concrete plants
First in the USA and from 1954 in Europe, thousands of ready-mixed concrete plants were built, which consumed around 50 % of the total cement production.

1950

1950´s – additive industry starts to grow

…

1970

https://www.concretenetwork.com/concrete-history/
www.wikipedia.org

Timeline of concrete and cement history - workability

1800

compacting by tamping (Stampfbeton)
(now: stamped concrete, roller compacted concrete)

1926

1926 – vibrating concrete
Development of internal vibrators for concrete

1962

1962 – flowable concrete
Development of BNS (Kao Soap, Japan) and
PMS (SKW, DE) plasticizers

1980

1980 – plasticized concrete
Development of PCE´s (superplasticizers)
Now: SCC, HPC, UHPC, 3D-concrete printing …

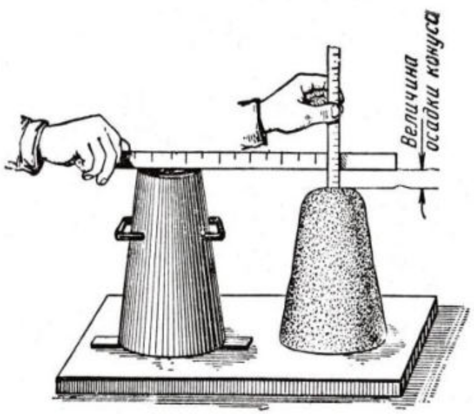
2000

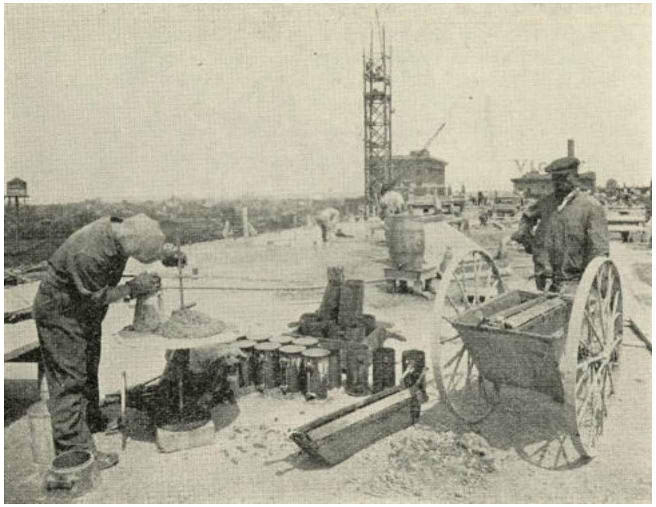
Timeline of concrete and cement history - testing

1900

1950

1970





1918 - Duff Abrams, Concrete Slump Test

„I believe that the big thing [the slump] test can do is to bring home the importance of water control in building construction“

- Showed that the strength of concrete is directly related to water-to-cement ratio
- Suggested determining a „relative consistency“ term calculated by measuring the slump test.

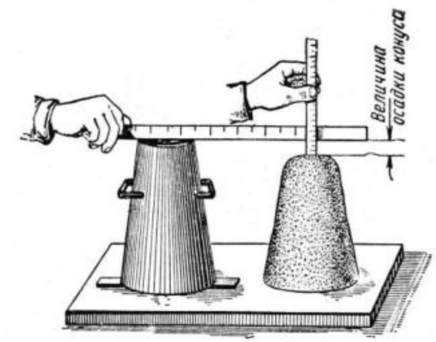
1924 – Slump Flow Test

Ahlers J.G., Walker S. „Field Tests of Concrete“, Proceedings of the Twentieth Annual Convention of the American Concrete Institute, 20, 1924.

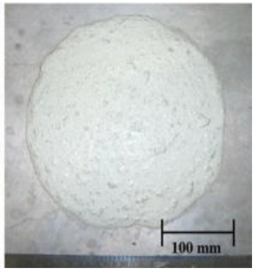
Abrams D.A. „Proportioning Concrete Mixtrues“, Proceedings of the American Concrete Institute, Detroit, MI, 1922
Ahlers J.G., Walker S. „Field Tests of Concrete“, Proceedings of the Twentieth Annual Convention of the American Concrete Institute, 20, 1924.

Concrete testing methods – 1920 - 2021

1900



1926



1962

1980

2021

1918 - Concrete slump test (ASTM C143, EN 12350-2)

1920 - Slump flow test

1930´s - flow table test (DIN 1048, EN 12350-5)

1990´s:

- ✓ Vebe consistometer (EN 12350-3)
- ✓ V-funnel test (EN 12350-9)
- ✓ L-Box test (EN 12350-10)

Timeline of concrete and cement history - rheology

1900

Eugene C. Bingham

1878 Cornwall, VT, USA
† 1945 Easton, PA, USA

Markus Reiner

* 1886 Czernowitz, Austria
✡ 1976 Haifa, Israel

1950

1970

ῥεῶ : rheo - I flow
λόγος : logos - word, science

1928 – from E.C. Bingham to M. Reiner, letter excerpt:
„ Here you, a civil engineer, and I, a chemist, are working together at joint problems. With the development of colloid chemistry, such a situation will be more and more common. We therefore must establish a branch of physics, where such problems will be dealt with.“

- **1929: Rheology … means… the study of the deformation and flow of matter….**

„An Introduction to Rheology“, Howard A. Barnes, John Fletcher Hutton, Kenneth Walters, Elsevier, 1989

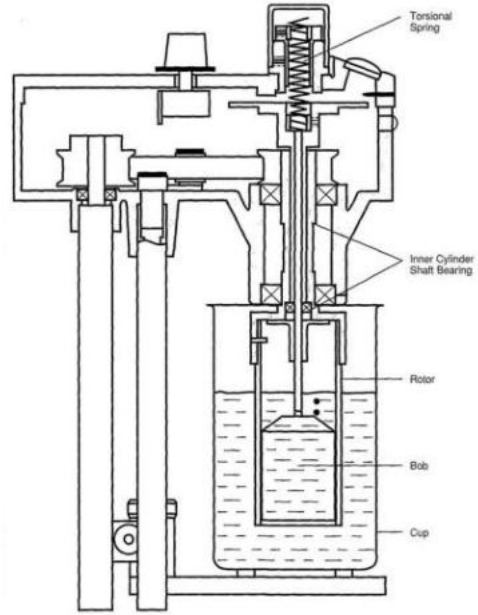
for Newtonian fluids

http://universaldomainexchange.com/whoswho/eugene-cook-bingham/ Physic Today – September 1976
„Rheologie“. In: Wikipedia, Die freie Enzyklopädie. Bearbeitungsstand: 5. Dezember 2017, 21:04 UTC. URL: https://de.wikipedia.org/w/index.php?title=Rheologie&oldid=171708014 (Abgerufen: 25. Februar 2018, 10:53 UTC)

Testing methods – development of concrete rheometers

1950

2021



1950´s – coaxial cylinder viscometer
basics for the characterisation the rheological properties of cement slurries and other oilfield fluids:

- ✓ drilling fluids (muds)
- ✓ spacers
- ✓ fracturing fluids

- ➢ FANN 35 Viscometer, FANN Instruments (API 13D, ISO 10414)
- ➢ Brookfield BF35 Viscometer, Brookfield
- ➢ Anton Paar rheometer
- ➢ 8-speed viscometer, MUDTEST a Leutert company, DE
- ➢ NXNQ Rotational Viscometer, Tianjin Nithons Technology CO,. Ltd., China

J.G. Savins, W.F. Roper, A direct-indicating viscometer for drilling fluids, American Petroleum Institute, API 54-007, 1954

Testing methods – development of concrete rheometers

1950

1962

1980

2000

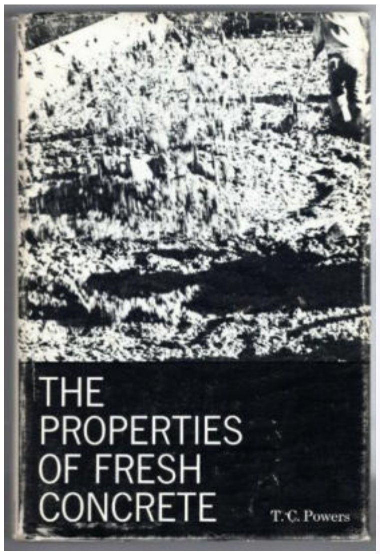
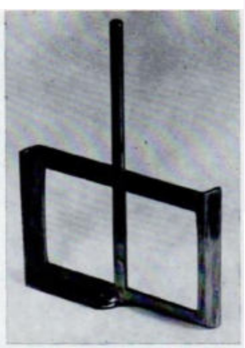


Bild 8. Speziell entwickeltes Meßpaddel für die Messung der Zementleimviskositäten mit dem VISCO-CORDER

Fig. 8. Specially developed measuring paddle for measuring cement paste viscosities by means of VISCO-CORDER

Fig. 8. Pale de mesure spécialement developpée pour la mesure des viscosités de pâtes de ciment moyennant le VISCO-CORDER



1970´s – basics for the development of modern rheometers for suspensions

The beginning of the development of the theory of flowability of cement based mixtures –
Non-Newtonian fluids.

1968 – Powers T.C. „Properties of Fresh Concrete“, New York, John Wiley & Sons.

1969 – Teubert J. „Determination of water/cement ratio as a function of cement, as an index for exposed concrete“, Betonstein-Ztg. 35, 1969:

Ermittlung eines zementabhängigen Grenzwasserzementwertes als Kenngröße für Sichtbeton

Determination of water/cement ratio as a function of cement, as an index for exposed concrete
Détermination d'un rapport limite eau/ciment, en fonction du ciment, comme indice pour béton exposé

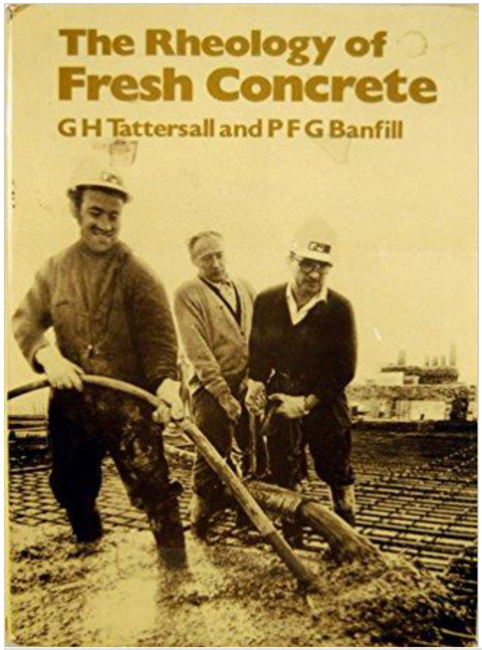
VON DIPL.-GEOL. JÜRGEN TEUBERT, POING

1969 – Visco Corder ® Brabender, Duisburg, Germany

Rheometer for mortar and paste

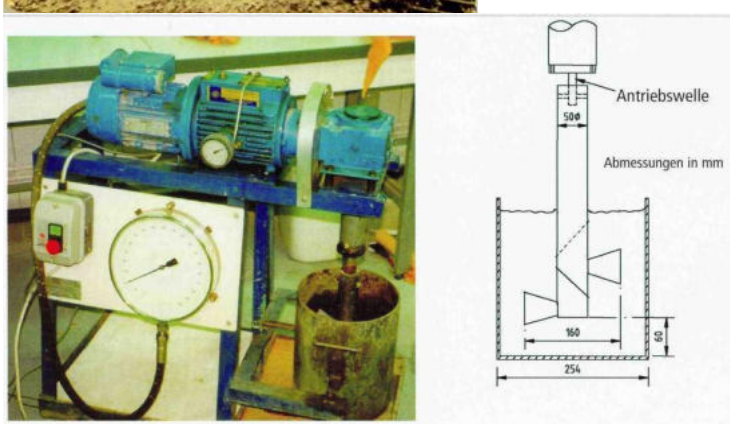
Testing methods – development of concrete rheometers

1980



1983 – Tattersall G.H., Banfill P.F.G. „The Rheology of Fresh Concrete“, Marshfield, MA. Pitman Publishing

- Classifies the workability of concrete: Class-I, Class-II and Class-III..
- Tattersall, splits up the workability test as single-point (slump test) and multi-point tests based on flow curve relating shear stress and shear rate.
- Single point tests are incapable for determining the parameter of fresh concrete.
- Multiple tests needed to describe different aspects of workability
- Two concretes with same slump may flow differently and have different workability. Workability is closely related to flow properties.
  - Yield stress is related to the force required breaking down structure and initiating the flow
  - Plastic viscosity describes the resistance to flow ones the concrete is flowing



. Das Zweipunkt-Rheometer mit dem unterbrochenen spiralförmigen Messpaddel, das bei Hochleistungsbetonen erwendet wird

1983 – Tattersall two-point rheometer (Mk-I)
by Tattersall, UK

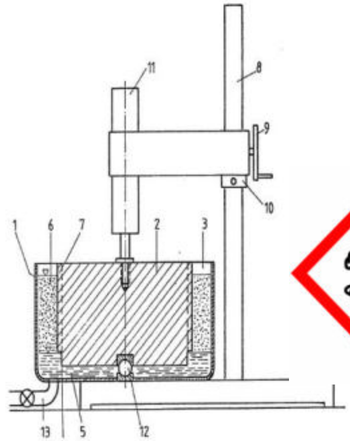
- Rheometer for coarse-grained mixtures such as concrete;
- torque is measured.

2000

Testing methods – development of concrete rheometers

1980

2018



1985 – Rotational viscometer
Patent No. DE 3423579, Nukem GmbH, Hannau, Germany
Rheometer for coarse-grained mixtures such as concrete based on sealing fluid with high density such as mercury or tetrabromoethane.

1987 - BML viscometer, (since 1992 ConTec viscometer)
Dr. Wallevik O.H., Iceland

- based on the Power and Wiler plastometer and the Tattersall two-point device.
- Inner cylinder measures torque as the outer cylinder rotates at variable angular velocity.
- Fully automated and are controlled by computer software (FreshWin).

http://www.contec.is/page11.htm
R. Zerbino et al, Workability tests and rheological parameters in self-compacting concrete, Mater. Struct. 42(7) 2009

Testing methods – development of concrete rheometers

1990

1989 - Viskomat PC
Schleibinger Geräte GmbH
- ➢ Rheometer for mortar and paste

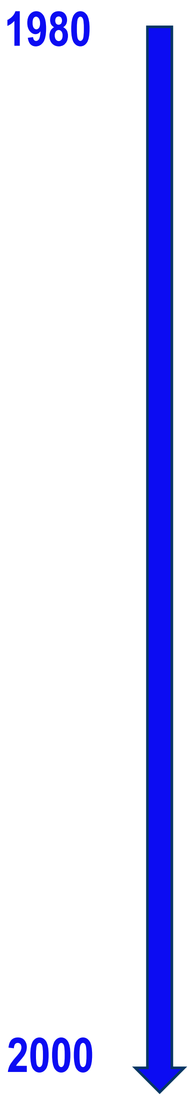
2000

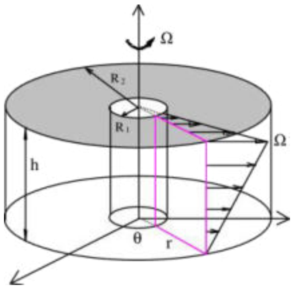
1998 - Viskomat NT
Schleibinger Geräte GmbH, Germany
- ➢ Velocity controlled 0.001-400 rpm
- ➢ Torque 0 – 500 Nmm
- ➢ Shear stress controlled
- ➢ Oscillation mode
- ➢ Different probes geometries
- ➢ Max. particle size up to 4 mm

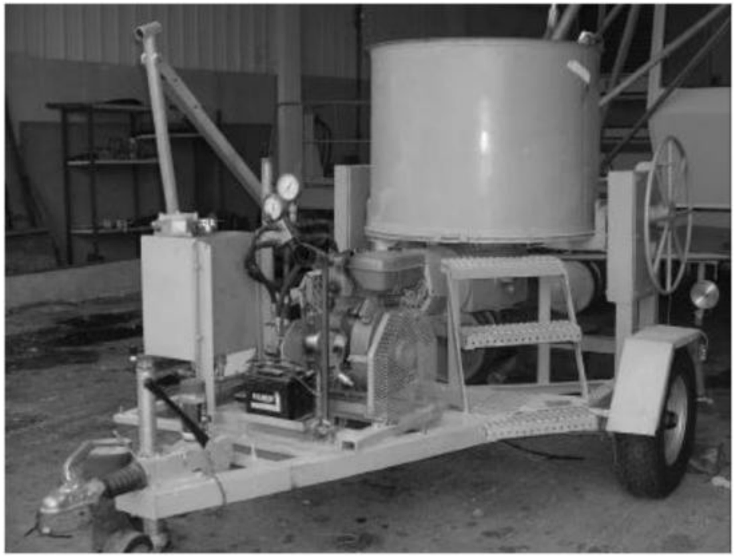
2021

J. Golaszewski, Influence of viscosity enhancing agent on properties of mortars with different cements and superplasticizers.

Testing methods – development of concrete rheometers







1989 – BTRheom parallel plate rheometer
Larrard et al., Laboratoire des Ponts et Chaussées (LCPC), París, France (since 2011 - IFSTTAR).

- It requires about 7 L of concrete that has at least 100 mm of slump.
- The rotation speed range is 0.1 rev/s to 1 rev/s.
- The maximum measurable torque is about 14 Nm.

1993 – CEMAGREF-IMG coaxial rheometer
by Coussot, PhD thesis, National Institite of Grenoble, France.

- originally developed for study of mud flow rheology
- The inner cylinder is rotated and the torque induced by the concrete on the inner cylinder is measured.
- approx. 500 L of concrete are needed.

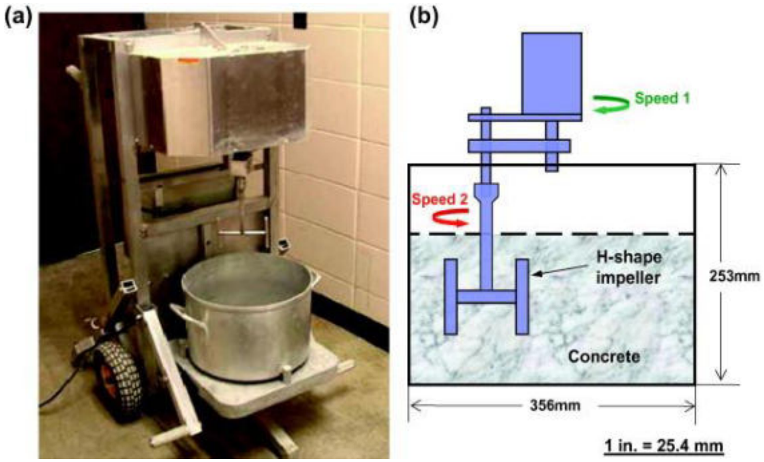
C.F. Ferraris, N.S. Martys, Understanding the Rheology of Concrete, 2012

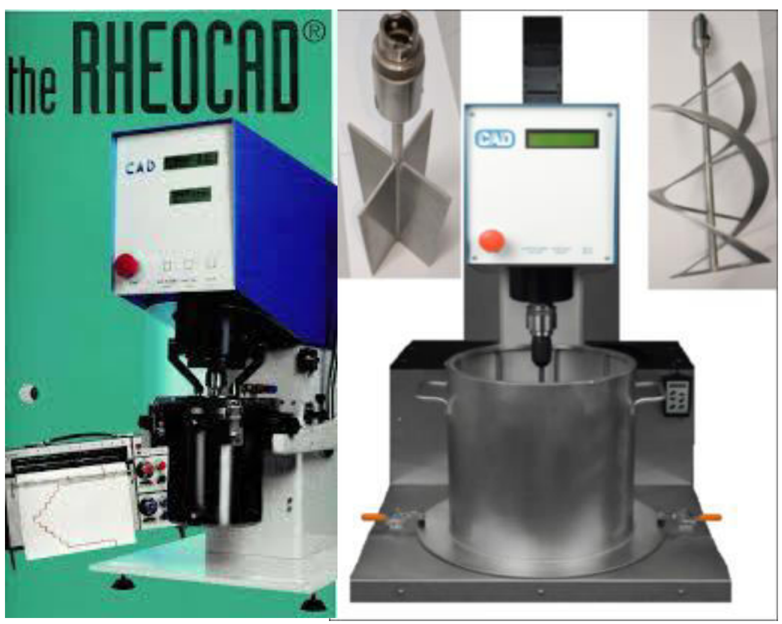
Testing methods – development of concrete rheometers

1990

2000

2021





1994 – IBB rheometer

by Beaupre & Mindness, Canada

- Modification of the Tattersall two-point device (MKIII).
- Originally developed to measure the rheology of wet-mix shotcrete, also used on a wide range of concretes (20mm to SCC)
- Fully automated and uses a data acquisition system to drive an impeller rotating in fresh concrete.
- The yield stress and plastic viscosity are displayed on the screen.
- H-shaped impeller

1997 – RheoCad rheometer

CAD Instruments, France

- Torque measurement in response to controlled rotation 0-250 rpm
- Sample volume 11 – 37 L
- Torque meter max. 10 Nm
- Weight approx. 95 kg.

J. Hu, K. Wang, Effect of coarse aggregate characteristics on concrete rheology, Constr. Build. Mater, 25, 2011, pp. 1196-1204.

Testing methods – development of concrete rheometers

1990

2000

2021

1994 – mobile rheometer BT
Schleibinger Geräte GmbH, Germany
Patent no. 195 03 028 „Verfahren zum Messen des Fließverhaltens grobkörniger Stoffgemenge“

further development:

- ✓ **BT2**
- ✓ **eBT2**
- ✓ **since 2016 - eBT-V**

- ➢ 15 L to 40 L vessel
- ➢ for aggregate particles up to 32 mm
- ➢ Max. torque 10 Nm
- ➢ Max. speed 40 °/s or 40 rpm
- ➢ Two different measurement modes
- ➢ for zero slump concrete to SCC
- ➢ Device weight approx. 15 kg

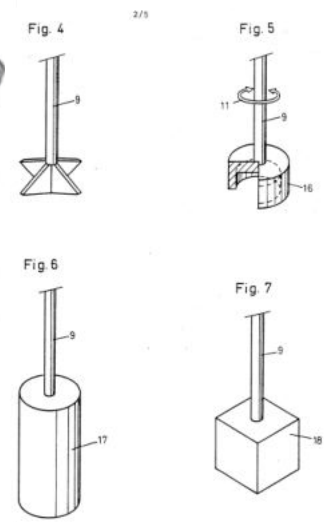
T. Ponikiewski, J. Golaszewski, The new approach to the study of random distribution of fibres in high performance self-compacting concrete, Cement, Wapno, Beton, 79 (3), 2012

Testing methods – development of concrete rheometers

1990

2000

2021



1993-2011 – FCT-101, Ruedi Enzler, ETH Zürich
Atrof Bauphysik AG

test apparatus for freshly mixed concrete

- electrically operated
- torque determination at certain speed.
- single-point measurement
- slump between 35 and 180 mm

2004 – ICAR (Plus) mobile rheometer
Koehler E.P., Fowler D.W., University of Texas at Austin, Austin, TX
German Instruments.

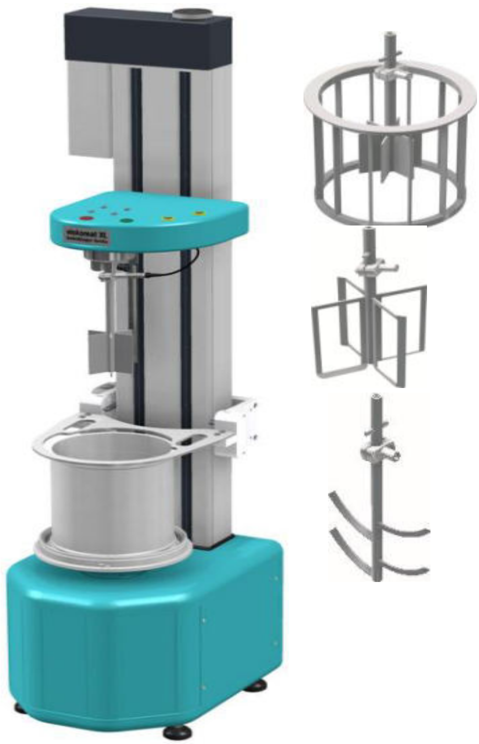
- maximum particle size 32 mm
- vane rotation speed: 0.06 to 40 rpm
- max. torque 32 Nm

https://www.atrof.ch/?Rpage=fct101d/?Rpage=
http://germann.org/products-by-application/rheology-of-concrete/icar-rheometer

Testing methods – development of concrete rheometers

2000

2021



2009 - Viskomat XL, Schleibinger Geräte GmbH
- 3L vessel for aggregate particles up to 16 mm
- speed 0 – 80 rpm
- max. torque 10 Nm
- shear stress controlled mode
- oscillation mode
- different probes available

2014 – Sliper – Sliding Pipe Rheometer,
Schleibinger Geräte GmbH / Putzmeister
- determining the pumpability
- Sample volume approx. 7 l
- for lab and construction site

Testing methods – development of concrete rheometers

2000

2007 – 4C-Rheometer, Danish Technological Institute, Taastrup

- Based on slump flow test
- Numerical simulation of slump flow
- Rheological parameters are determined by analysis of the spread vs. time curve.

→ elimination of shear induced particle migration for measurements:

2005 – Mixer with sequence automation and process data control

Eirich, Germany

- mixer incl. rheometric tools
- sample volume 40 L, 75 L or 150 L.

https://www.dti.dk/4c-rheometer-8211-measuring-rheology-of-self-compacting-concrete/the-equipment/21743
https://www.eirich.com/en/meta/news/news-detail/consistency-measurements-in-eirich-production-mixers-and-rheological-measurements-in-laboratory-mix/

2021

Testing methods – development of concrete rheometers

2000

2021

2008 – Laboratory Mixer KKM-RT 15, 22,5
Kniele, Germany

- Mixer incl. rheometric tools
- Sample volume 15 L
- Weight approx. 1 t.

2016 – Pheso rheometer, Calmetrix, MA, USA

- Planetary movement and attritor shaped impeller for continuous mixing
- 5L, 25 L vessel for aggregate particles up to 25 mm
- Max. torque up to 147 Nm
- Weight approx. 130 kg

https://www.kniele.de/en/mixing-systems/laboratory-mixer-kkm-rt
https://www.calmetrix.com/rheometers

Testing methods – development of concrete rheometers

1980 – plasticized concrete

1962 – flowable concrete

1960 1980 2000 2021

Rheometers from Schleibinger

1989

2021

One company – different testing solutions for different kind of applications

Thank you for your attention!

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