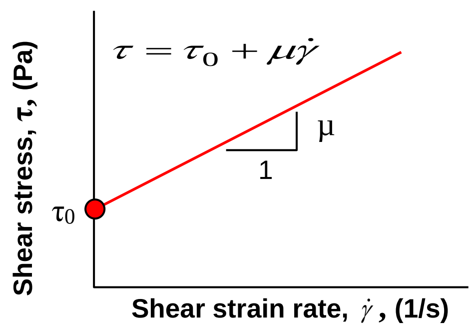
ICAR Plus

Purpose

The **ICAR Plus Rheometer** is a rugged, portable instrument for measuring fundamental flow (rheological) properties of fresh concrete. The instrument was developed at the International Center for Aggregate Research (ICAR) located at The University of Texas at Austin to fill the need for a method to characterize the true flow behavior of concrete mixtures. The traditional methods of measuring slump or slump flow are not capable of characterizing the fundamental rheological properties of concrete that exist during the processes of mixing, transporting, and placement. As a result, the true performance of innovative concrete mixtures cannot be measured with these traditional methods. The **ICAR Plus** appears as a low-cost and simple to operate instrument that can be used for:

- Research and development to characterize the influence of new materials on concrete rheology
- Optimizing mixture proportions so that the resulting concrete flows readily but is resistant to segregation (especially important for self-consolidating concrete or pumped concrete)
- On-site quality control of mixtures

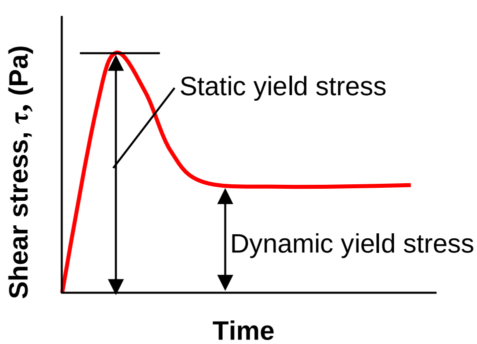
Principle



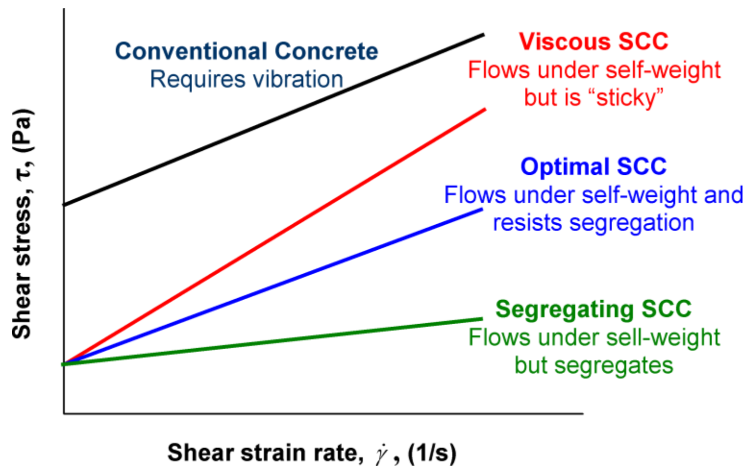
Fresh concrete can be considered as a fluid, which means that it will flow under the action of shear stresses. The flow behavior of concrete can be represented by the following two-parameter relationship:

$$\tau = \tau_o + \mu\,\dot{\gamma}$$

which is known as the **Bingham model**: The parameter τ_o is the **yield stress** and represents the shear stress required to initiate flow. The slope of the line is the **plastic viscosity**, **μ**, and it affects the resistance to flow after the yield stress has been surpassed. These two parameters, which define the **flow curve**, provide a complete description of the flow behavior of a fluid.



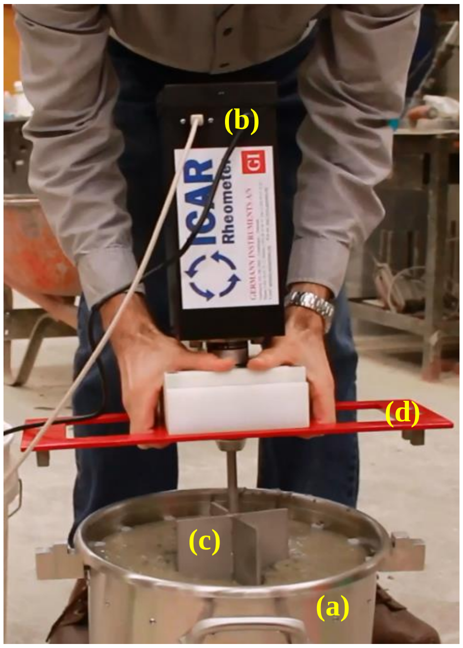
Concrete, however, is not a simple fluid because it displays **thixotropic** behavior, which means that the shear stress required to initiate flow is high if the concrete has been in an "at rest" condition, but a lower shear stress is needed to maintain flow once it has begun. This type of behavior is summarized in the schematic plot shown to the left, which shows the variation in shear stress with time for the case of a **low** applied shear strain rate. At the start, the shear stress increases gradually with time but there is no flow. When the stress reaches the **static yield stress**, the concrete begins to flow and the stress required to maintain flow is reduced to the **dynamic yield stress**. If the applied shear strain rate is reduced to zero and the concrete is allowed to rest, inter-particle forces create a weak framework that restores the static yield stress. With time, the static and dynamic yield stresses increase as the effectiveness of water-reducing admixtures diminish and hydration proceeds, which is commonly referred to as "slump loss."



The **ICAR Plus** is designed to characterize the **static yield stress**, the **dynamic yield stress** and **plastic viscosity** of the concrete. A high static yield stress is desirable because it reduces formwork pressure and increases the resistance to segregation. But for ease of pumping, placement, and self-consolidation, a low dynamic yield stress is necessary. The dynamic viscosity provides cohesiveness and contributes to reducing segregation when concrete is flowing. The schematic plot to the right shows dynamic flow curves for conventional concrete and different types of self-consolidating concrete (SCC) mixtures. The conventional concrete has a high dynamic yield stress and additional energy (vibration) is needed to consolidate the concrete after it is placed in forms. The self-consolidating mixtures all have low dynamic yield stress and will consolidate due to self-weight, but they have different rheological properties. The SCC with a high plastic viscosity (red line) will be sticky and difficult to place and strike off. On the other hand, the mixture with low plastic viscosity (green line) will be prone to segregation. Thus by determining the dynamic flow curves of concretes with different mixture proportions and type of admixtures, and optimum balance between ease of flow and resistance to segregation can be realized. These types of determinations cannot be done using conventional slump-based tests.

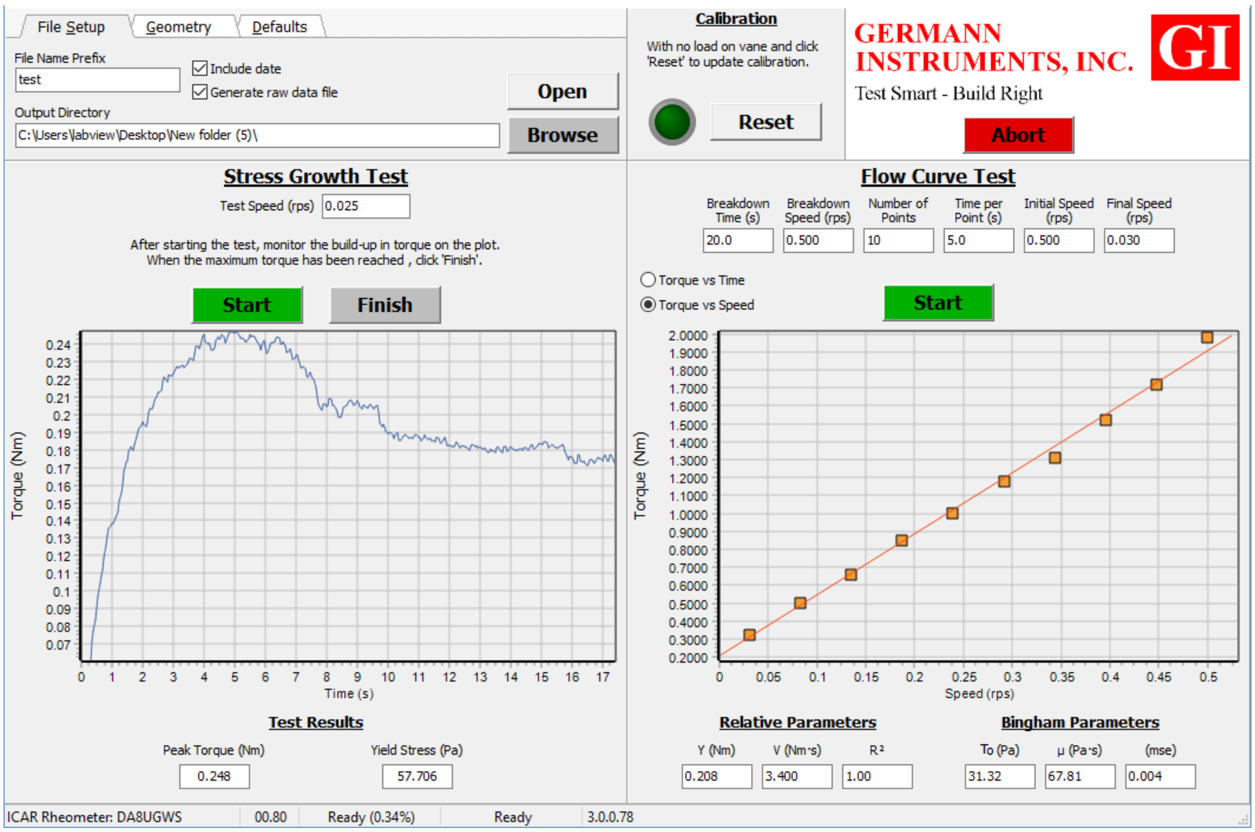
Method of Operation

The **ICAR Plus Rheometer** is composed of a container (a) to hold the fresh concrete, a driver head (b) that includes an electric motor and torque meter; a four-blade vane (c) that is held by the chuck on the driver; a frame (d) to attach the driver/vane assembly to the top of the container; and a laptop computer to operate the driver, record the torque during the test, and calculate the flow curve parameters. The container contains a series of vertical rods around the perimeter to prevent slipping of the concrete along the container wall during the test. The size of the container and length of the vane shaft are selected based on the nominal maximum size of the aggregate. The vane diameter and height are both 127 mm. A multiple blade **"Carrousel"** vane (e) is also available to be used with a container for maximum aggregate size of 13 mm (f). This vane generates a more uniform flow velocity profile and provides more accurate and stable measurements for flow curve tests on materials like high flow self-consolidating concrete (e.g. slump flow > 600 mm), flowable mortars or grouts (e.g. self-leveling), mortars for 3D printing, etc.



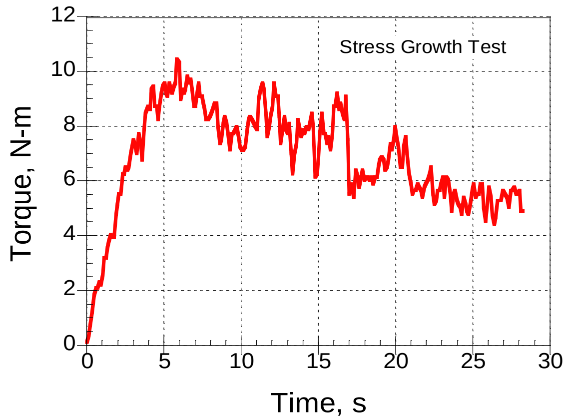
Two types of tests are performed. The first type is a **stress growth test** in which the vane rotates at a constant slow speed of 0.025 rev/s. The initial increase of torque is measured as a function of time. The maximum torque measured during this test is used to calculate the **static yield stress**. The second type is a **flow curve test** to determine the **dynamic yield stress** and the **plastic viscosity**. The flow curve test begins with a "breakdown" period in which the vane is rotated at maximum speed to breakdown any thixotropic structure that may exist and to provide a consistent shearing history before measuring the Bingham parameters. The vane speed is then decreased in a specified number of steps, which is selected by the user but at least six steps are recommended. During each step, the vane speed is held constant and the average speed and torque are recorded. The plot of torque versus speed of vane rotation defines the **flow curve** from which the Bingham parameters are calculated. The equipment also allows to set the steps of speeds in ascending order if required, such as for thixotropy measurements.

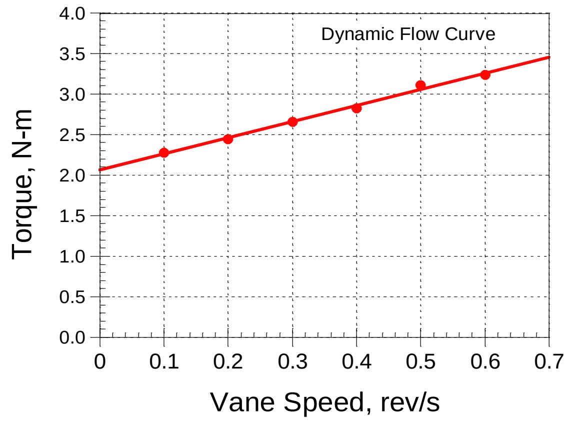
The **ICAR software** operates and calibrates the driver, records the torque, computes test results, and stores data. The entire testing is controlled from a single screen as shown below. A simple press of the "Start" button initiates the stress growth test or the flow curve test. Both tests are completed within 1 minute. The automatic digital calibration allows users to always have a ready to use system. After calibration, the uncertainty torque measurement value is displayed, which is typically less than 0.5%.



Example Results

The next figure on the left shows the results of a stress growth test. The program uses the peak torque and test geometry to calculate the static yield stress, which is displayed at the bottom of the computer display. The figure on the right shows the average torque versus average vane rotation measured during six steps of the flow curve test. The software computes a best-fit line to the data and reports the intercept and slope as relative parameters. Based on the test geometry, the software computes the Bingham parameters: dynamic yield stress and plastic viscosity.





ICAR Plus Features and Specifications

- Minimum slump: The concrete has to have a slump greater than 75 mm, otherwise, the concrete is too stiff for being tested
- Nominal maximum size of aggregate (NMSA): up to 32 mm for the largest available container
- Vane rotation speed: 0.001 to 0.667 rev/s
- Motor type: Integrated Servo Motor
- Minimum Torque: 0.01 Nm
- Peak Torque: 90 Nm for not more than 2 seconds
- Continuous Maximum Torque: 32 Nm
- Power Supply: Input of 100-240 VAC – 3.5A.
- Output of 48V - 6.7A.
- Digital Calibration can be performed by at any time
- Performs static stress growth and dynamic flow curve tests
- Software computes static yield stress, dynamic yield stress, and plastic viscosity in fundamental units
- Test time: ≈ 1 minute
- Computer requirements: Windows 7 or higher. Processor Intel I3 or higher
- Motor drive dimensions: 11 x 11 x 43 cm
- Motor console weight: 7.5 kg
- Carrying Case dimensions: 67 x 52 x 28 cm
- Carrying Case weight: 20 kg, including motor drive, base frame, vane, power supply and cables

RHM-4000 ICAR Plus Kit. Ordering Numbers

Item	Order #
Motor drive/torque meter unit	RHM-4001
Power cord for motor drive unit	RHM-4002
Base frame	RHM-3003
Container for max. 19 mm NMSA *	RHM-3005
Four-blade vane for 19 mm NMSA *	RHM-3009
Container for max. 13 mm NMSA	RHM-3004
Carrousel vane for 13 mm NMSA	RHM-3020

Item	Order #
USB cable	RHM-3012
Laptop computer with software	RHM-4013
Software on CD-ROM	RHM-4014
User manual	RHM-4015
Carrying case for laptop computer	RHM-4016
Carrying case for Rheometer	RHM-4017

The RHM-4000 ICAR Plus Kit

Available containers and vanes for different NMSA

	Nominal Maximum Size of Aggregate (NMSA)			
	13 mm	**19 mm**	**25 mm**	**32 mm**
Container	RHM-3004	RHM-3005*	RHM-3006	RHM-3007
Four-blade vane	RHM-3008	RHM-3009*	RHM-3010	RHM-3011
Carrousel vane	RHM-3020			

*Default size supplied along with the RM-4000 ICAR Plus Kit if another size is not specified.

Optional Items

Item	Order #
30,000 centistokes silicone oil for verification of instrument (25 L or 19 L pail)	RHM-3018