HYDROGEN AND FUEL CELL LABORATORY

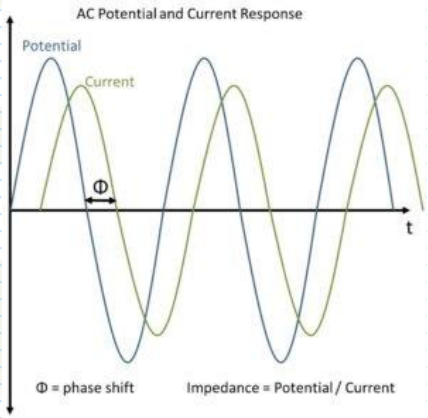
Analytical and non-analytical instruments

ANALYTICAL INSTRUMENTS

Device: Frequency response analyzer

Introduction

A Frequency Response Analyzer (FRA) is a high precision measurement instrument used to analyze components, circuits and systems (known as devices under test, or DUT's) in the frequency domain. This device generates a signal with a certain frequency and a certain amplitude. The response of the system to this signal is also a periodic signal. The FRA measures both amplitudes and the phase shift (the time difference between the transmitted and received signal). This measurement is repeated at different frequencies. In a graph the researcher can see how the different frequencies influence a certain system. This information is useful, for example, when testing batteries or coatings. At low frequencies only slow changes will occur; chemical processes are responsible for the major contribution. At high frequencies, physical properties will influence the signal.



AC potential-current response of a hypothetical system

Device: Impedance/Gain-phase analyzer

Manufacturer: *SOLARTRON ANALYTICAL*

This lab is equipped with a frequency response analyzer with the following specifications.

Technical specifications

Frequency range	**10 µHz to 32 MHz**
Frequency resolution	**1 in 65million (0.015ppm)**
Measures impedances	**>100Mohms**
Polarization voltage	**±40.95V**

*** 0.1%, 0.1° accuracy.**

*** Resolution to 0.001dB, 0.01°**

*** 2-, 3- and 4-terminal measurement configurations**

*** Automatically sweeps frequency, amplitude or bias**

*** Null, normalize and auto-impedance modes**

*** Gain, phase, group delay and impedance measurements**

*** Built in statistical analysis**

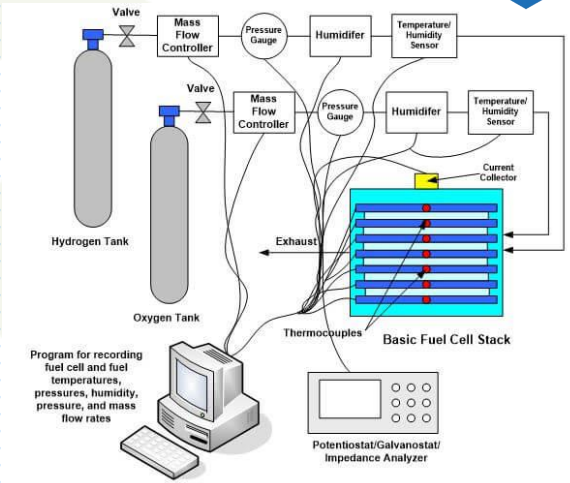
*** Displays a,b,r,q,t,Z,R,X,Y,G,B,L,C,Q,D,D%**

*** Operates standalone or within a computer-controlled system**

Device: Potentiostat / Galvanostat

Introduction

A potentiostat / galvanostat (sometimes called an electrochemical workstation) is an instrument that manages the application of voltage or current to an electrochemical cell electrode. The potentiostat is the main measurement tool used in electrochemical and electroanalytical experiments. Potentiostats are vital measurement and control tools used primarily in electrochemical research, as well as in other industrial fields. In electrochemistry, potentiostats are used in both fundamental and applied research to understand electrode processes, analytical chemistry, battery research, and corrosion research. Secondary applications include chemical synthesis and biology. Potentiostats are used to keep the potential (voltage) between a working electrode and a reference electrode at a constant value. Galvanostats are used to maintain a constant flow of current through an electrolytic cell.



Role of Potentiostat / Galvanostat in fuel cell testing

Device: Potentiostat / Galvanostat

Manufacturer: *SOLARTRON ANALYTICAL*

This lab is equipped with a potentiostat / galvanostat with the following specifications.

Technical specifications

Current measurement resistor range	**0.1 Ω to 1 MΩ**
Frequency resolution	**1 in 65million (0.015ppm)**
Maximum resolution	**1 µV/ 1 pA**
Operating temp. range	**0-50 °C**
Voltage	**Range: ±14.5 V**
	Limit of error: 0.2%±10 mV
	Resolution: 5 mV
Current	**Ranges (full scale): 200 nA to 2 A**
	Limit of error: 0.2%±1% of range
	Resolution: 1% of range
Power	**14.5 V / 2A**

*** 2-, 3- and 4-terminal cell connections, all floating**

Device: Precision lab balance

Manufacturer: *KERN*

Technical specifications

Accuracy	**0.0001 g**
Weighting capacity	**250 g**

Device: Multimeter

Manufacturer: *AGILENT / 34401A*

Technical specifications

Resolution	**6½ digit**
Measurement functions	**DC/AC voltage, DC/AC current, 2- and 4-wire resistance, diode, continuity, frequency, period**
Basic accuracy	**0.0035% DC, 0.06% AC**
max voltage input	**1000 V**
max current input	**3 A**

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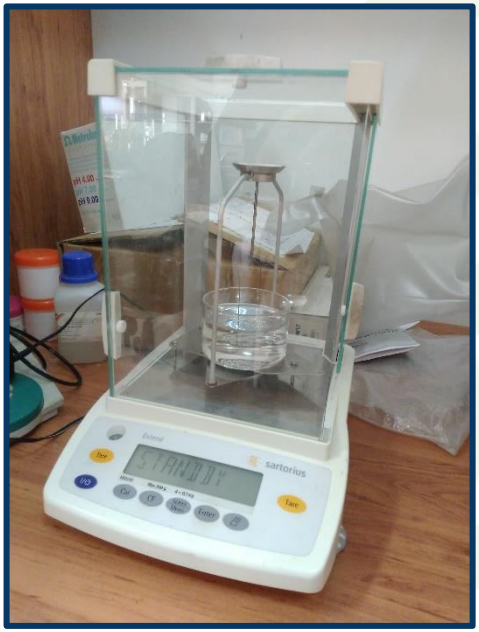
Device: Precision lab balance

Manufacturer: ***SARTORIUS ED224S***



Density measurement kit

Technical specifications

Readability	**0.0001 g**
Weighting capacity	**220 g**
Repeatability	**0.0001 g**

*** Equipped with a density measurement kit by the Archimedes method**

Device: Multimeter

Manufacturer: *MEGATEK / MT-1941*

Technical specifications

Test parameters	**DCV, ACV, DCI, ACI, Ω2W, Ω4W, FREQ, PERI, CONT, diode**
Direct voltage	
range	**200 mV-1000 V**
minimum resolution	**10 µV**
accuracy	**0.03%+0.02%**

Technical specifications (cont.)

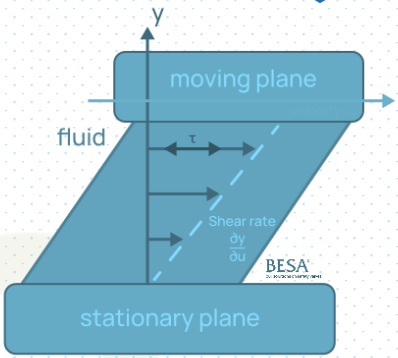
Direct current	
range	**2 mA-20 A**
minimum resolution	**100 nA**
accuracy	**0.08%+0.02%**
Alternative voltage	
range	**200 mV-750 V**
accuracy	**0.4%+0.05%**
Alternative current	
range	**2 mA-20 A**
accuracy	**0.5%+0.12%**
frequency width	**20 Hz-20 kHz**
Resistance	
test current	**45 nA-0.5 mA**
accuracy	**0.1%+0.01%**
Frequency	
range	**5 Hz-200 kHz**
voltage sensitivity	**200 mVrms**
minimum resolution	**0.01 Hz**
accuracy	**0.01%+0.008%**

Device: Viscometer

Introduction

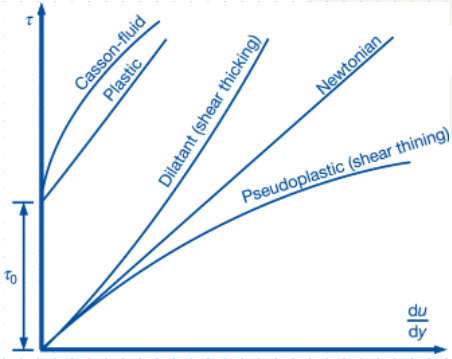
In simplest terms, viscosity is defined as “the resistance to flow” and is often referred to as the thickness of a fluid. When a shear force is acted upon a constrained film of a liquid, a velocity distribution would be developed as shown. Newton first considered this problem and assumed that a following relation to be exist between the applied shear stress and the developed velocity distribution:

$$\tau = \eta \, {}^{\partial v}/_{\partial y}$$



Developed velocity gradient in a fluid subjected to shear stress

Where τ is the applied shear stress, η is the viscosity, v is the velocity in the direction of the applied shear stress, and y is the distance perpendicular to the applied shear.



Viscosity, itself, may be a function of the applied shear rate, therefore it is of scientific and practical importance that the apparatus used for measuring the viscosity of the desired fluid, allows the measurement to be made under various shear rates.

$\tau - du/dy$ curves corresponding to different materials indicating the ways by which viscosity may be affected by the shear rate

Device: Viscometer

Manufacturer: ***FUNGILAB - ALPHA SERIES***

This lab is equipped with a viscometer with the following specifications.

Technical specifications

Precision	**± 1% of full scale**
Resolution	**Using low viscosity adapter: 0.01**
	For lower than 10.000 viscosity cP: 0.1
	For viscosity equal to or above 10.000 cP: 1
Repeatability	**0.2%**
Rotation speed	**0.3-100 (18 steps)**
Measuring range (cP)	**20-2000000**

NON-ANALYTICAL INSTRUMENTS

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Device: Vacuum pump

Manufacturer: *VALVE / VE 135N*

Technical specifications

Flow rate		
	50 Hz	**100 l/min**
	60 Hz	**114 l/min**
Ultimate vacuum		
	Partial pressure	**2 Pa**
	Total pressure	**150 micron**
Oil capacity		**310 ml**

Device: Ultrasonic bath

Manufacturer: *BACKER / VCLEAN1-L4*

Technical specifications

Power	100 W
Frequency	40 kHz
Temperature	**0-80 °C**
Power control	**50% and 100%**
Dimensions (cm)	**28 × 17 × 24**

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Device: Digital oven

Manufacturer: *PARSIAN TEB*

Technical specifications

Maximum temperature	**200 °C**
Minimum temperature	**ambient temperature**
Temperature accuracy	**±2 °C**
Capacity	**55 l**
Number of trays	**2**

Device: Digital oven

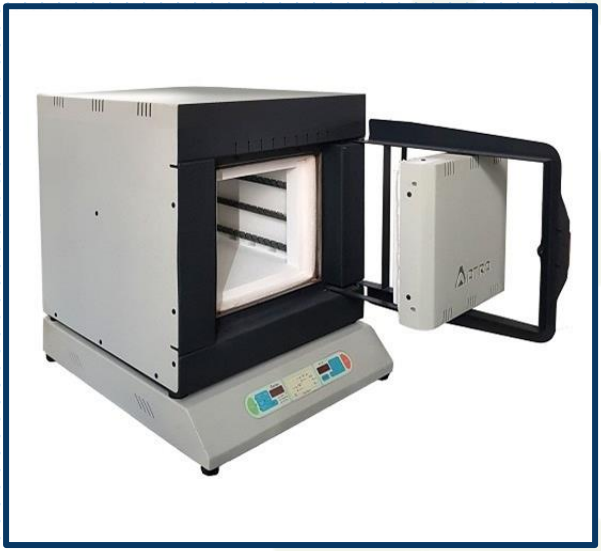
Manufacturer: *MEMERT*

Technical specifications

Maximum temperature	*** °C**
Temperature accuracy	*** °C**

Device: Electrical furnace

Manufacturer: *ATRA / AFE1200L-8DH*



Technical specifications

Max temperature	**1200 °C**
Temperature accuracy	**± 5 °C**
Inner dimensions (mm)	**160 × 200 ×250**

*** PID controller with special features programmable of PC series**

Device: Horizontal tube furnace

Manufacturer: *ATRA / ATE1100L-50H30S*

Technical specifications

Maximum temperature	**1100 °C**
Temperature accuracy	**± 5 °C**
Heating zone size	**L=30 cm & D=5 cm**

*** PID controller with special features programmable of PC series**

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Device: Vertical tube furnace

Manufacturer: *ATRA / ATE1100L-50V30S*

Technical specifications

Maximum temperature	**1100 °C**
Temperature accuracy	**± 5 °C**
Heating zone size	**L=30 cm & D=5 cm**

*** PID controller with special features programmable of PC series**

Device: Hydraulic press

Manufacturer: *DAVENPORT*

Technical specifications

Maximum capacity	**20 tons**

*** Providing temperatures up to 200 °C**

Device: Hydraulic press

Manufacturer: *CARVER / Model C*

Technical specifications

Maximum load	**12 tons**
Threaded Rod Length	**37”**

Device: Hydrogen generator

Manufacturer: *MAD AZMA POOYESH*

Technical specifications

*** Hydrogen generation with water electrolysis**

Production rate	**300 ml/min**
Output pressure	**4 bar**
Hydrogen purity	**99.999%**

Device: Magnetic stirrer

Manufacturer: *IKAFLON / C-MAG HS 7*

Technical specifications

Speed range	**100-1500 rpm**
Heating temperature range	**50-500 °C**
Heating rate heating plate	**5 K/min**
Stirring quantity max. (H2O)	**10 l**

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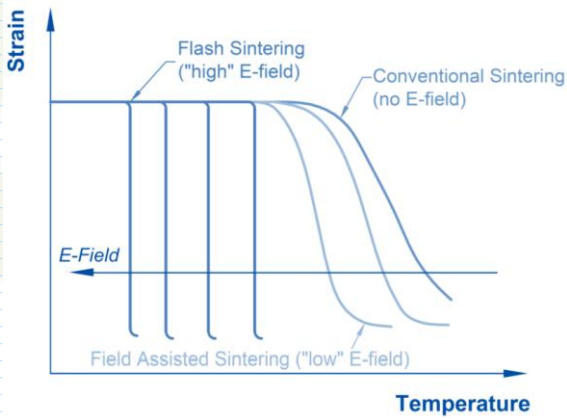
Flash sintering

Introduction

Flash sintering belongs to the wider class of Field Assisted Sintering Techniques (FAST) and, more specifically, to the Electric Current-Assisted Sintering (ECAS) processes. In FS practice, an electric field is directly applied to the green specimen and the current is forced to flow within the ceramic body. At a specific onset combination of electric field/furnace temperature, the material densifies in an extremely short time, typically from some seconds to few minutes. Since the sample is conventionally heated up to the onset flash temperature, FS can be observed in green or partially sintered ceramics. Flash sintering has several advantages when compared to conventional sintering processes including: lower temperatures, lower sintering times, energy saving, requirement of less expensive equipment, smaller final grain size, and possibility to sinter metastable phases.



Sintering strain as a function of the furnace temperature for specimens subjected to different electric fields

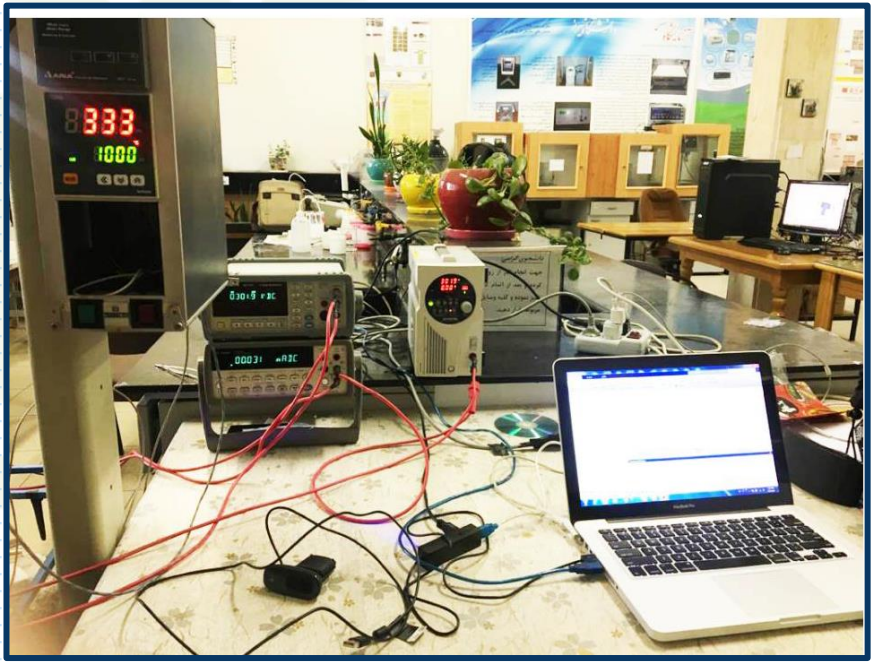
Setup: Flash sintering

Manufacturer: *MNUFACTURED IN-HOUSE*

This lab is equipped with a flash sintering setup with the following technical specifications. The power supply of this setup is introduced in the next page.

Technical specifications

Maximum temperature	**1100 °C**



Device: DC power supply

Manufacturer: *GW INSTEK / PSB-2400H*

This lab is equipped with the following power supply which runs the flash sintering setup and has the following specifications.

Technical specifications

Output Wattage	**400 Watts**
Wattage	**800 watts**
Output voltage rating	**800 V**
Output current rating	**3A**
Output power rating	**800 W**

*** Constant power output for multi-range (V&I) operation**

*** Series and parallel operation (2 units in series or 4 units in parallel maximum)**

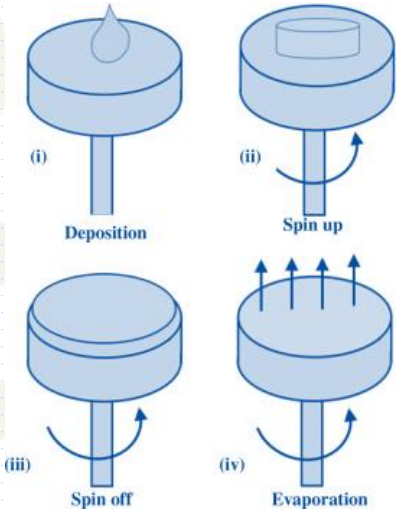
*** Programmable switching D.C. power supply**

*** Capable of switching from constant voltage to constant current**

Device: Spin coater

Introduction

Spin coating is used for the fabrication of thin films to deposit uniform coating on flat surfaces. Spin coating is performed in four steps, deposition, spin up, spin off, and evaporation. In the first stage the material is deposited on the turntable and then spin up and spin off occur in sequence while the evaporation stage occurs throughout the process. The applied solution on the turntable is distributed via centrifugal force. High spinning speed results in thinning of the layer. This stage is followed by drying of the applied layer. Uniform evaporation of the solvent is possible because of rapid rotation. High volatile components are removed from the substrate because of the evaporation or simply drying and the low volatile components of the solution remain on the surface of the substrate. Thickness of the deposited layer is controlled by the viscosity of the coating solution and the speed of rotation. One of the main disadvantages of spin coating is the limitation on the size of the substrate which can not be too large. Additionally, the material efficiency in this process is very low and only 2-5% of material is dispensed onto the substrate.



Schematics of spin coating

Device: Spin coater

Manufacturer: ***BACKER***

This lab is equipped with a spin coater with the following technical specifications.

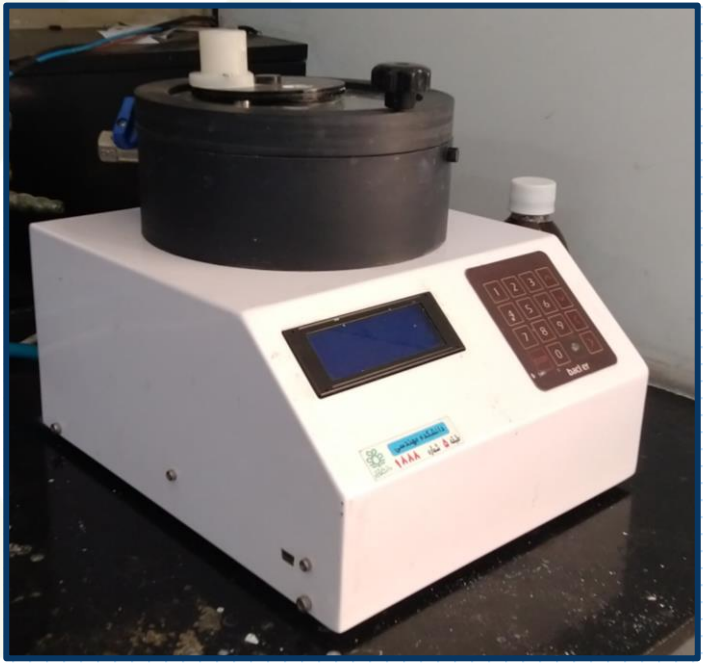
Technical specifications

Rotation speed	**500-9000 rpm**
Rotation time	**1 s-60 min for each step**
Ramp time	**1-59 s for each step**
Substrate diameter	**10-100 mm**

*** Holding substrate by vacuum**

*** Capable of providing atmosphere of interest**

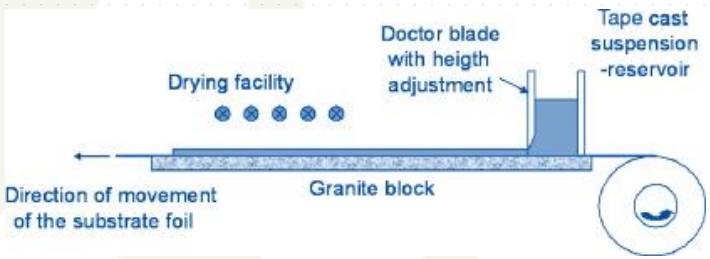
*** Rotational injection system**



Device: Tape casting

Introduction

Tape casting, also known as the doctor blading technique, has been advanced since the end of World War II as the best way to form thin, flat, large-area ceramic or metallic articles. Tape casting is a well-established practice for making ceramic substrates in electronic devices. The possible thicknesses are in the range of 0.01 to a few millimeters. Such parts can impossibly be obtained by pressing or extruding. It is a wet-shaping technique that uses a tape cast suspension with mostly pseudoplastic properties. The suspension is constituted from the inorganic powder chosen, several organic additives, and a liquid medium. The heart of the process is the so-called doctor blade that acts as a knife, spreading out the tape cast suspension over a moving carrier film. After spreading over the carrier film, a drying installation is foreseen. The drying rate can be crucial to the success of making a crack-free membrane. Next to the suspension properties, the gap height under the doctor blade and the speed of the carrier relative to the doctor blade are important variables in a tape cast process.



Schematic of tape casting

Device: Slip casting

Manufacturer: *MTI CORPORATION*

This lab is equipped with a slip casting device with the following specifications.

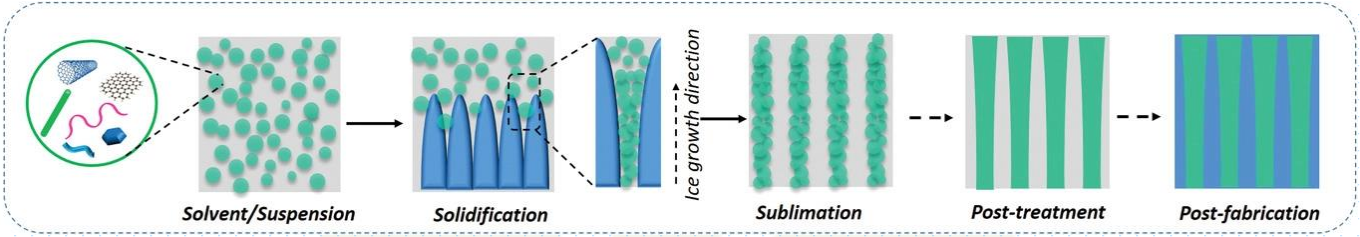
Technical specifications

Traverse speed	**5 - 100 mm/sec**
Traverse speed accuracy	**10mm/sec**
Stroke Length	**10-250 mm adjustable**
Vacuum chuck	**Al alloy with < 1.0 mm holes**
Heating cover	**Top heating, maximum of 100 °C**
Temperature control	**± 1 °C**
Thickness adjustment	**0.01-3.5 mm**
Coating area (standard)	**320 mm (L) x 100 mm (W)**
Coating area (max)	**350 mm (L) x 180 mm (W)**
Applicator width	**100 mm**

Freeze casting

Introduction

Freeze-casting is a solidification technique for fabricating porous materials. This process involves the controlled solidification of a solution, suspension, sol or gel, followed by the sublimation of the solvent (mostly commonly water) under reduced pressure, and subsequent densification by posttreatment such as sintering. During the controlled solidification process, as the solvent solidifies, phase separation takes place, with the resulting solid phase (usually ice) serving as a template. For this reason, freeze casting is also commonly referred to as ice-templating. Afterwards, the solidified solvent template is removed by sublimation while the structural framework is retained, eventually yielding a well-shaped monolith.



Schematics of freeze casting

Setup: Freeze casting setup

Manufacturer: *MANUFACTURD IN-HOUSE*

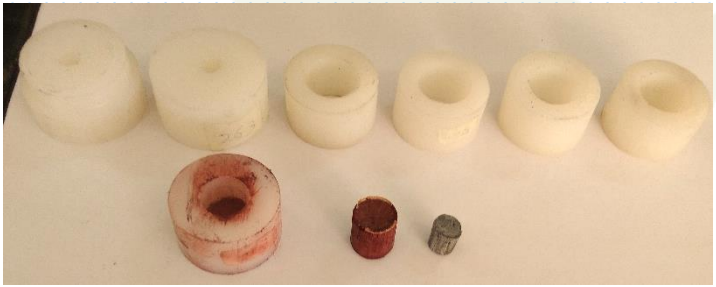
This lab is equipped with a freeze casting setup with the following specifications. The current and voltage is supplied by the DC power supply introduced in the next page.

Technical specifications

Minimum attainable temperature	**-60 °C**
Maximum cooling rate	**-3 K/min**
Maximum mold cavity dimension	**< 35 mm**

*** Capable of controlling cooling rate**

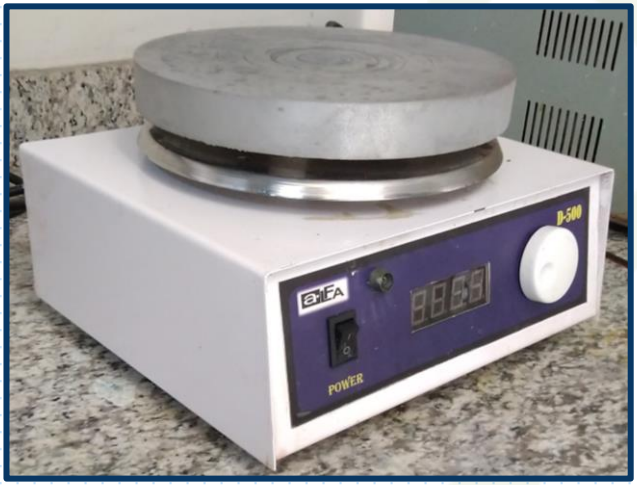
*** Teflon and Copper molds in different sizes are available**



Teflon molds

Device: Digital hot plate

Manufacturer: *ALFA / D500*



Technical specifications

Maximum temperature	**370 °C**
Rotational velocity	**10-180 rpm**
Maximum temperature	**350 °C**
Temperature accuracy	**±2 °C**
Plate	**18 cm diameter aluminum plate**

Device: Direct driven stirrer

Manufacturer: *FINTECH*

Technical specifications

Maximum rotational speed	**3000 rpm**

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Device: Rectifier

Manufacturer: *IPC / SI20PRC*

Technical specifications

Maximum voltage	**12 V**
Maximum current	**20 A**

*** Pulsed (PC), pulsed-reverse current (PRC), and DC modes**

Full digital and programmable

Device: DC power supply

Manufacturer: *MEGATEK / MP-3005*

Technical specifications

Maximum voltage	**30 V**
Maximum current	**3 A**

Device: Tile cutter

Manufacturer: *EINHELL / TC-TC 618*

Technical specifications

* Scale for adjustable cutting width
* Mitre stop supports exact 45° cuts
* Tilt steel table with angle scale
* Water container provides a clean cold cut
* Parallel guide stop for accurate straight cuts

Device: Eclectic furnace

Manufacturer: *AZAR / F2L 1500*

Technical specifications

Maximum temperature	1450 °C
Accuracy	± 2 °C
Dimensions (D×H×W)	18×10×12 cm³

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Device: Roll jar mill

Manufacturer: *SANAT CERAM*

Technical specifications

Distance between rolls	**60-200 mm**
Rotational speed range	**0-50 rpm**

Device: Attrition mill

Manufacturer: *M & R STARKY / STA*

Technical specifications

Rotational speed range	**180-2770 rpm**

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