TECHNISCHE UNIVERSITÄT DARMSTADT

ISM+D
Institute of Structural Mechanics and Design
Institut für Statik und Konstruktion

Glass Competence Center

Glazing mistakes and solutions

How to learn from practice **and** basic research

Prof. Dr.-Ing. Jens Schneider
Institute of Structural Mechanics and Design (ISM+D) – Glass Competence Center
TU Darmstadt, Germany

TU Darmstadt
Institute of Structural Mechanics and Design

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ISM+D

Institute of Structural Mechanics and Design
Institut für Statik und Konstruktion

Prof. Dr.-Ing. Uli Knaack

Prof. Dr.-Ing. Jens Schneider

Structural Dynamics Unit

Generative Design Lab

Energy Efficient Construction

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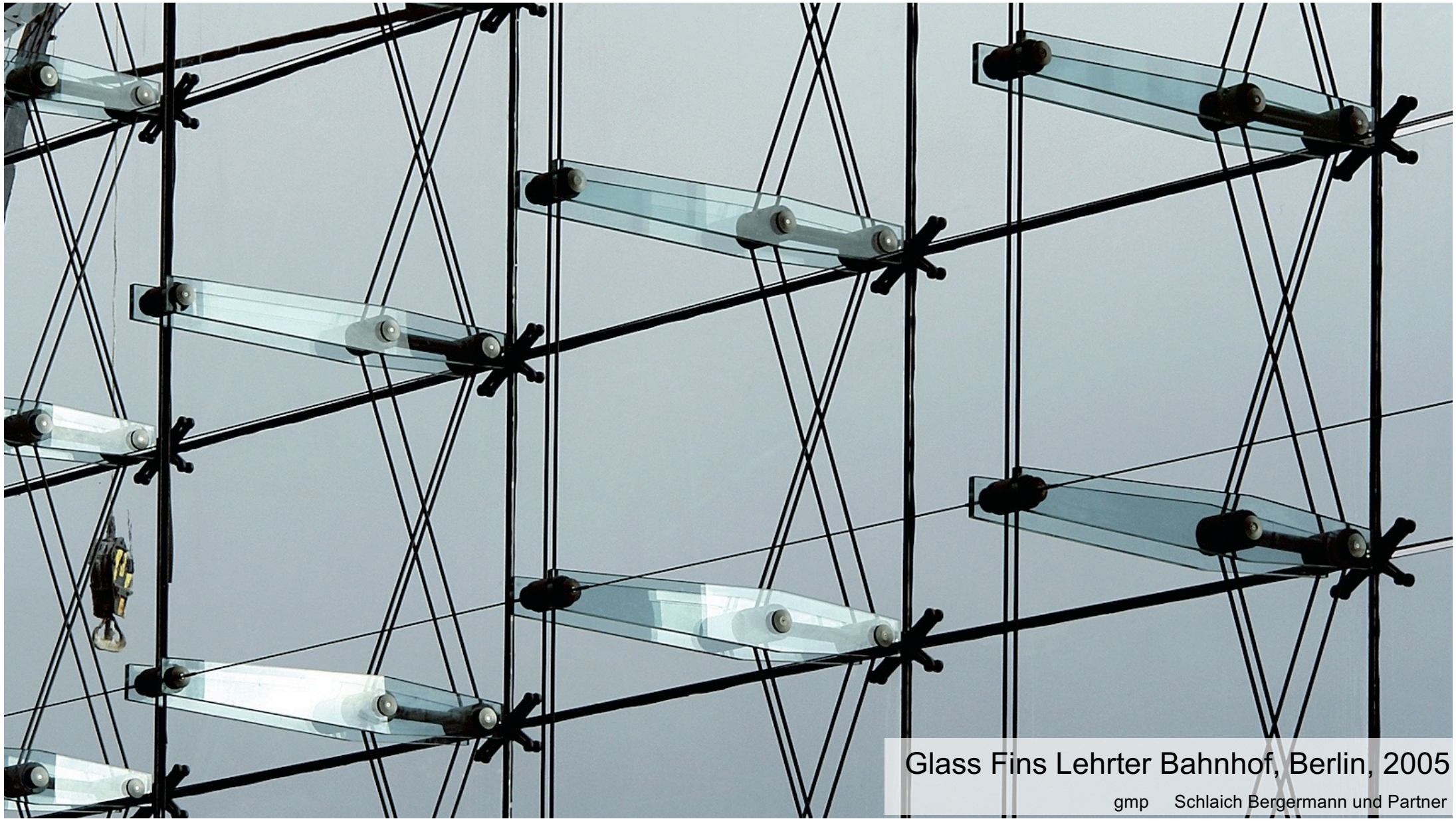
Paper Construction and Design

New Trade Fair Leipzig - Central Glass Hall, 1994

Architects: Ian Ritchie und gmp



Glass Fins Lehrter Bahnhof, Berlin, 2005

gmp Schlaich Bergermann und Partner

Glass Competence Center just opened 07.09.2022

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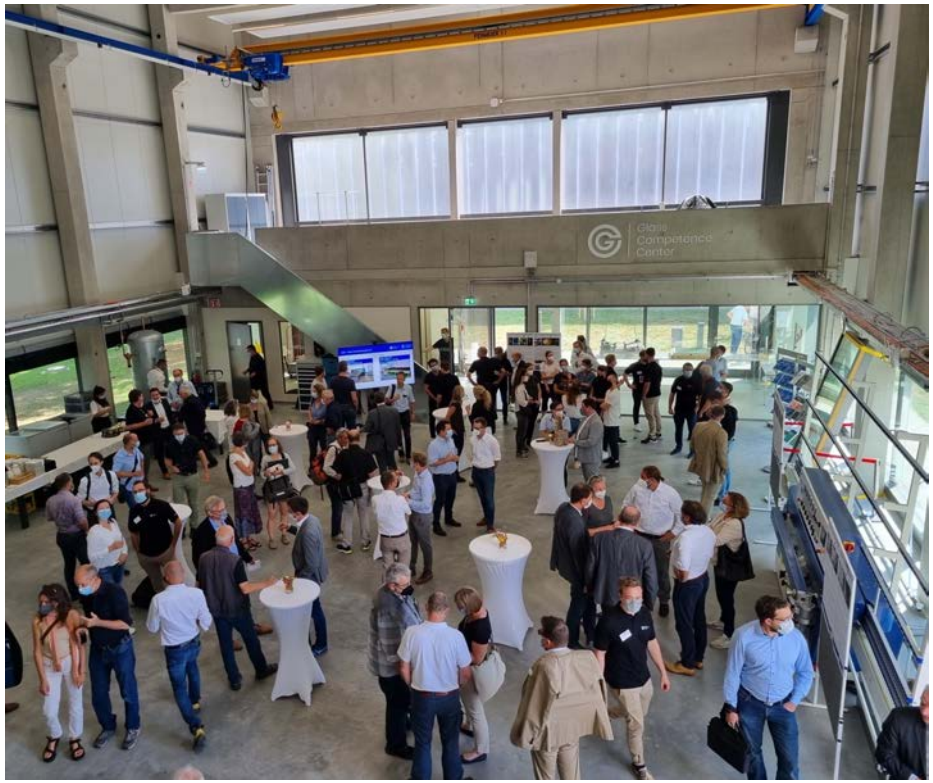

GCC – Building & Lab

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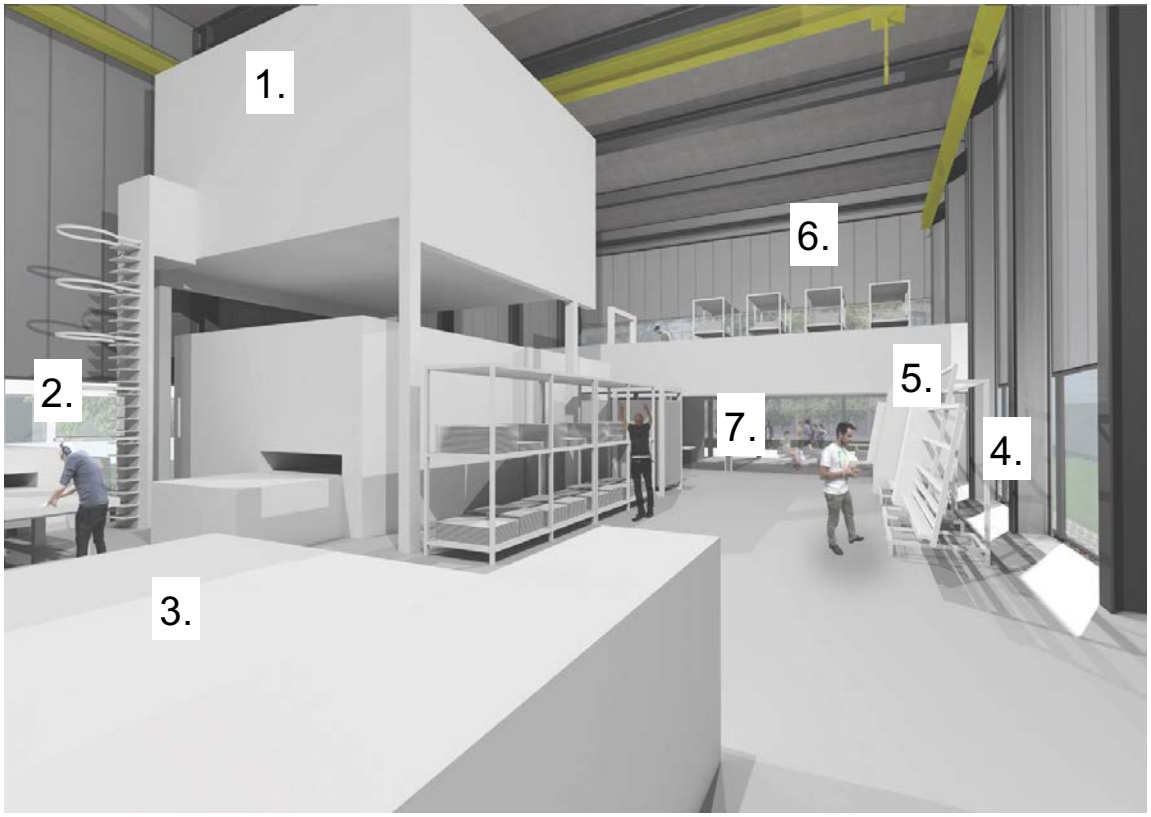
Glass processing of flat glass in lab scale up to 3.3 m x 2.5 m size

1. Thermal Tempering
2. Lamination
3. Glass Cutting
4. Glass Grinding
5. Glass Washing
6. Facade Test Rig
7. Conference Room

+ Drilling + Adhesive lab
+ Optical lab (microscope, stress optics,…)
+ Melting lab with 3D-glass printer
+ Open space weathering



Source: Dietz • Joppien Architekten AG

Glass processing equipment

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GCC Portfolio

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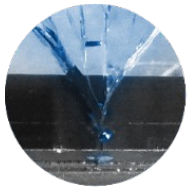
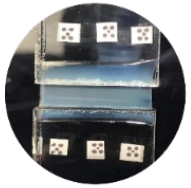
Surface & Edge Strength

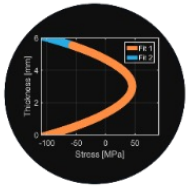


Thermal Breakage

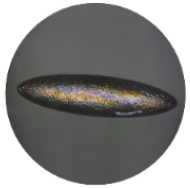


Laminated Glass & Interlayers

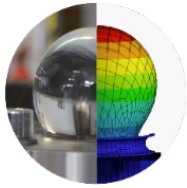
Additive Manufacturing Glass



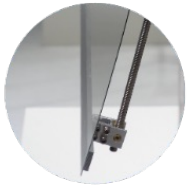
Pre-stressed Glass



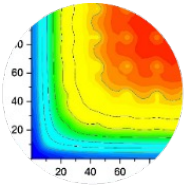
Glass Inclusions



Polymers in Glass Construction

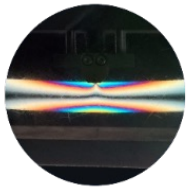


Thin Glass



Insulating & Vacuum Insulating Glass (IGU & VIG)

and more



Photoelasticity & Anisotropy

From Glass to Glazing

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1. Glass melting and production from raw materials
2. Glass processing:
   - cutting
   - cleaning
   - edge treatment
   - coating
   - tempering
   - lamination
   - IGU assembly
3. Transport and logistics
4. Assembly
5. Use

Thermal loading and fracture

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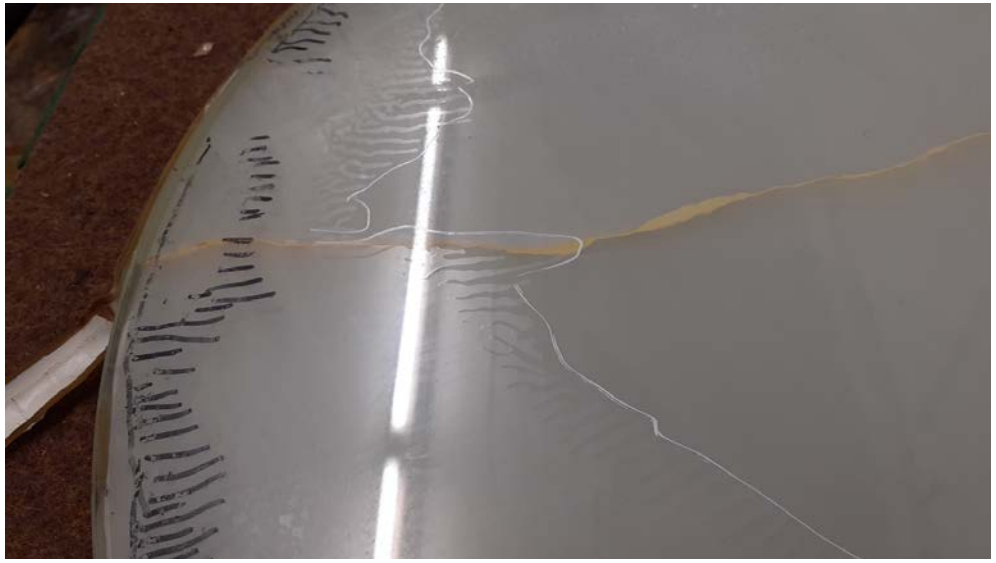
Material incompatibility



Polymer incompatibility in laminated glass

Metal incompatibility stainless steel - aluminium

Wrong assembly

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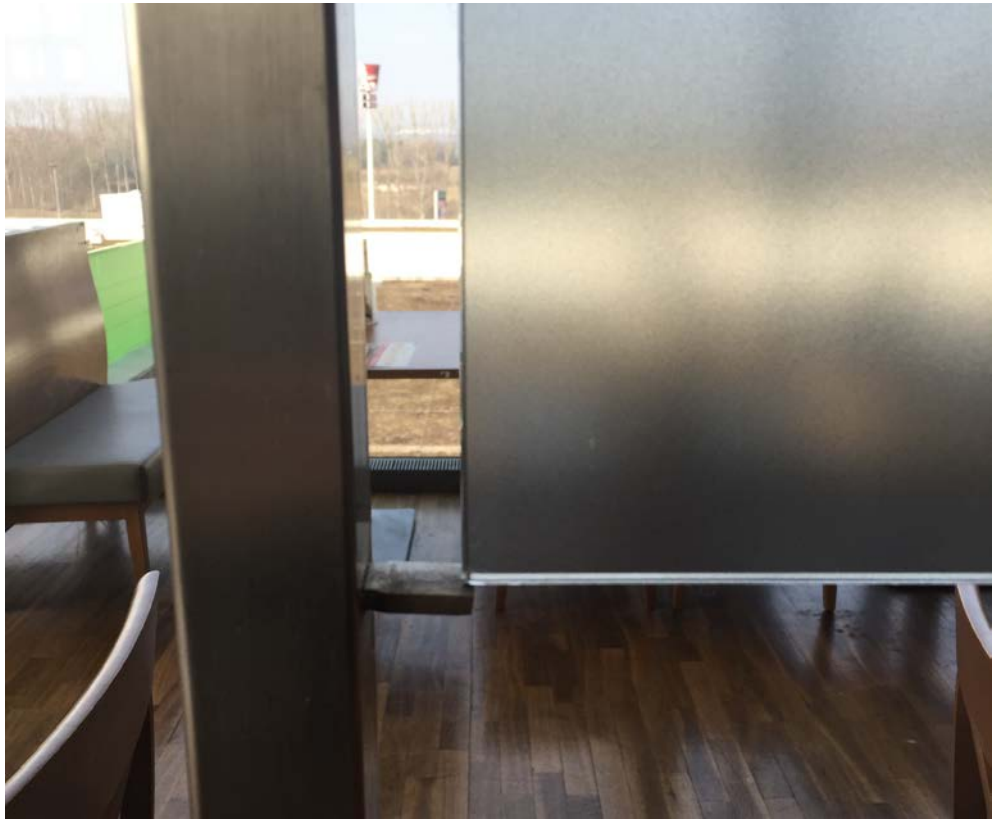

Tolerances and wrong assembly

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Surface damage by alkaline fluids – fresh concrete slurry

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Transport, logistics and storage

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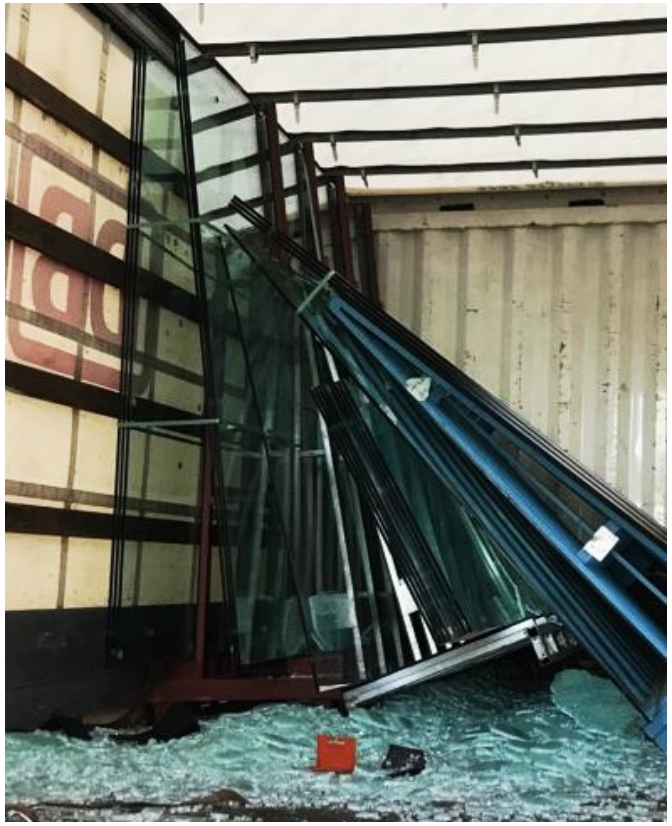

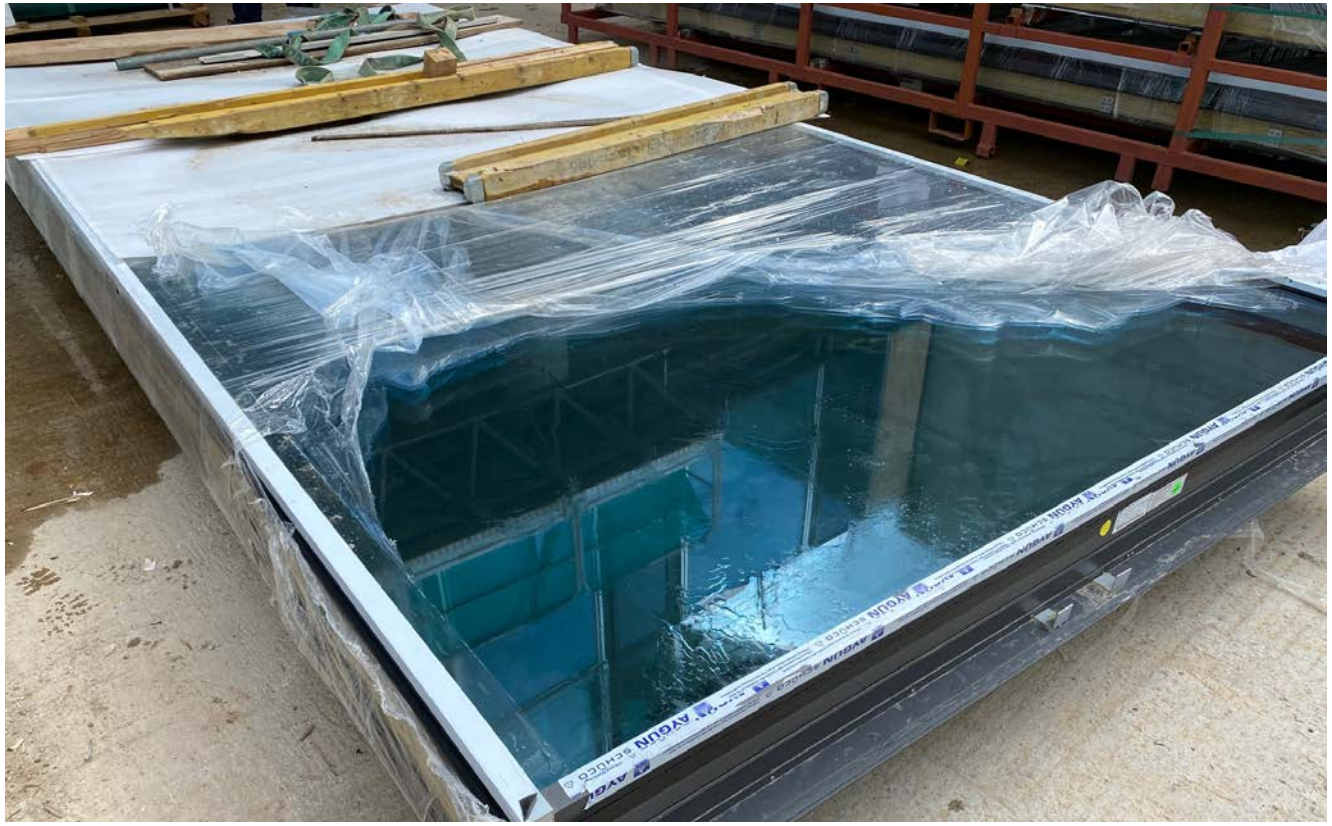

IGU condensation

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IGU condensation

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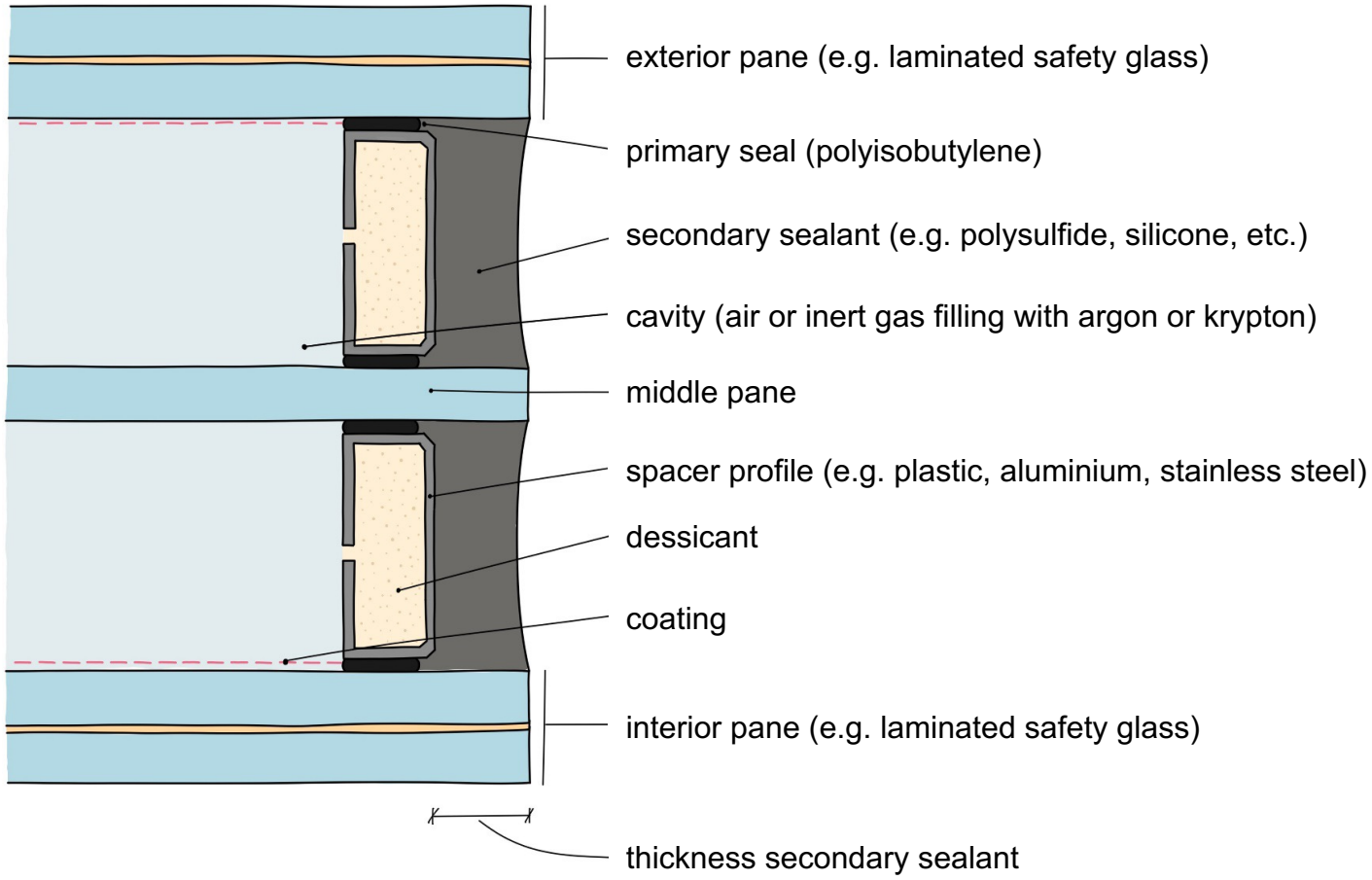
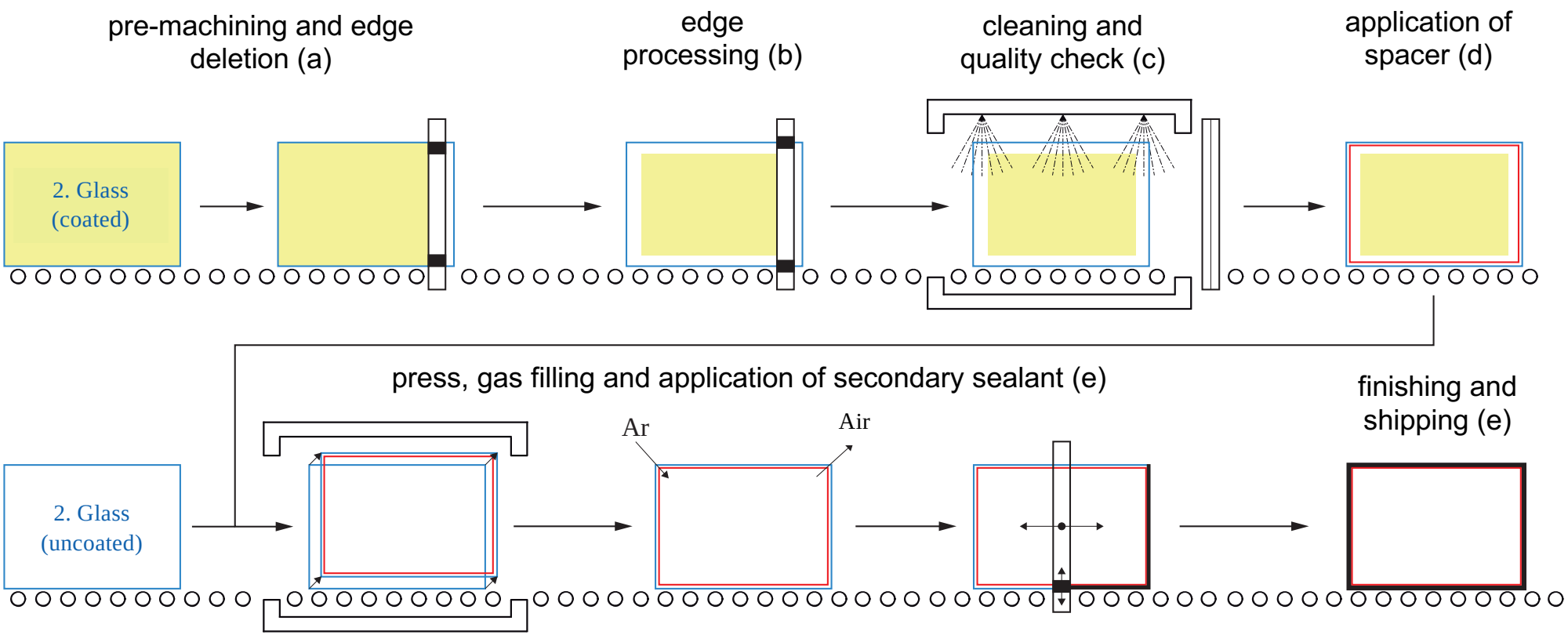
(Triple) Insulating Glass - IGU



Insulating glass (IGU) processing



IGU assembly problems

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IGU assembly problems

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Coating corrosion and coating defect

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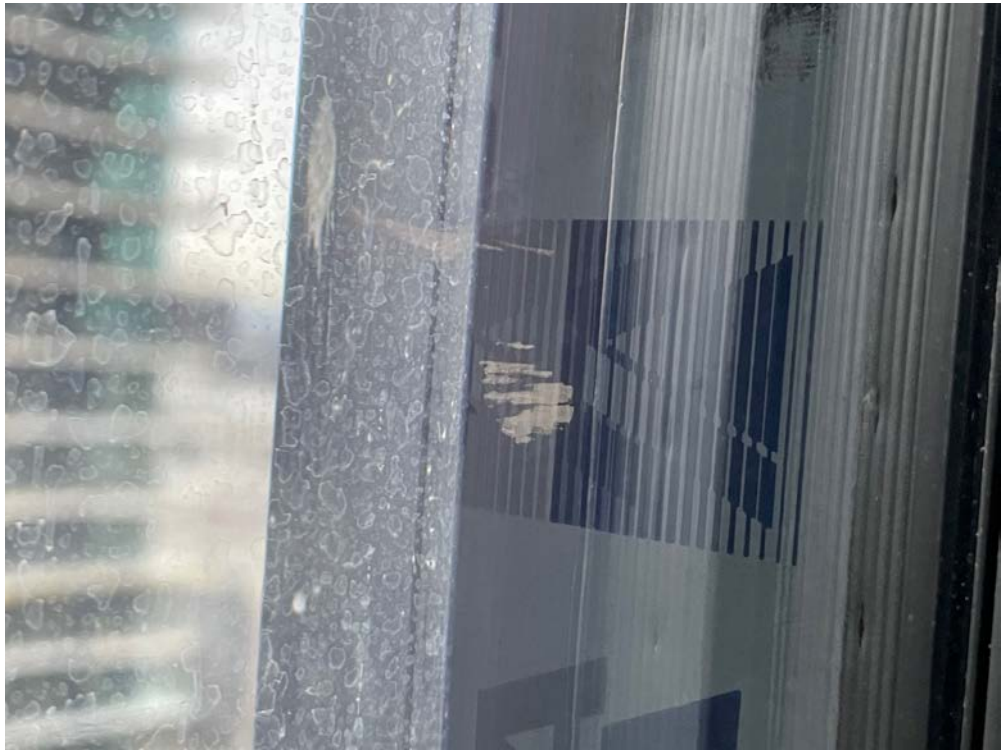
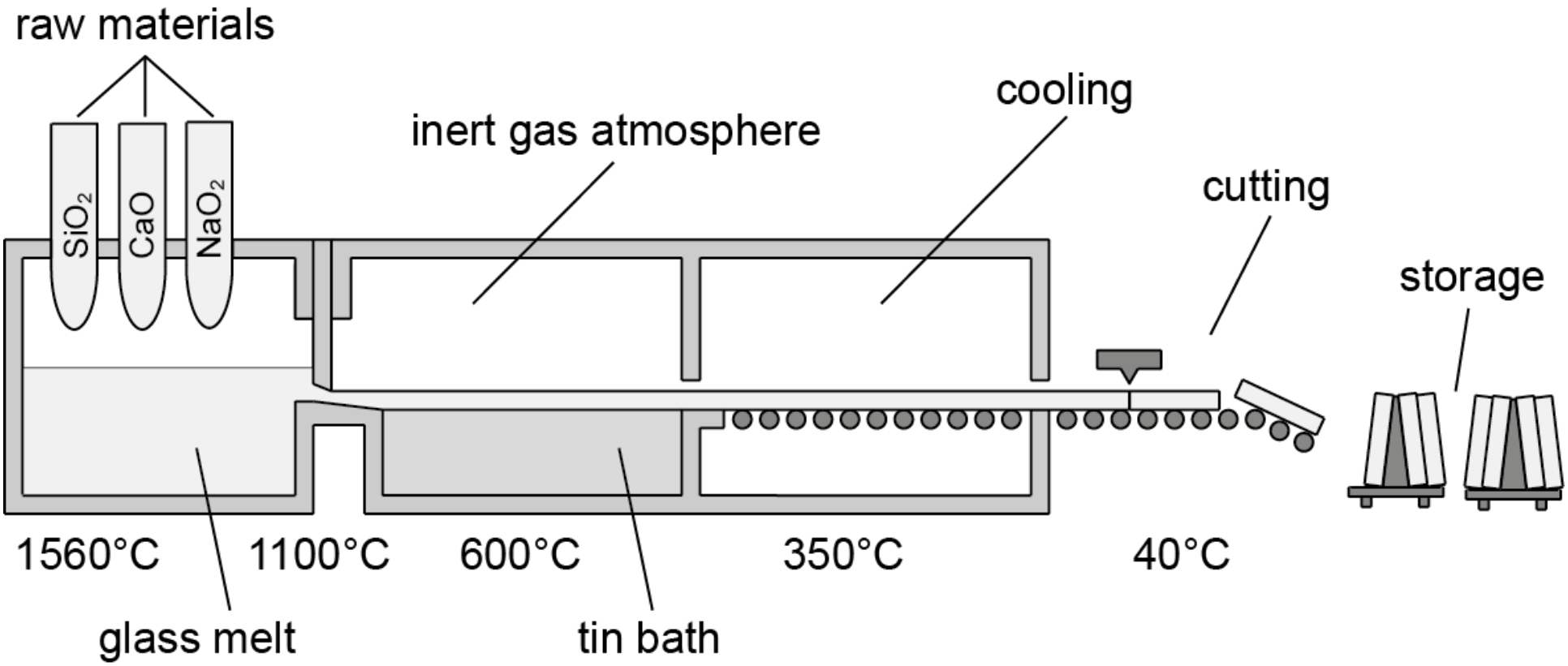


Float Glass Process

Maximum width typically 3.30 m (3.21 m usable)



Soda Lime Silicate Glass

69-74 %	silicone dioxide (SiO_2)
5-14 %	calcium oxide (CaO)
10-16 %	sodium oxide (Na_2O)
0-6 %	magnesium oxide (MgO)
0-5 %	aluminium oxide (Al_2O_3)
0-5 %	others

recycled material | soda | quartz sand | lime | dolomite feldspar potash

photo: Glas Trösch

photo: Glas Trösch

photo: Tim Hursley

Length scale: from human to atom

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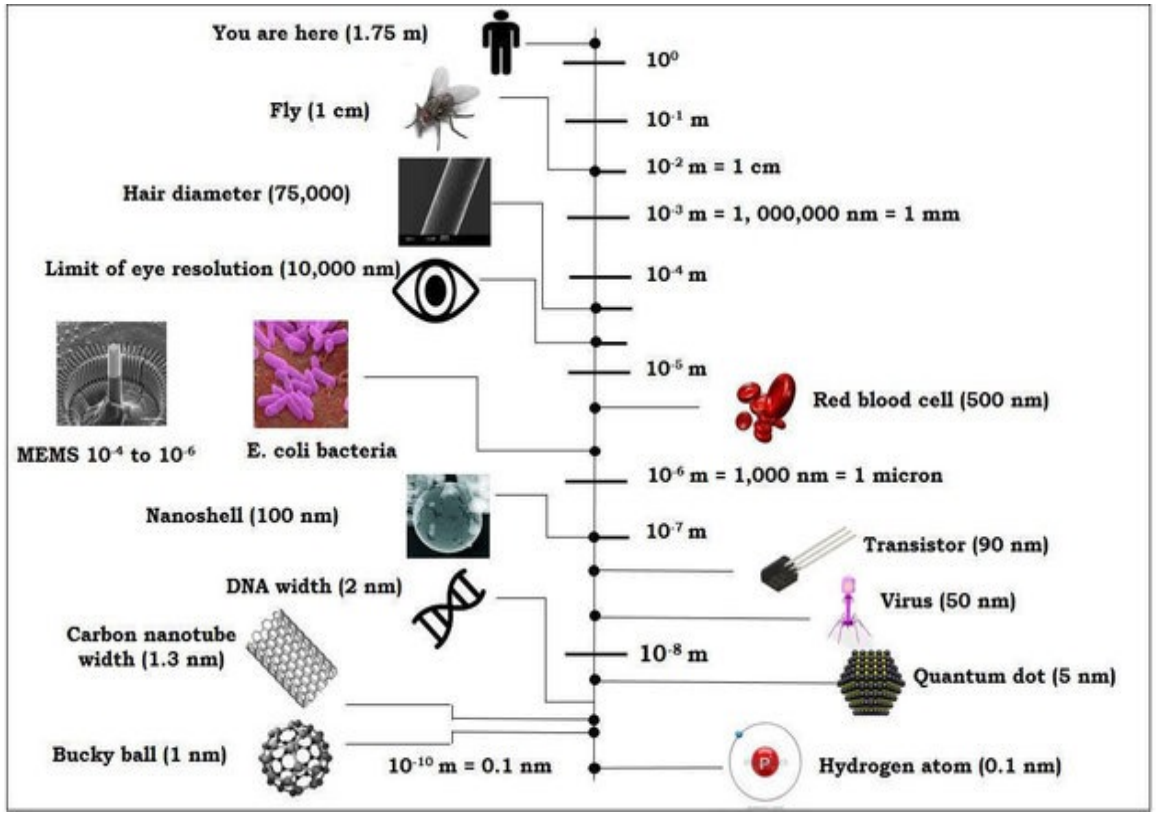
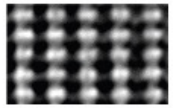
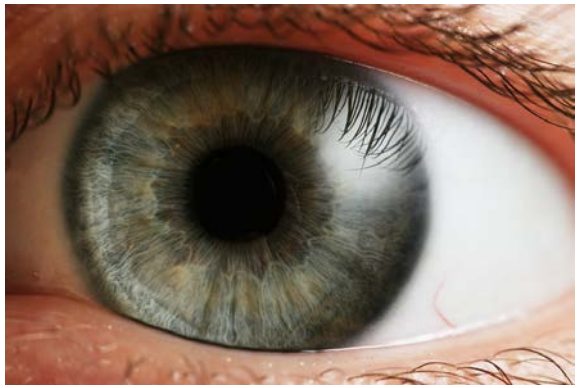


Figure from: Shivananda C S: SYNTHESIS OF SILVER NANOPARTICLES USING SILK FIBROIN : CHARACTERIZATION AND POTENTIAL ANTIBACTERIAL PROPERTIES, January 2017, DOI: 10.13140/RG.2.2.20649.62566



Atoms of silicon
spacing 0.078 nm

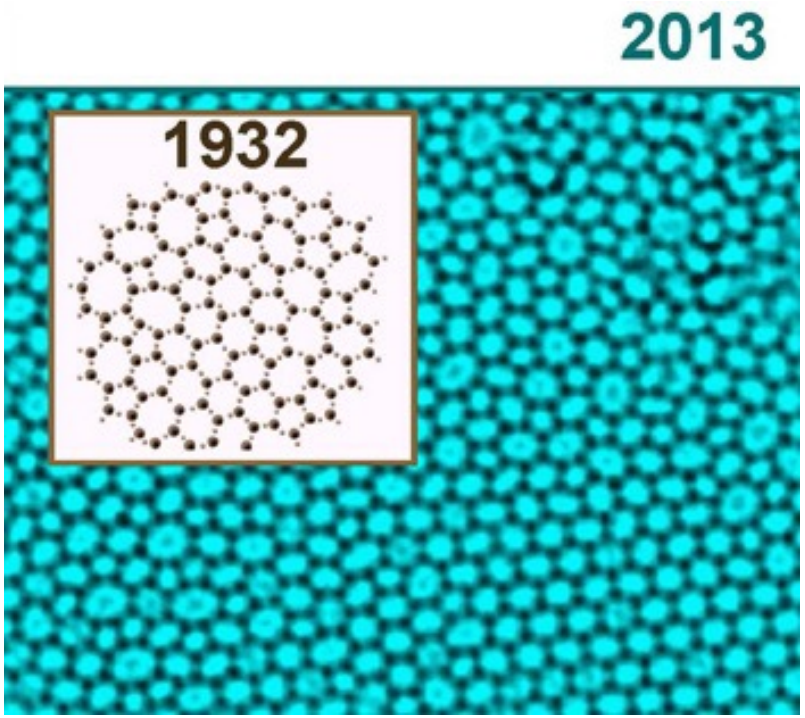


Petr Novák, Wikipedia, CC BY-SA 2.5,
https://commons.wikimedia.org/w/index.php?curid=441286

The resolution of the human eye is about 10 micrometer (0,01 mm).

Bonaque-González, S., Trujillo-Sevilla, J.M., Velasco-Ocaña, M. *et al.*
The optics of the human eye at 8.6 μm resolution. *Sci Rep* **11**, 23334 (2021).
https://doi.org/10.1038/s41598-021-02653-w

Glass on atomic scale



https://phys.org/news/2013-10-guinness-world-discovery-thinnest-glass.html

W.H. Zachariasen, 1932 Physicists form Ulm & Cornell, 2013

Model from theory (1932) compared to an electron microscope picture with the highest resolution available today (2013)

Pinshane et. al: Direct Imaging of a Two-Dimensional Silica Glass on Graphene.
Nano Lett. 2012, 12, 1081−1086 DOI: dx.doi.org/10.1021/nl204423x

Pinshane Y. Huang et al.
Imaging Atomic Rearrangements in Two-Dimensional Silica Glass:
Watching Silica's Dance. Science 342, 224 (2013)
DOI: 10.1126/science.1242248

Glass inclusions from production and melting

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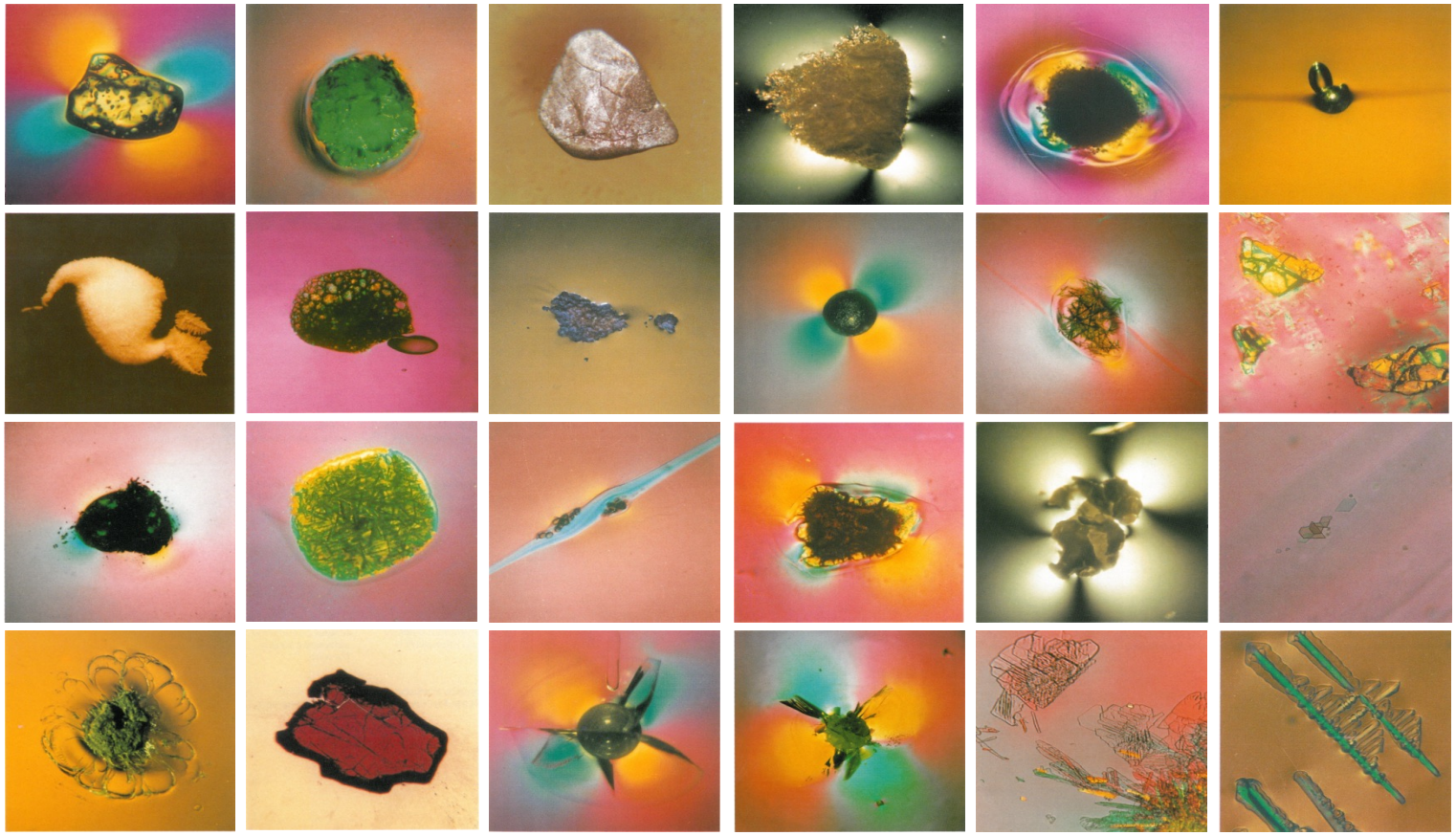

Soruce: Farbbild-Atlas der Steinchen und Einschlüsse in Glas

100 micrometer = 0,1 mm

Nickel-Sulphide inclusion in tempered glass

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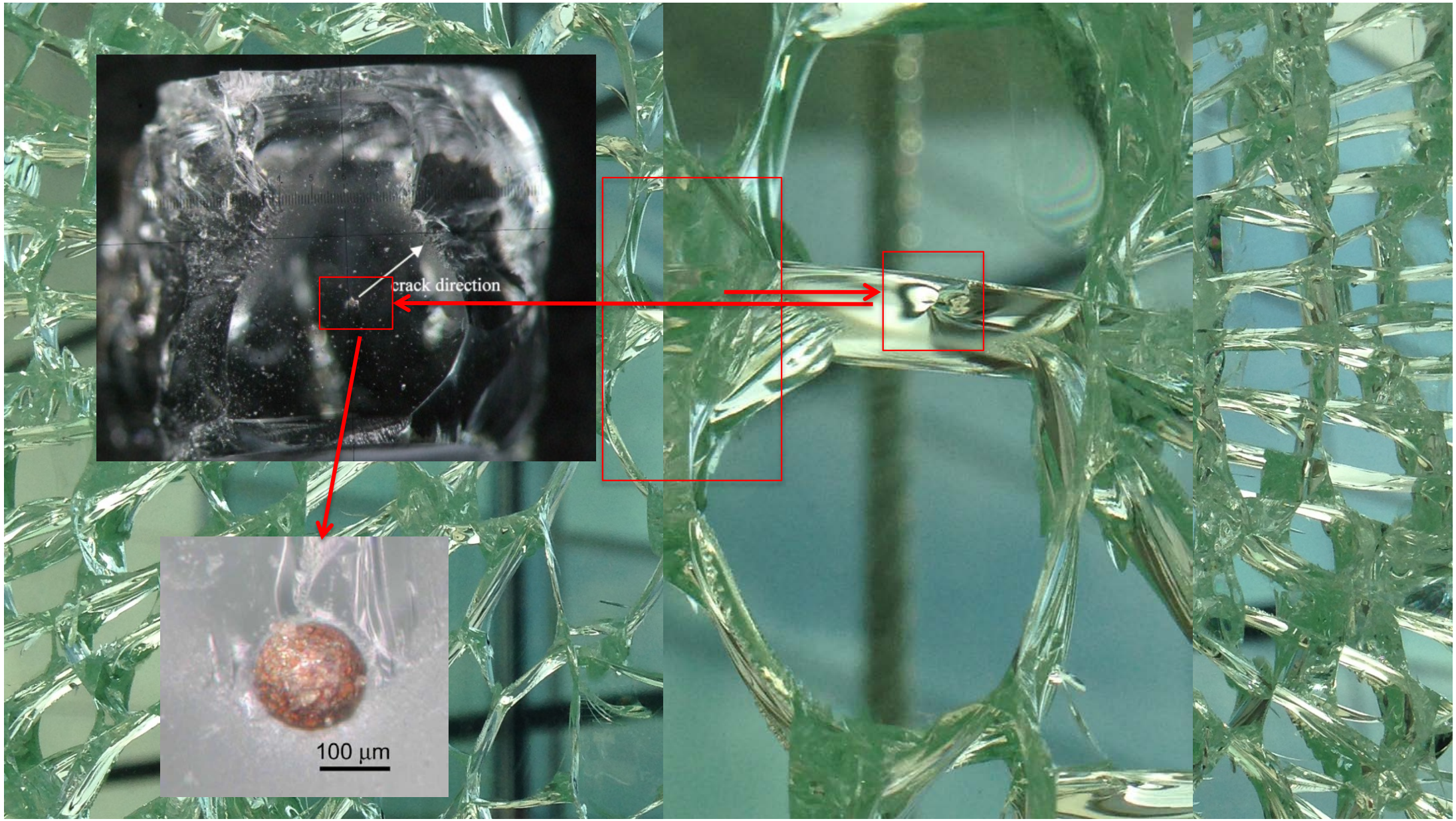
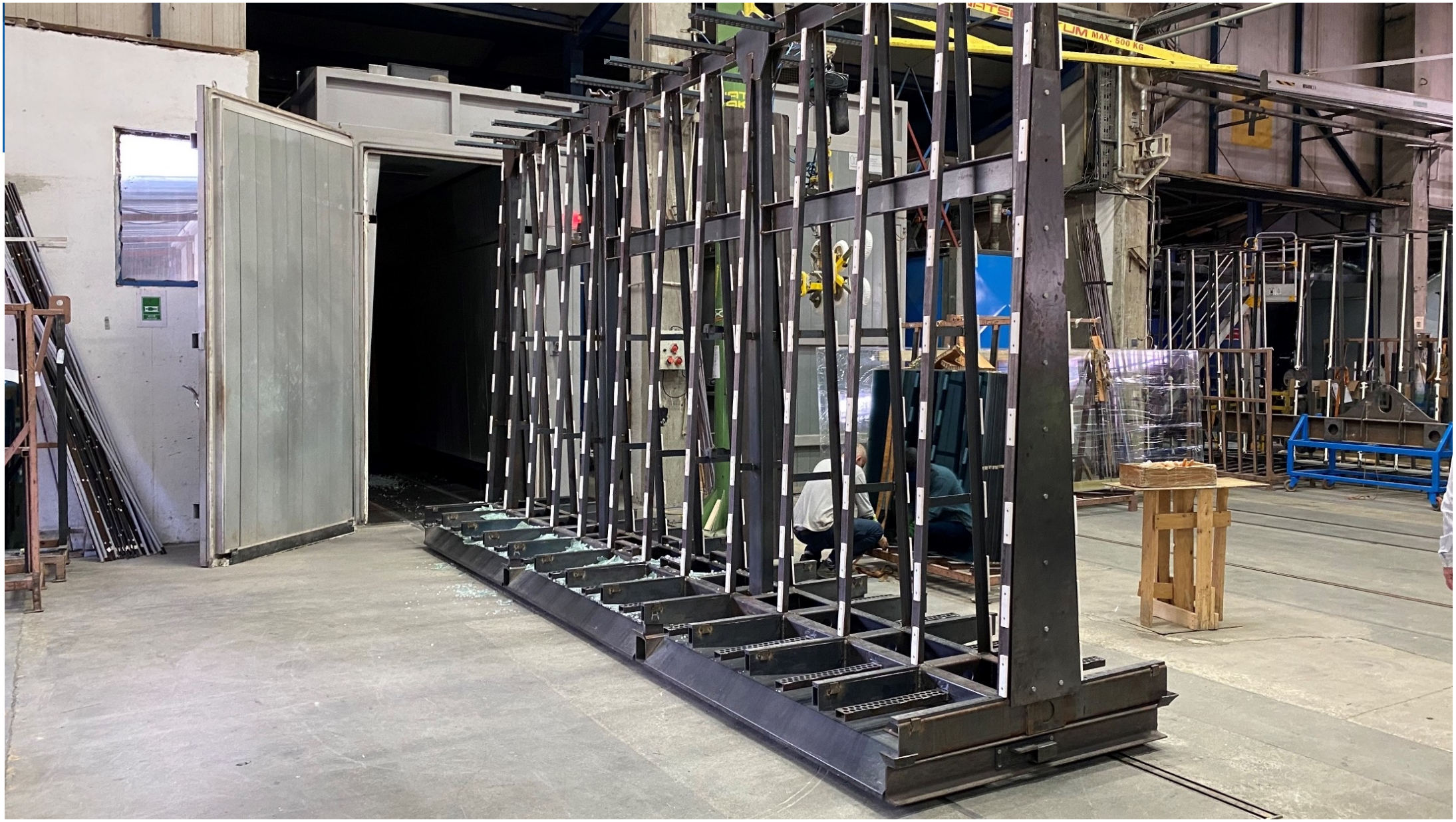
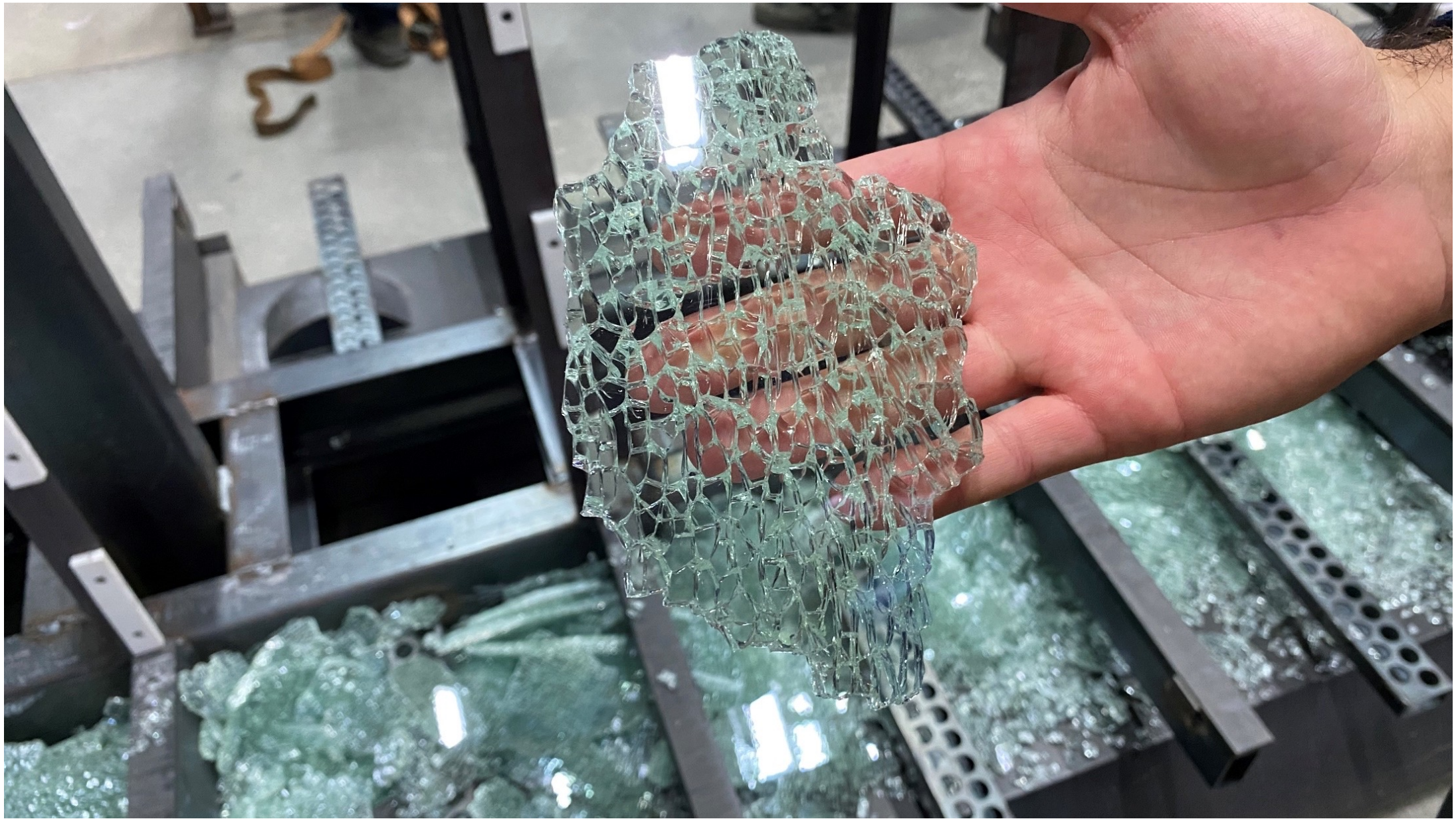

crack direction
100 µm


LJM MAX. 500 KG



QC
boraident
LASER-NANOTECHNOLOGIES IN GLASS
8ml e
HEAT SOAK TEST checkmarker® pen
Temperaturveränderliche Tinte zum Nach-
Thermocromic ink for evidence of the Heat

Scratches and surface defects

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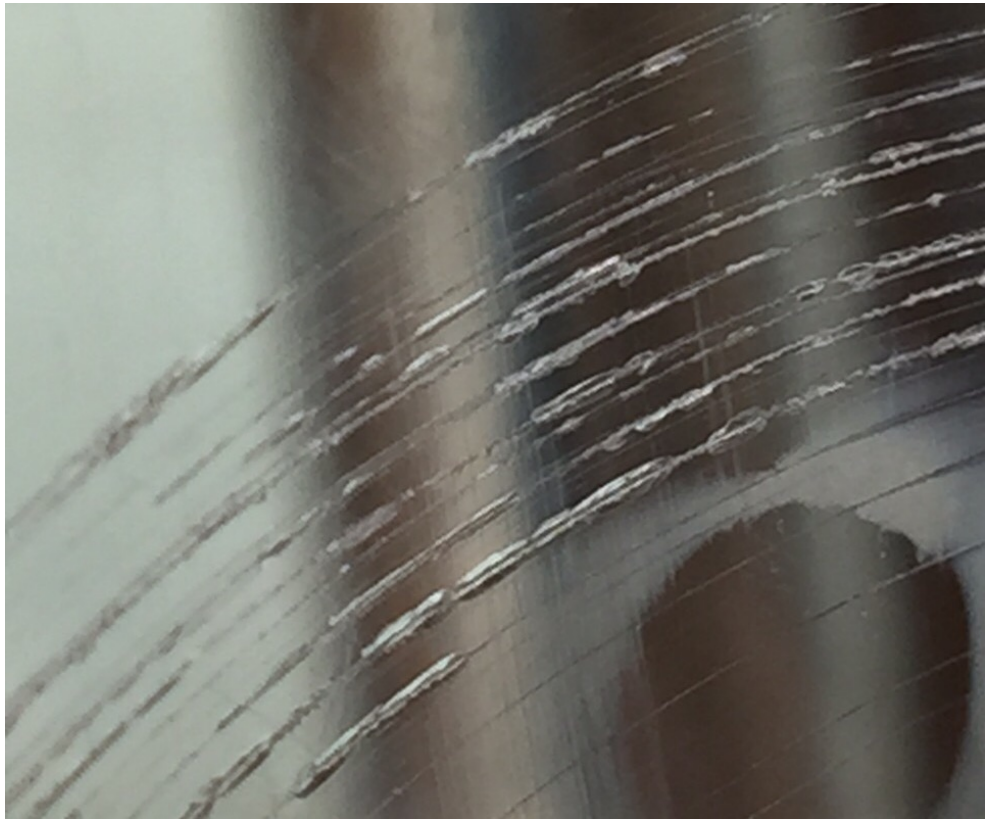

Indentation

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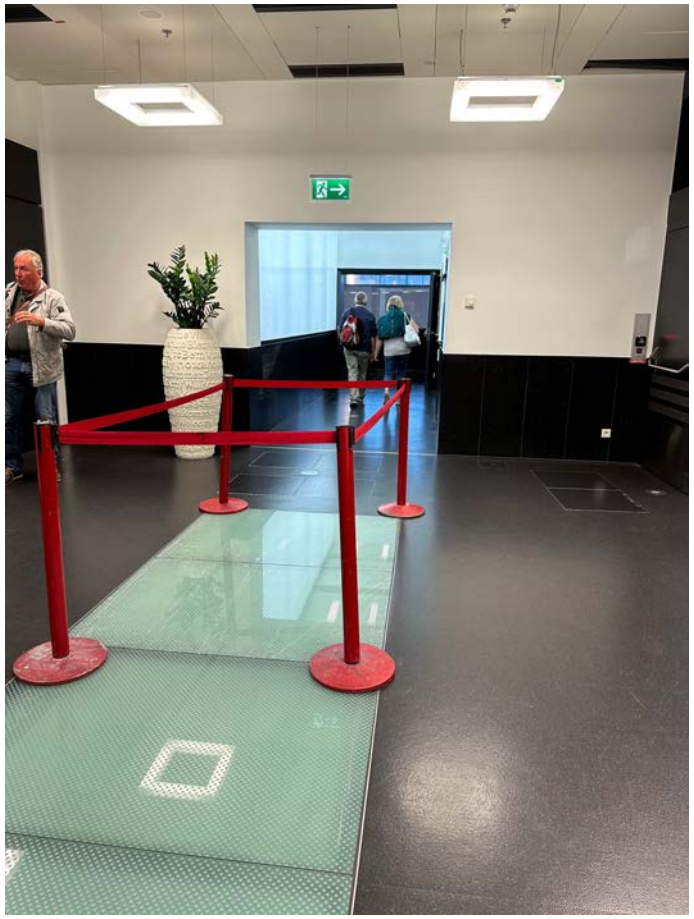

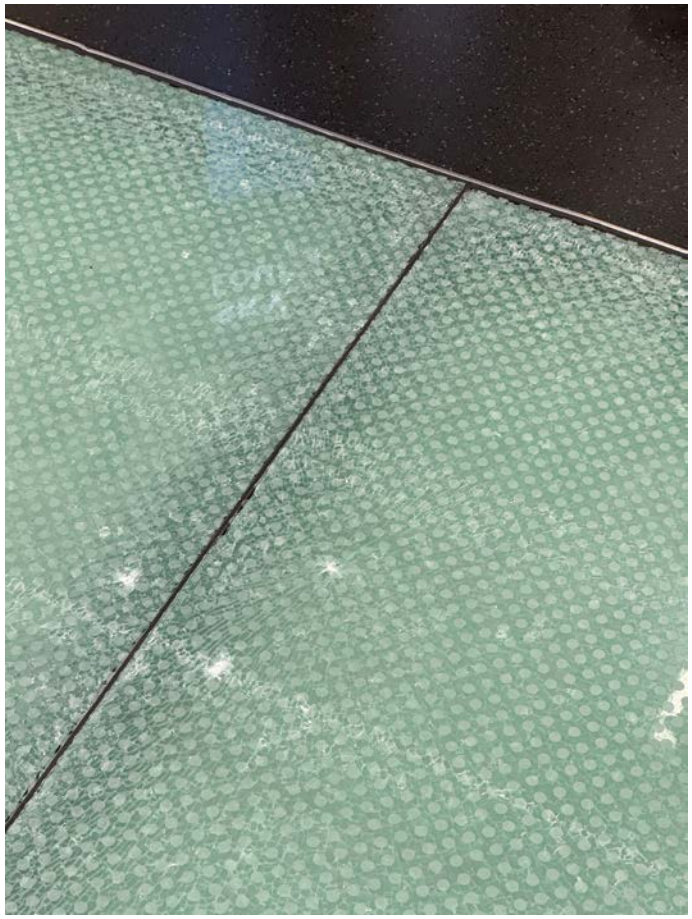

Potential root causes for scratches and indentation
Production, transport, handling, use, cleaning

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Production

Walking on the surface

Assembly

Dirt from the building site

Cleaning

Use of a glass cleaning knife

Model for crack initiation by indentation

Vertical crack and lateral cracks

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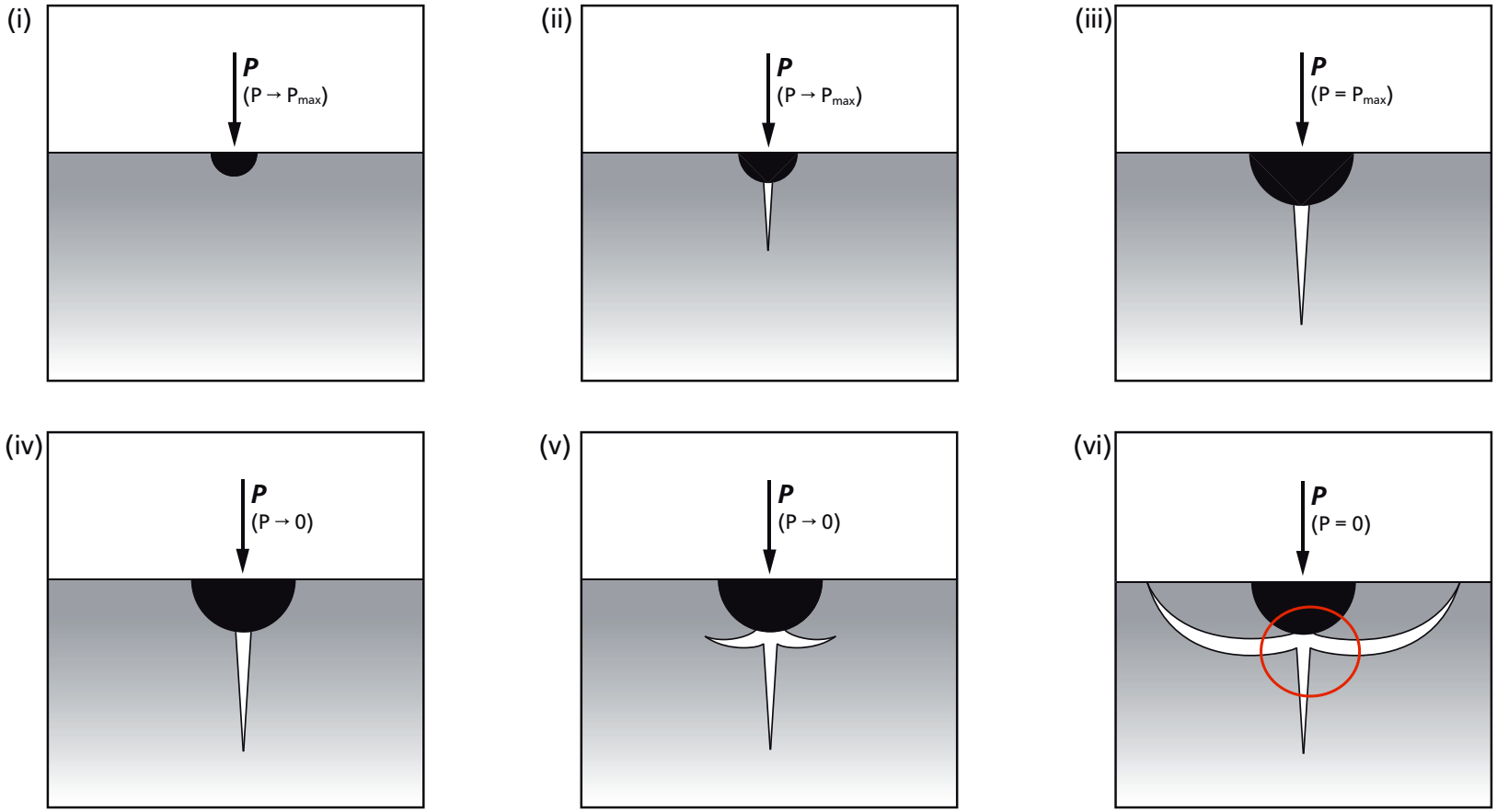
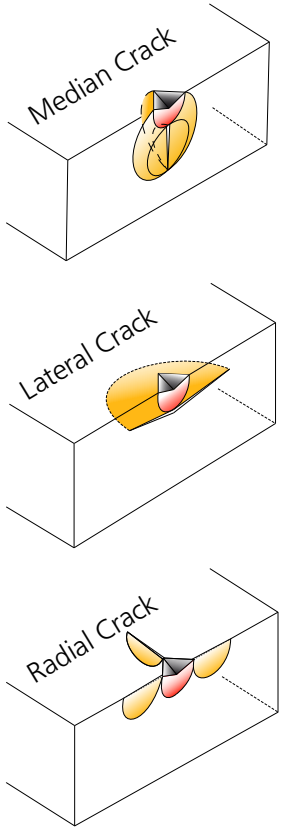
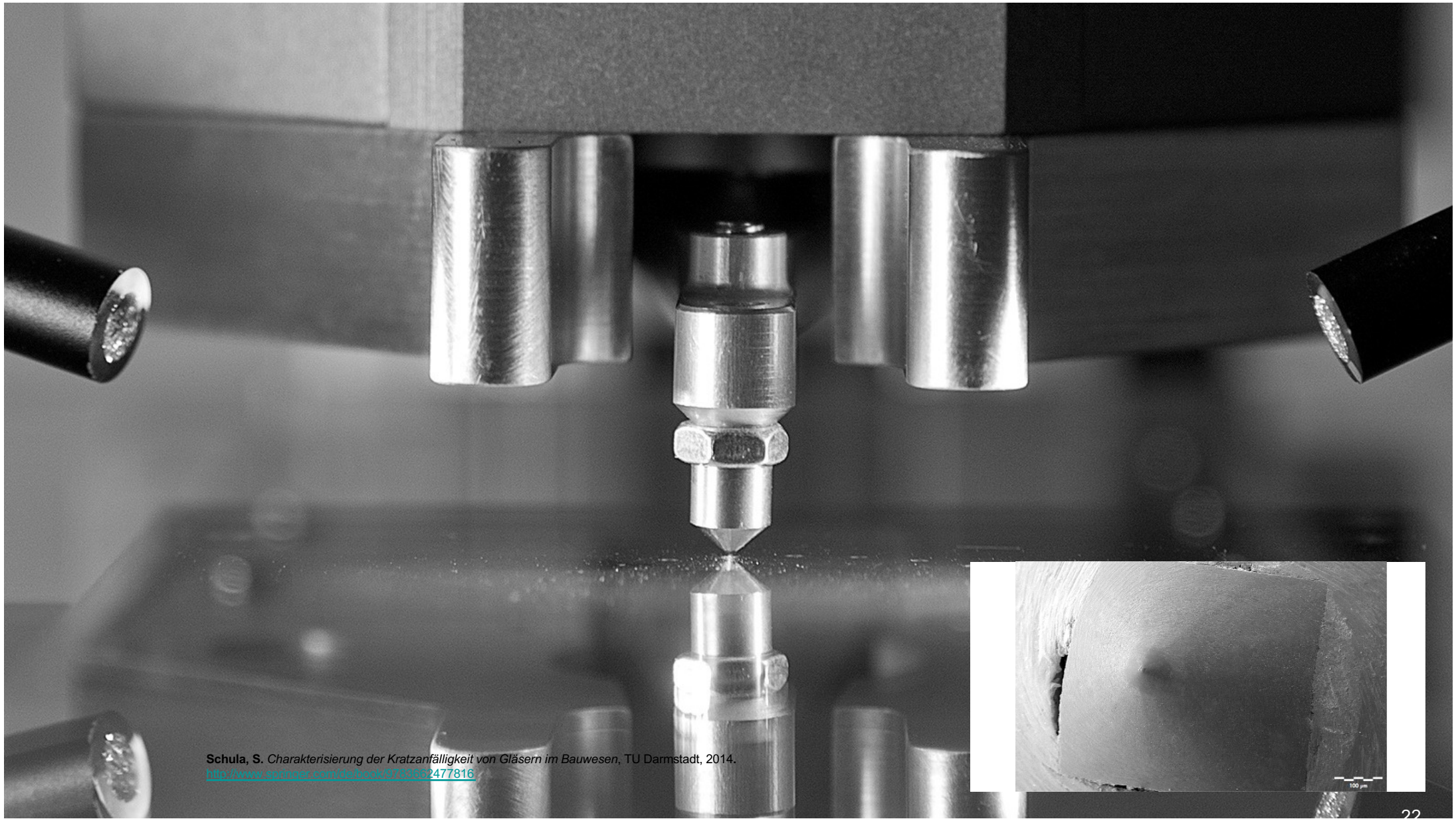
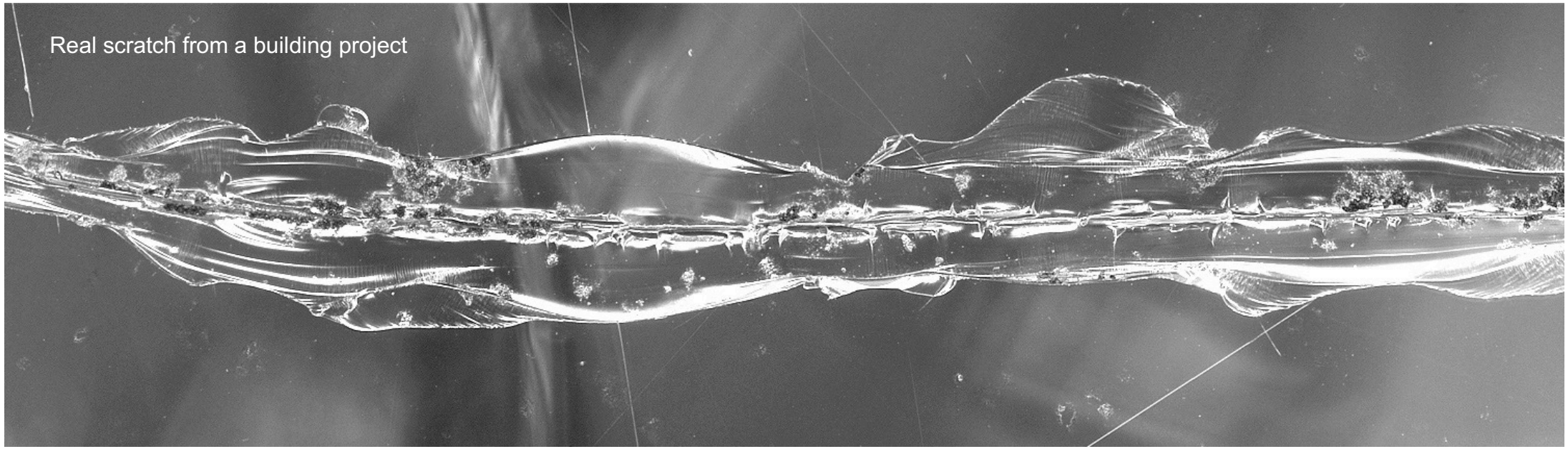


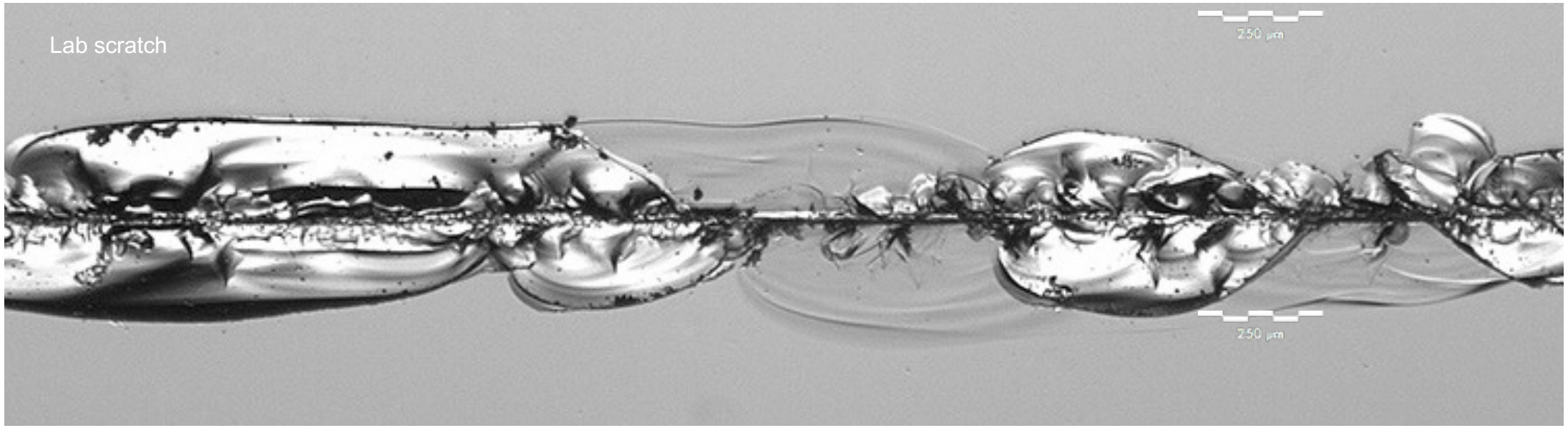


Lawn, 1993

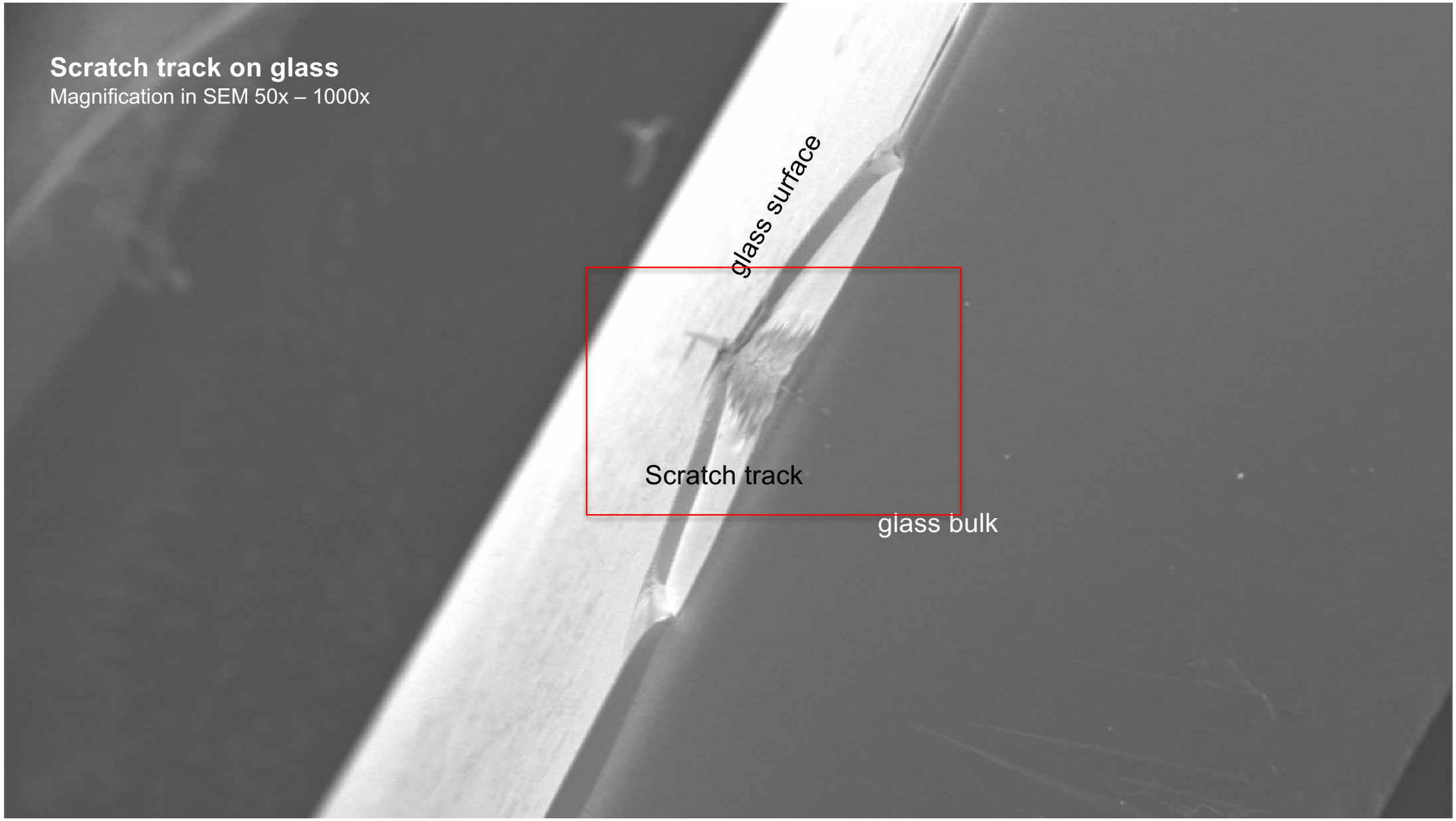


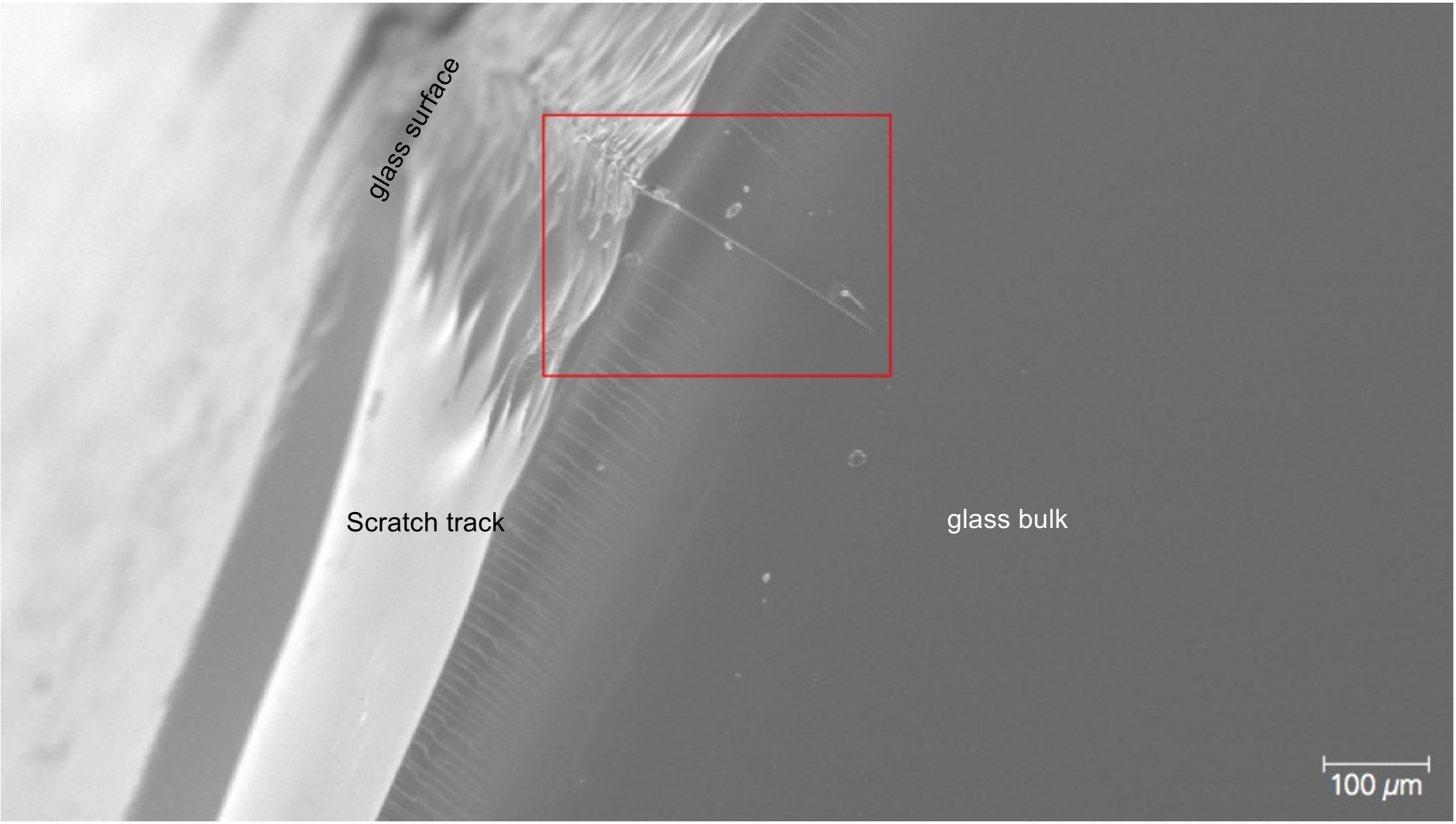
Schula, S. *Charakterisierung der Kratzanfälligkeit von Gläsern im Bauwesen*, TU Darmstadt, 2014.
http://www.springer.com/de/book/9783662477816

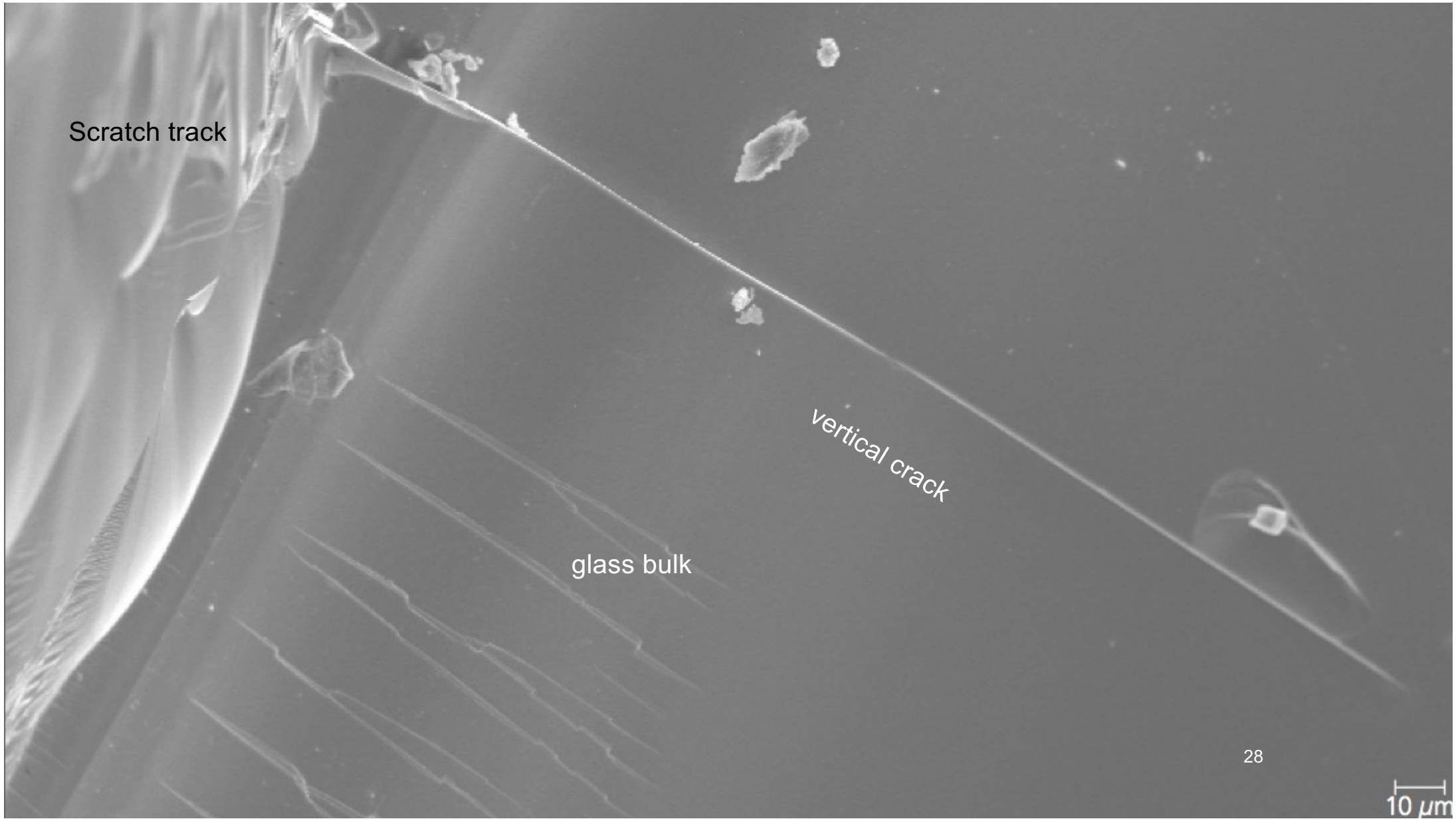

Real scratch from a building project

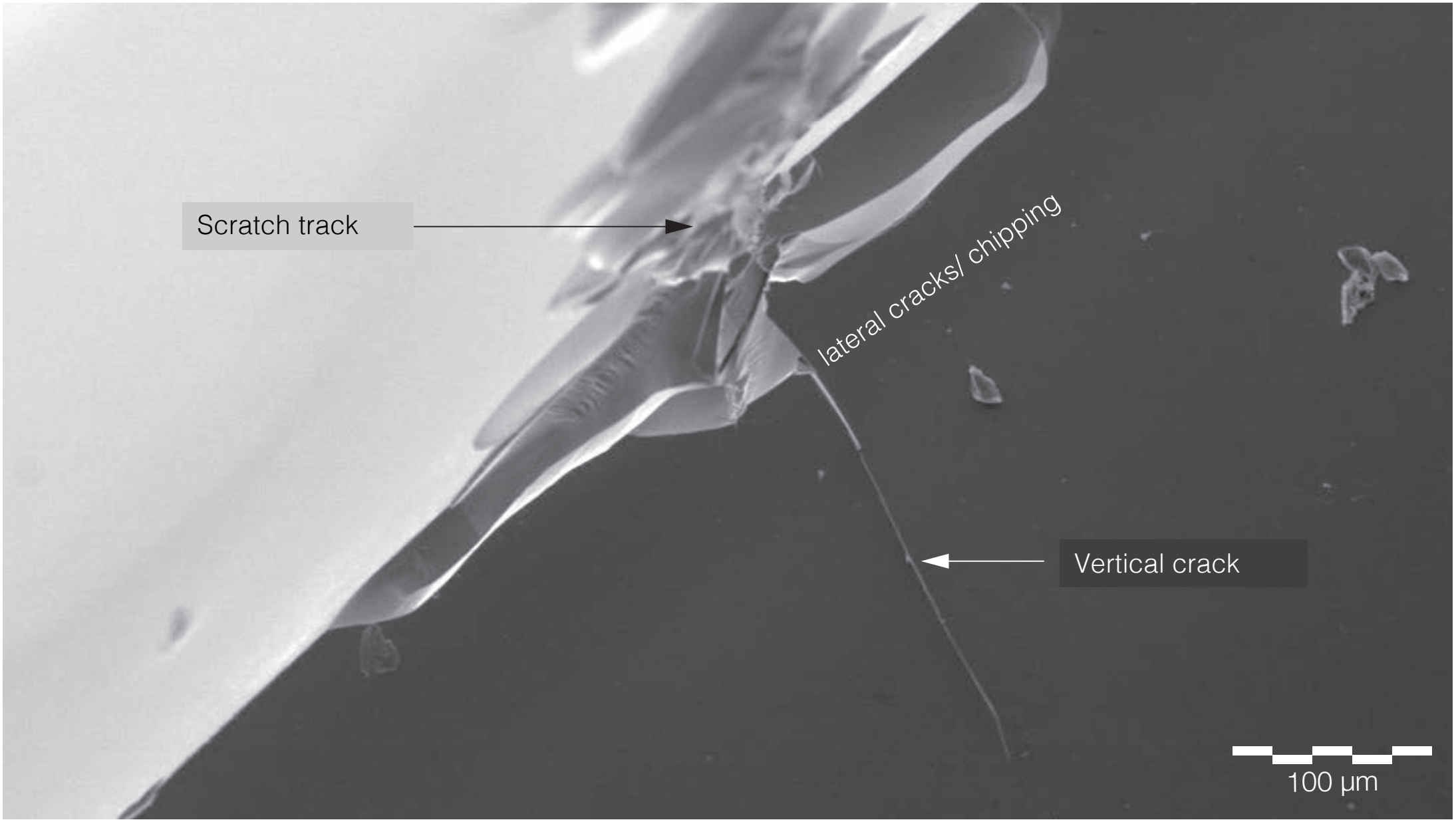

Lab scratch
250 µm
250 µm

Scratch track on glass
Visibility with the human eye
2,0 cm
Schönwiese GmbH


Scratch track on glass
Magnification in SEM 50x – 1000x
glass surface
Scratch track
glass bulk


glass surface
Scratch track
glass bulk
100 μm


Scratch track
vertical crack
glass bulk
10 μm


Scratch track
lateral cracks/ chipping
Vertical crack
100 µm

Crack growths of lateral cracks depends on residual stresses

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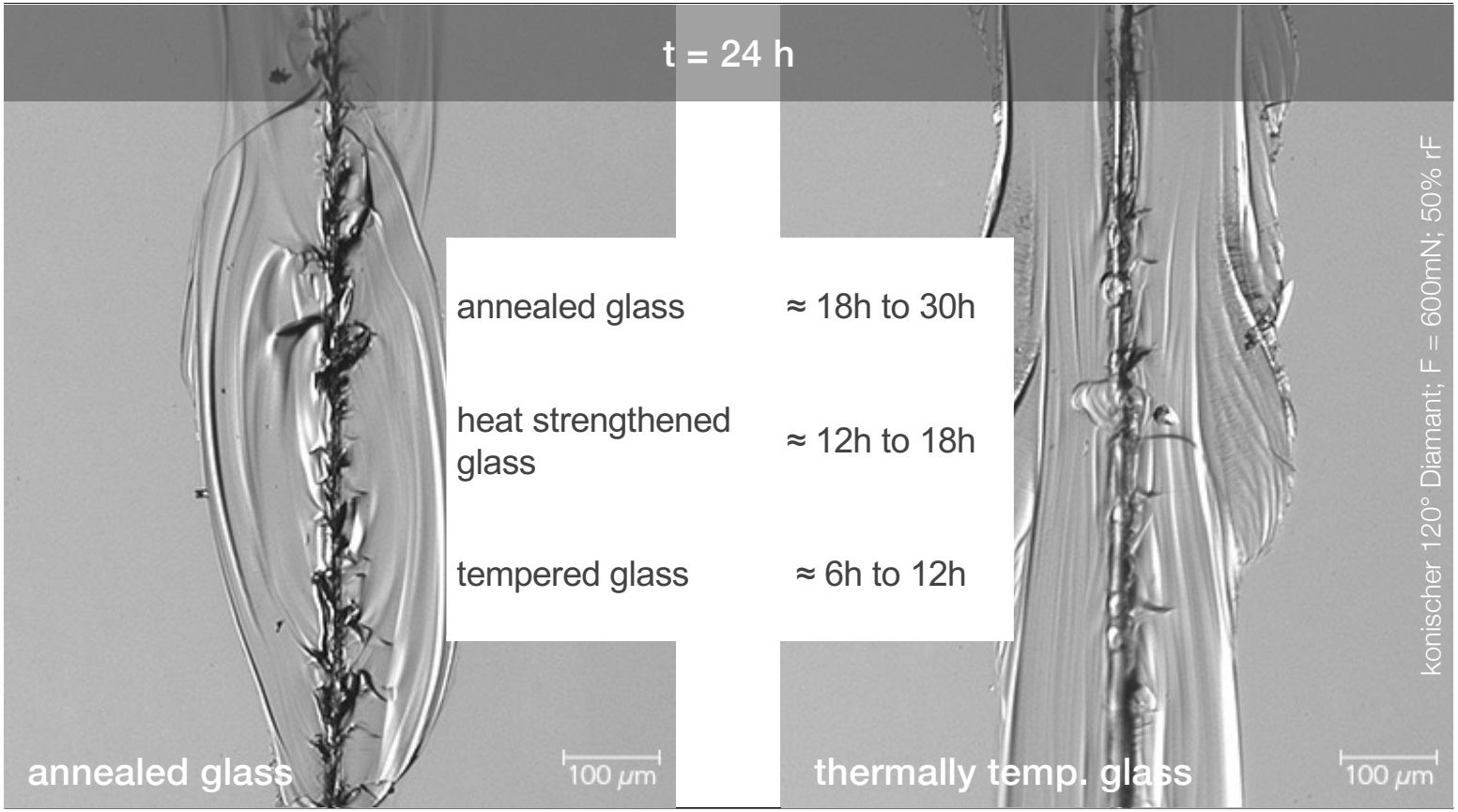

annealed glass	≈ 18h to 30h
heat strengthened glass	≈ 12h to 18h
tempered glass	≈ 6h to 12h

Scratch visibility

strongly depends on the lateral cracks

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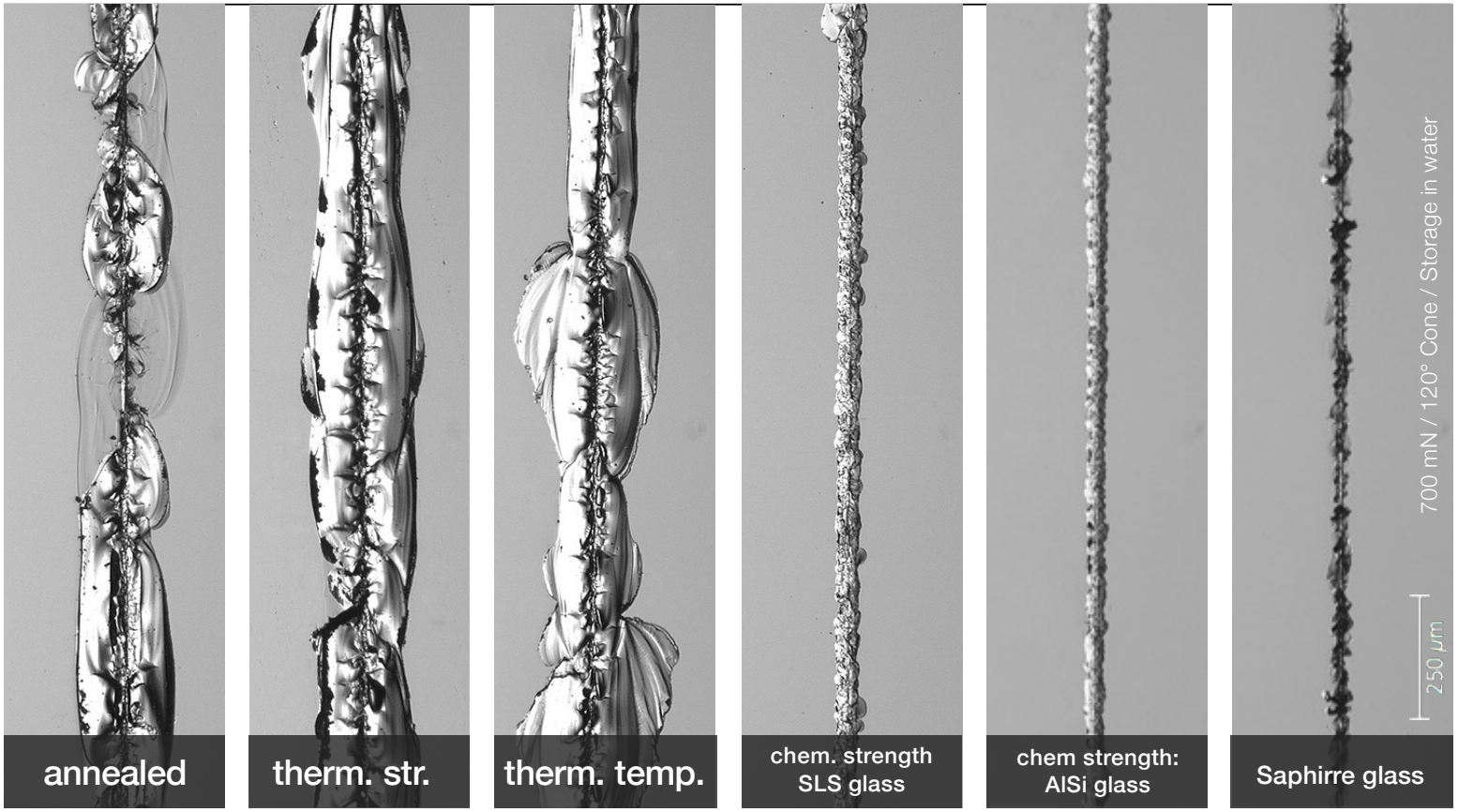

Glass cutting process

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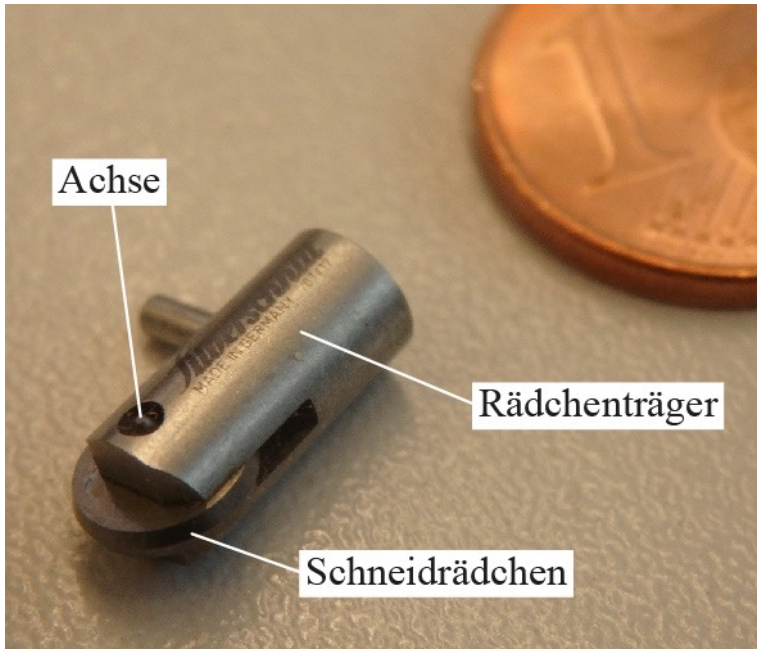
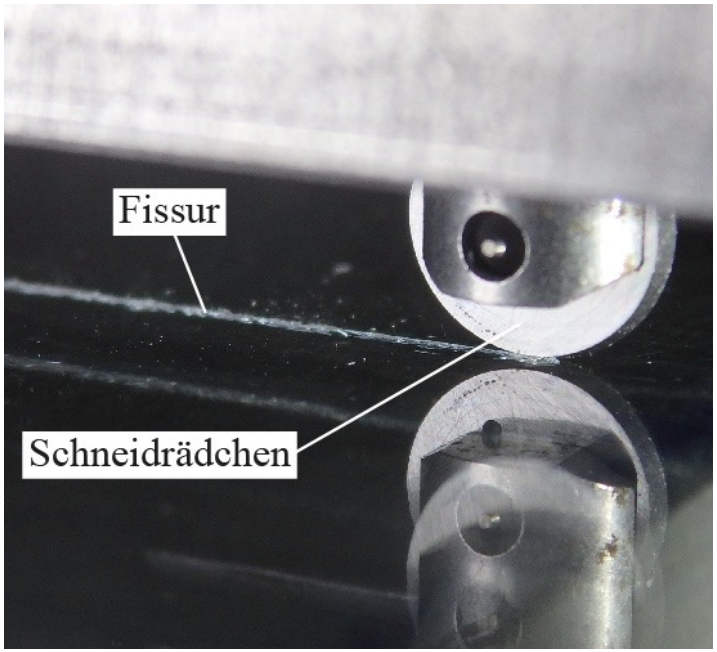
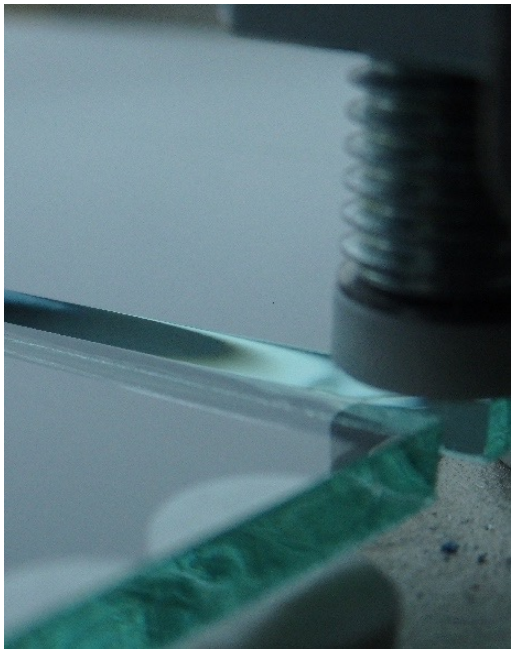


Cutting wheel



Crack initiation



Fracture along crack

Glass Edge Treatment

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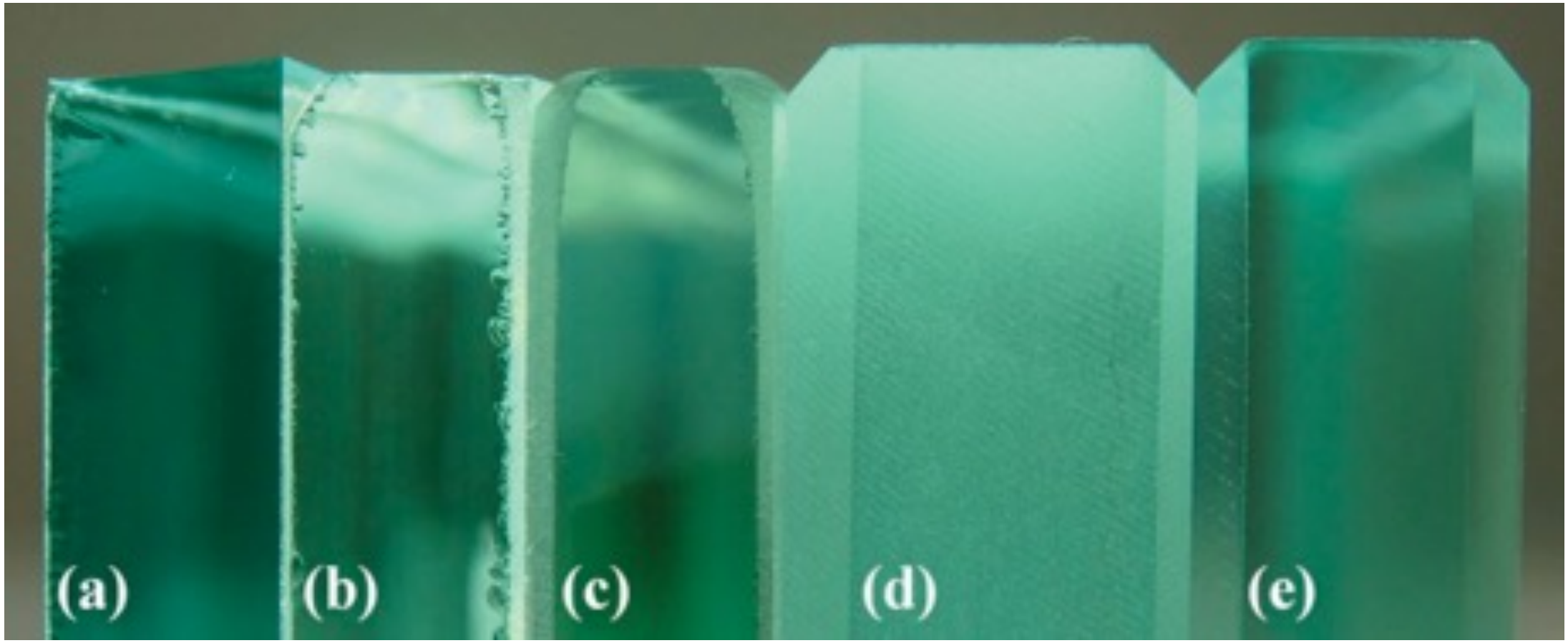

Wrong glass edge from cutting

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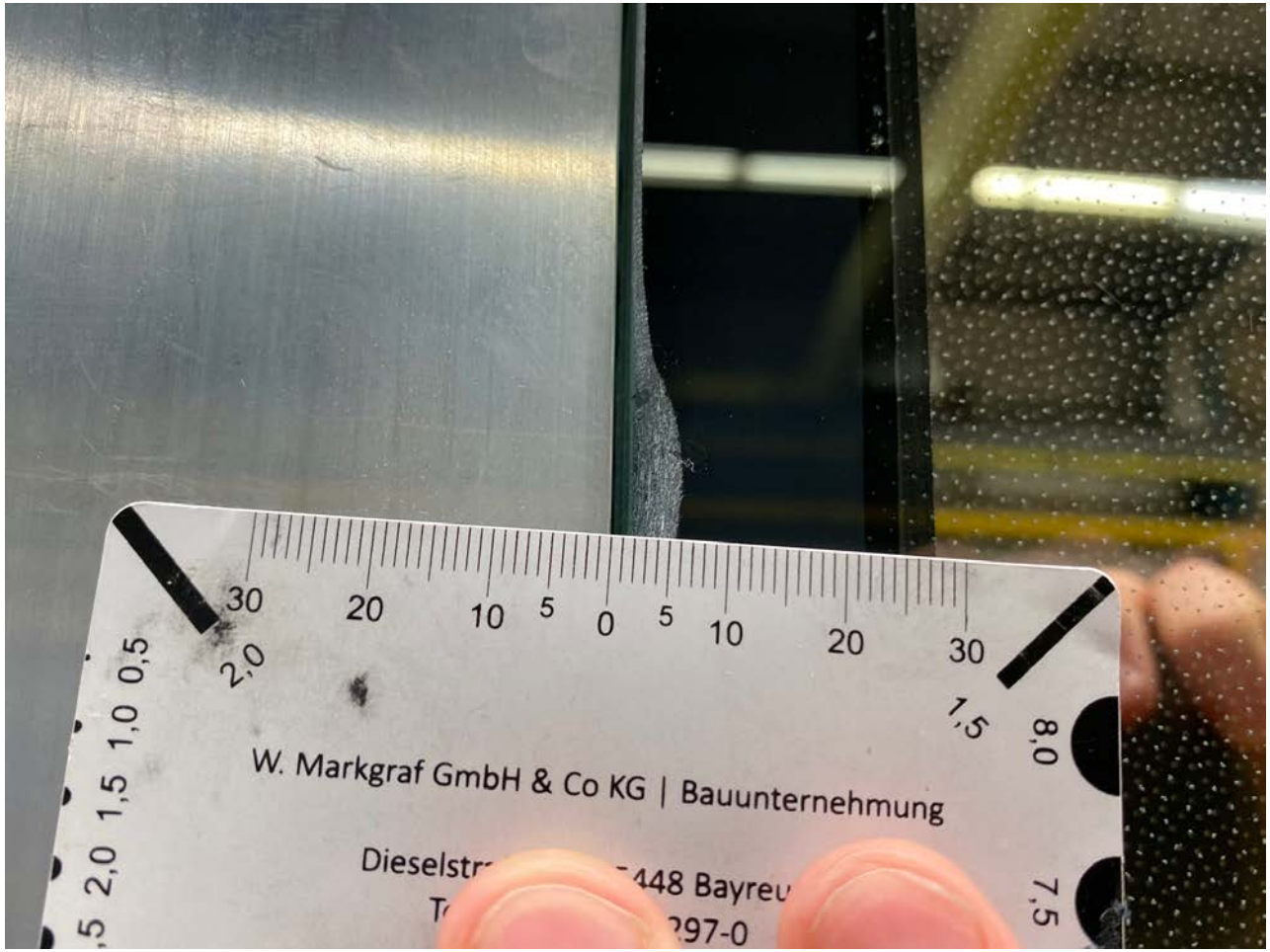

Thermal Tempering of Glass Process

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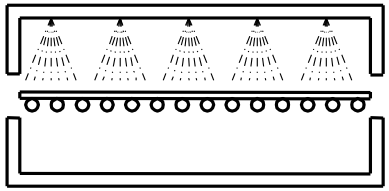
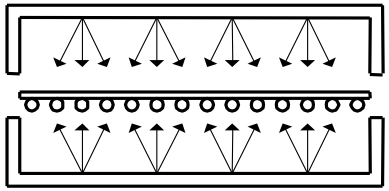
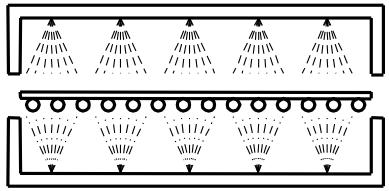


cleaning



heating

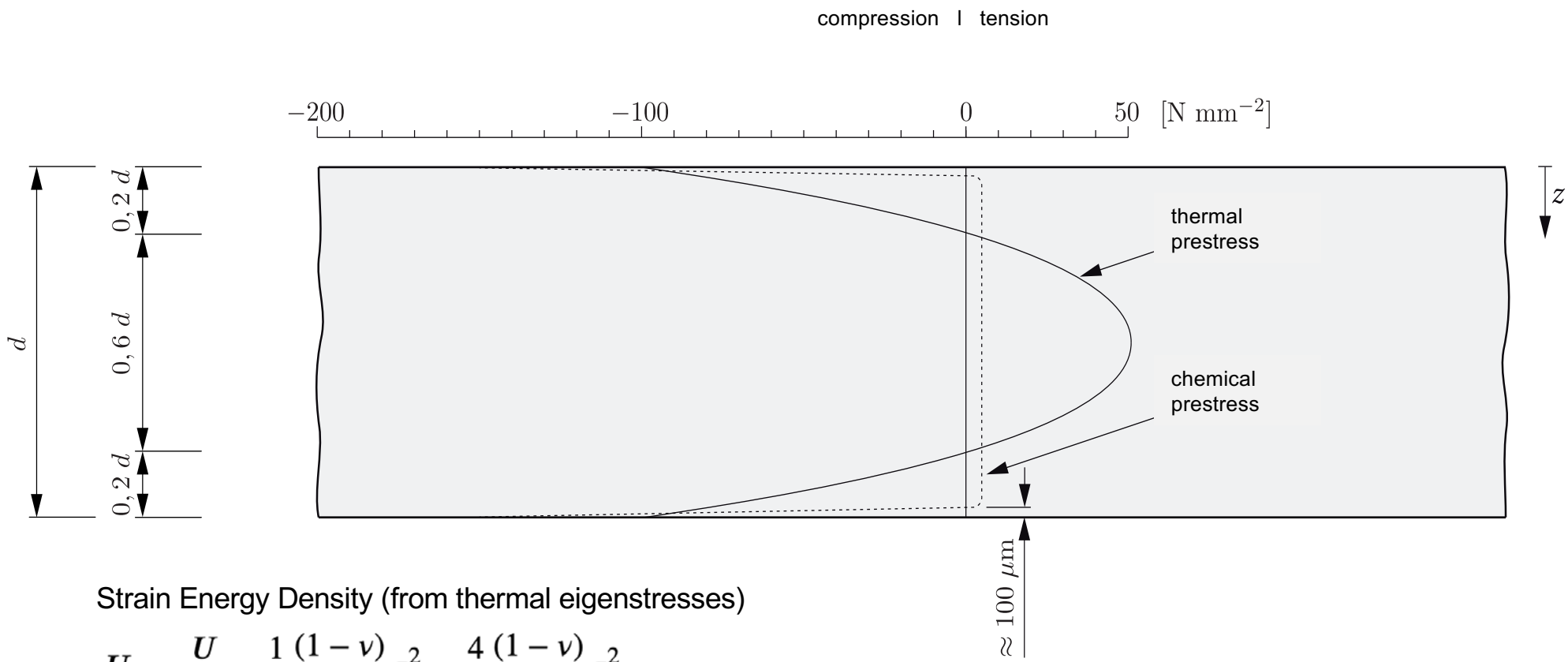


cooling

Source: Glasston

glaston

Thermal vs. Chemical Strengthening residual stress states



Strain Energy Density (from thermal eigenstresses)

$$U_D = \frac{U}{h} = \frac{1}{5}\frac{(1-\nu)}{E}\sigma_s^2 = \frac{4}{5}\frac{(1-\nu)}{E}\sigma_m^2$$

St. Rupert‘s drop: sudden cooling of glass drops in water

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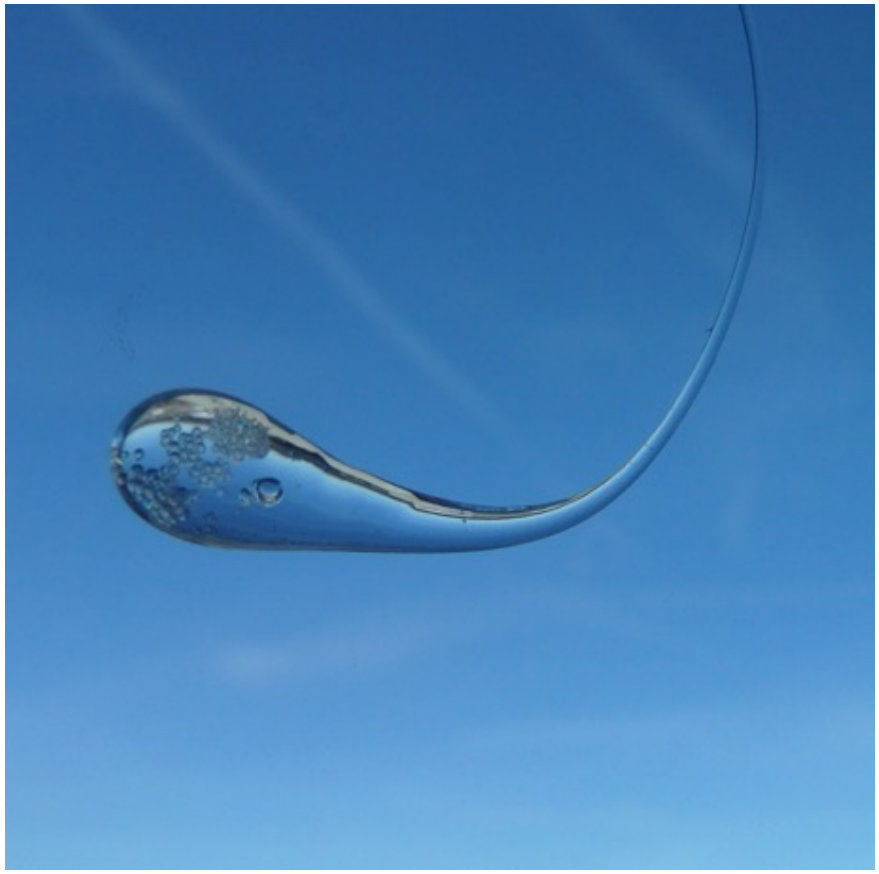

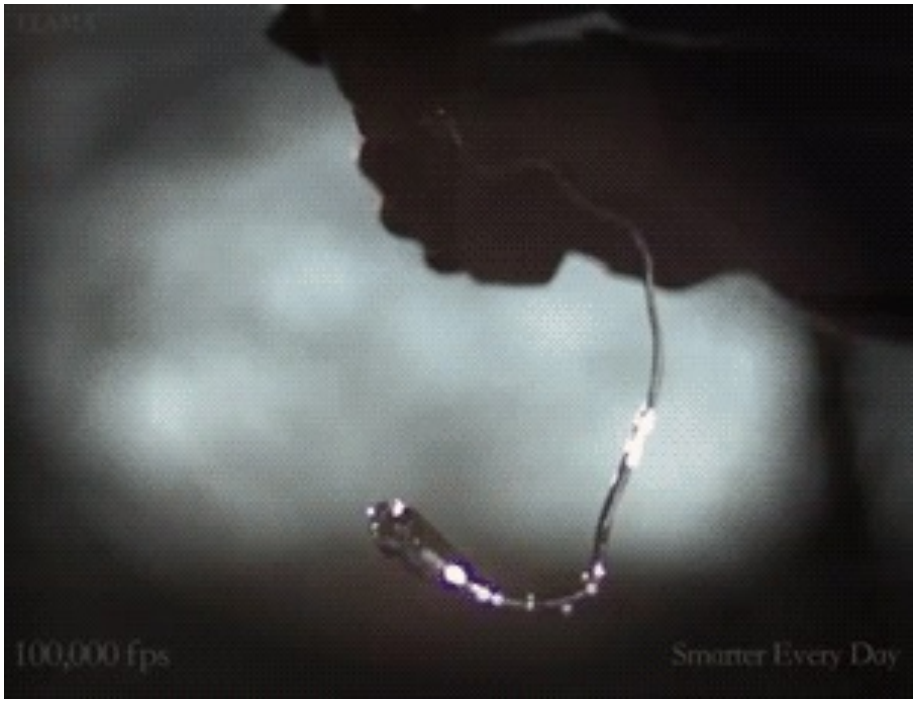

https://medium.com

Fracture speed of tempered glass vs. a bullet speed

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Highspeed-images: crack front v=1530 m/s (!)

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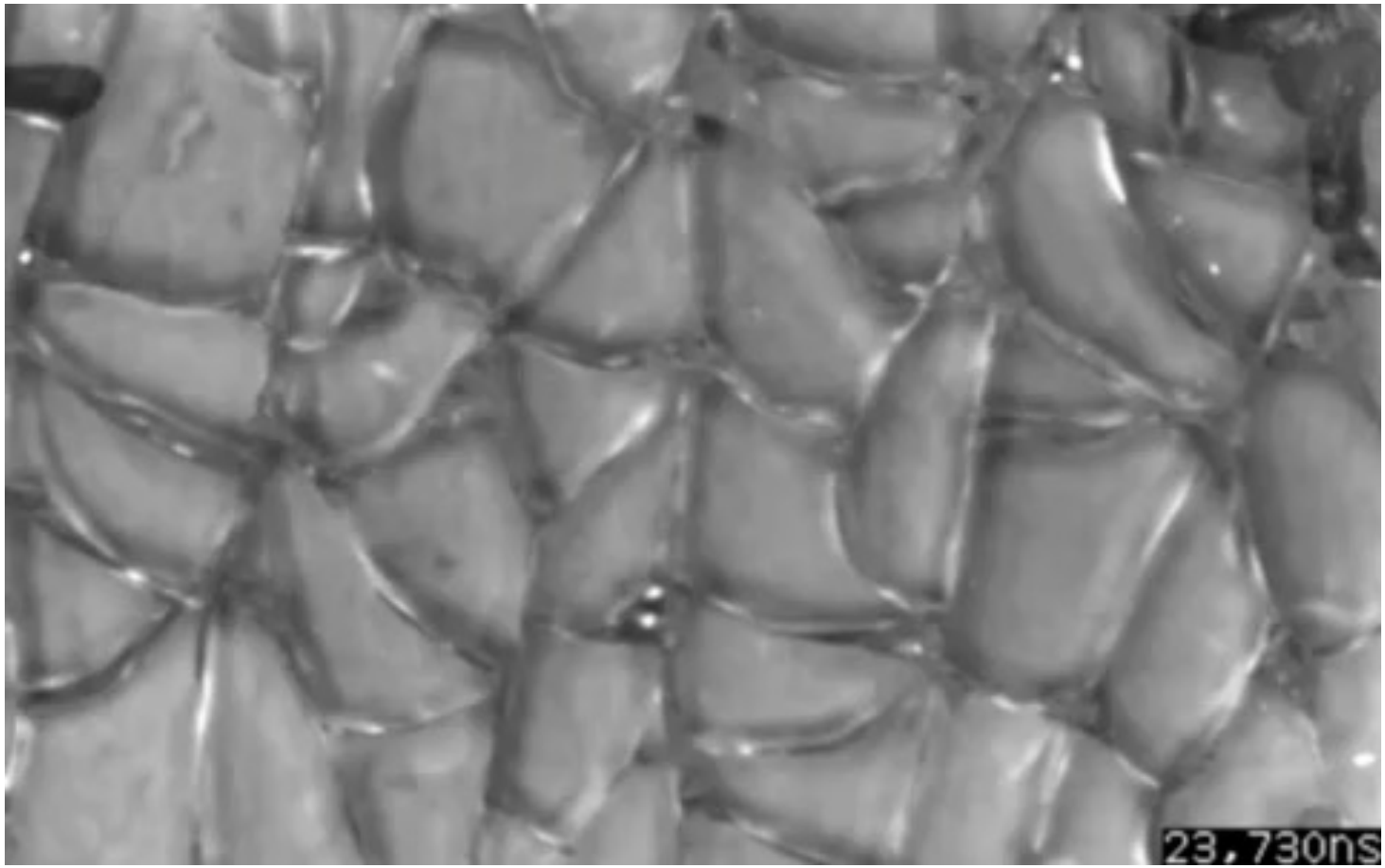

Marking of heat treated glass

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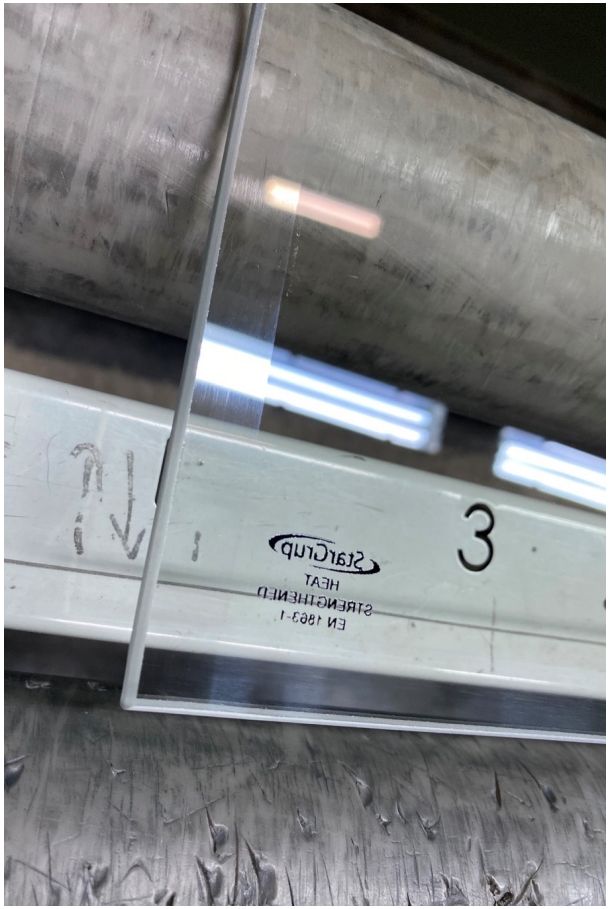

Wrong temper process

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Kevlar wraps the steel

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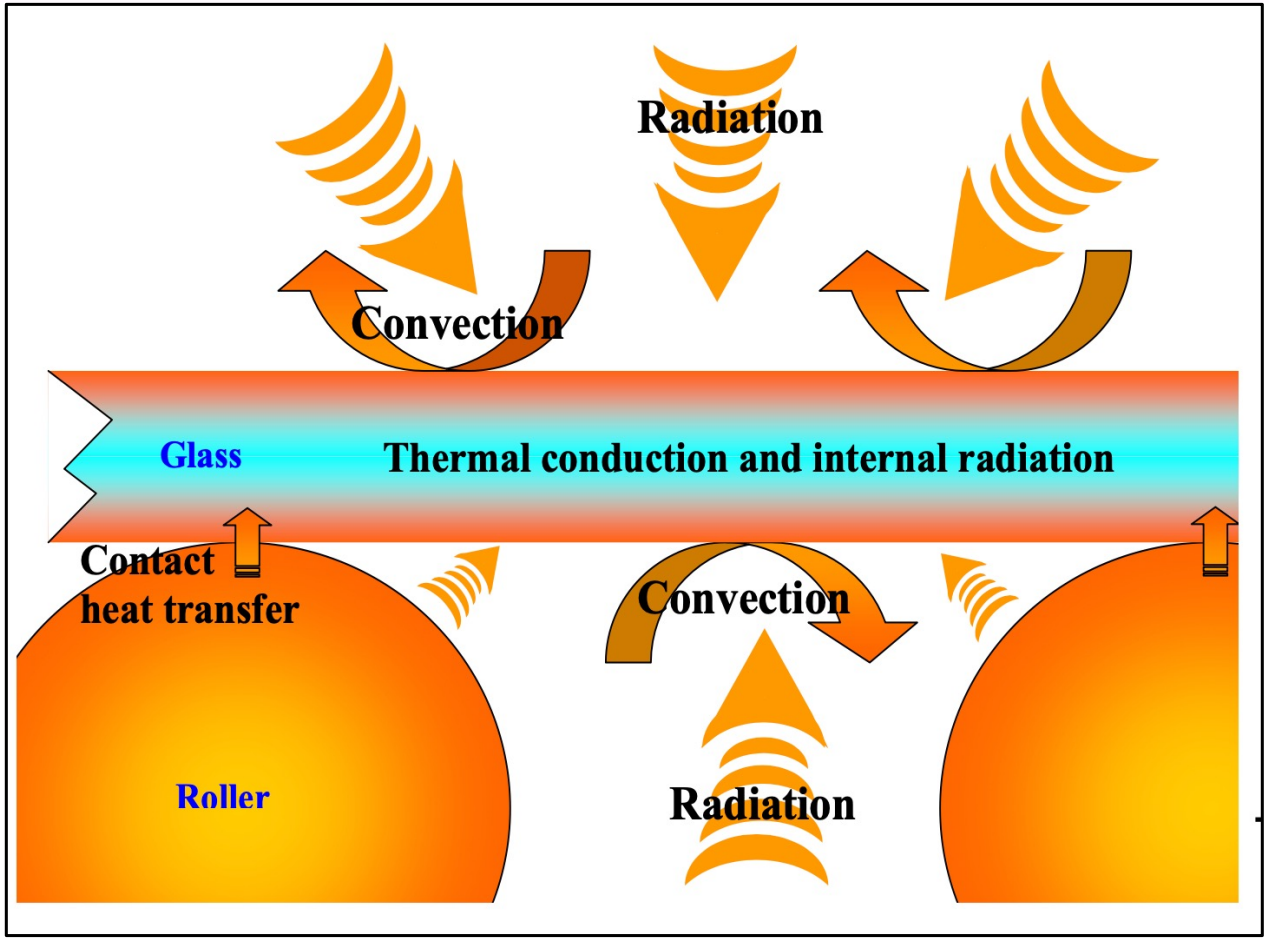
Physical effects during glass cooling



Antti Mikkonen, Reijo Karvinen, Antti Aronen, Mikko Rantala (2017) Effects of non-uniform heat transfer in a tempering process on glass quality. GPD 2017

Optical anisotropies

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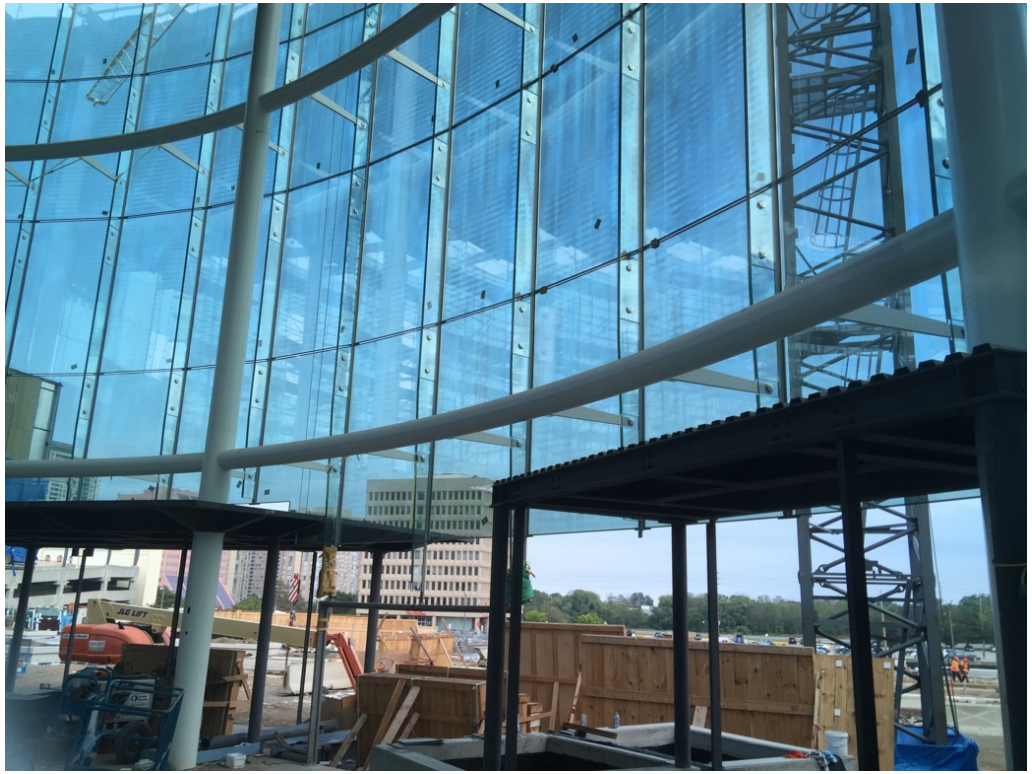

iLooK
glaston

schüco

Warping, roller waves, edge kink: product standard limits

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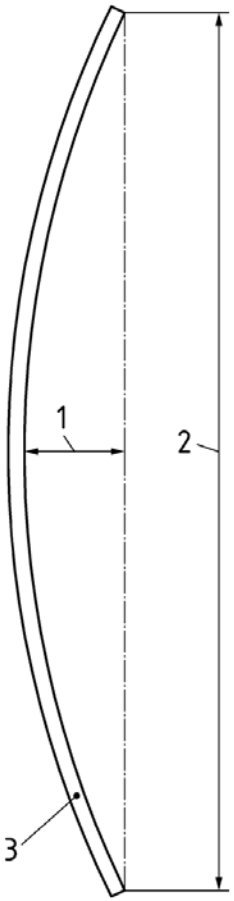
general warping



roller waves

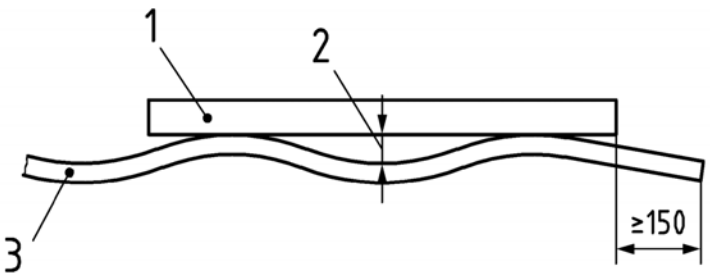


Tabelle 4 — Zulässige Höchstwerte der generellen Verwerfung und der Verwerfung durch Roller Waves bei horizontal vorgespanntem Glas

Glasart	Zulässiger Höchstwert der Verwerfung	
	Generelle Verwerfung	Roller Wave
	mm/m	mm
Unbeschichtetes Floatglas nach EN 572-1 und EN 572-2	3,0	0,3
Sonstige[a]	4,0	0,5
ANMERKUNG Eine geeignete Fühlerlehre ist in Abhängigkeit von der Wellenlänge der Roller Wave zu verwenden.		
[a] Zu emailliertem Glas, dessen Oberfläche nicht vollflächig überzogen ist, sollten die Hersteller befragt werden.		

edge kink

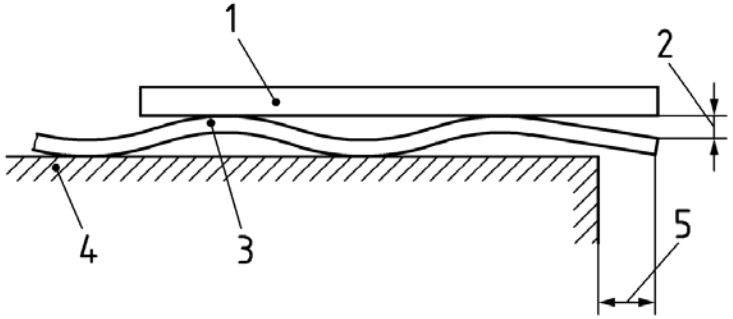
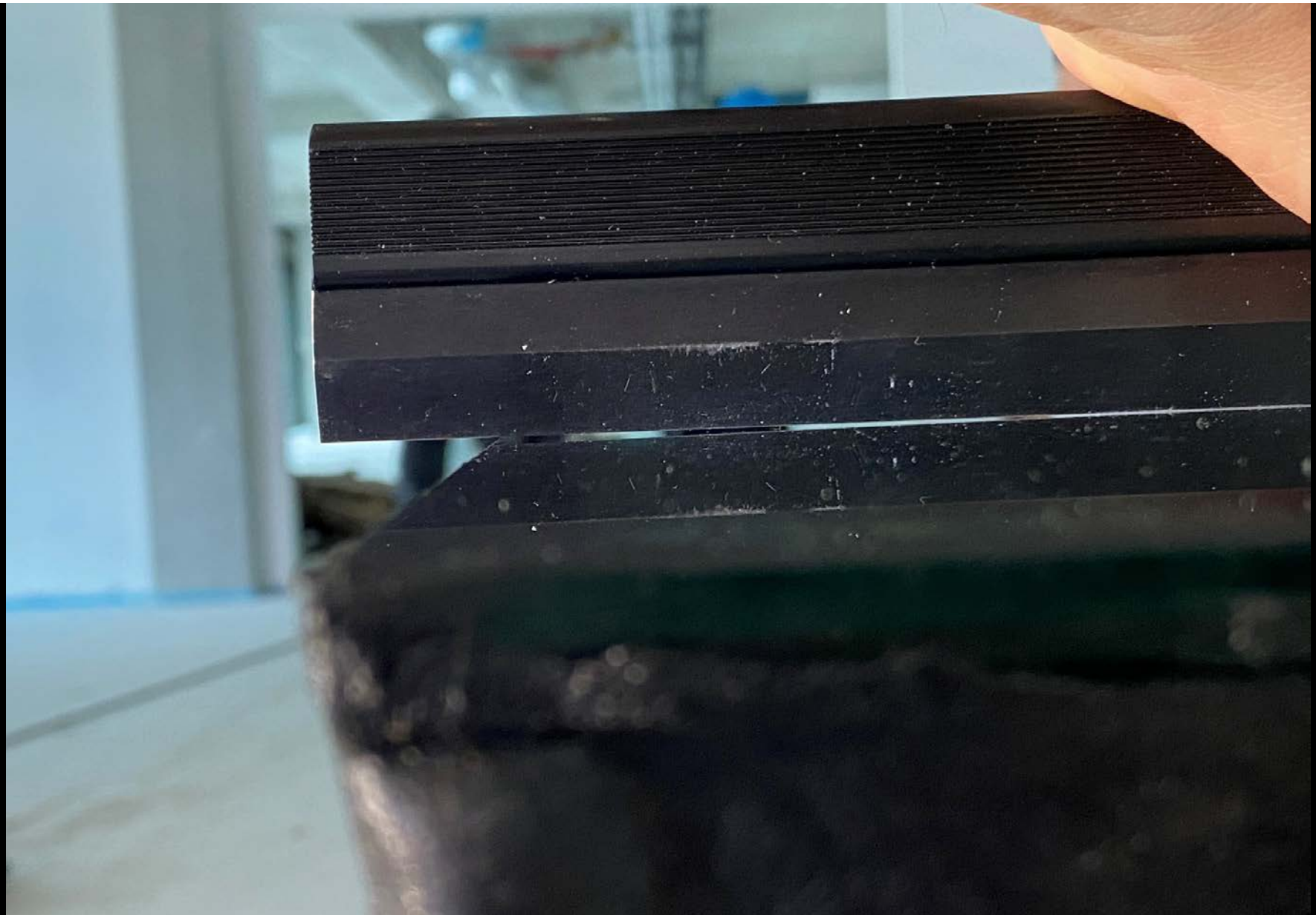


Tabelle 5 — Zulässige Höchstwerte für die Unebenheit der Kanten bei horizontaler Vorspannung

Glasart	Glasdicke	Zulässige Höchstwerte
	mm	mm
Unbeschichtetes Floatglas nach EN 572-1 und EN 572-2	3	0,5
	4 bis 5	0,4
	6 bis 25	0,3
Sonstige[a]	3 bis 19	0,5
ANMERKUNG 1 Eine geeignete Fühlerlehre ist in Abhängigkeit von der Wellenlänge der Roller Wave zu verwenden. ANMERKUNG 2 Zu unbeschichtetem Floatglas mit einer Dicke von 2 mm sollten die Hersteller befragt werden.		
[a] Zu emailliertem Glas, dessen Oberfläche nicht vollflächig überzogen ist, sollten die Hersteller befragt werden.		



0.25 mm
0.60 mm
0.65 mm
0.55 mm
0.50 mm
0.70 mm
0.30 mm

Roller waves on bent glass

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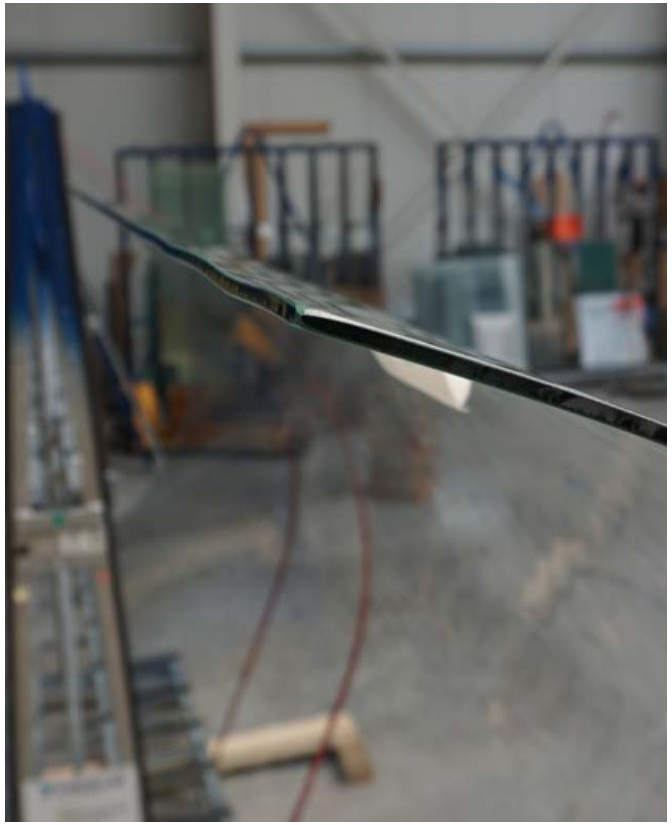

Standards on visual defects, and optical anisotropies, no standard on optical distortions exists

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BF-Guideline 006 / 2019 – Revision index 0

BF Bundesverband Flachglas

Guideline to Assess the Visual Quality of Glass in Buildings

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May 2022

DIN SPEC 18198

DIN

ICS 17.180.99; 81.040.20

Measurement and evaluation methods for optical anisotropic effects in thermally toughened glass
English translation of DIN SPEC 18198:2022-05

Messung und Bewertung von optischen Anisotropie-Effekten bei thermisch vorgespanntem Glas
Englische Übersetzung von DIN SPEC 18198:2022-05

How to overcome the brittle nature of glass?

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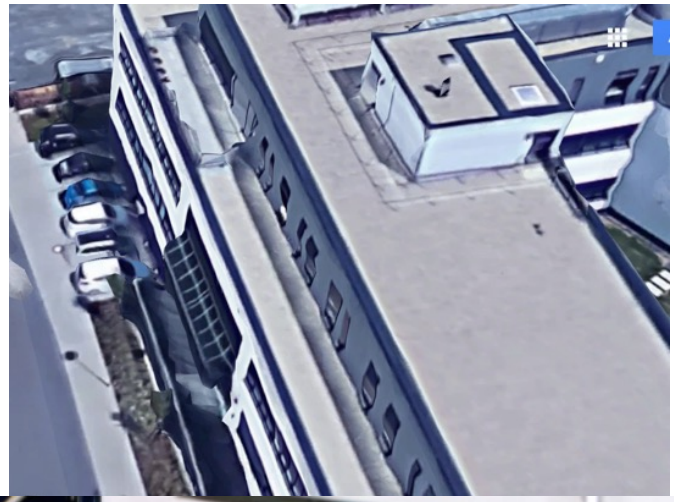

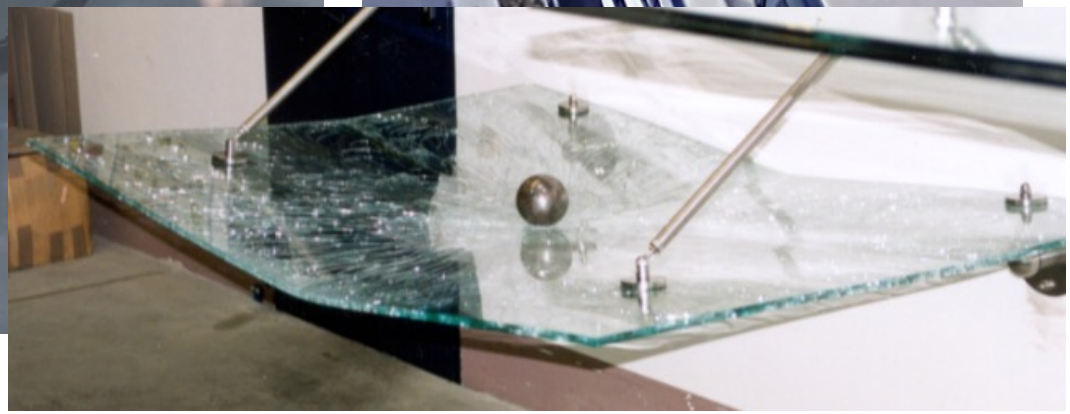

Fail-Safe my lamination

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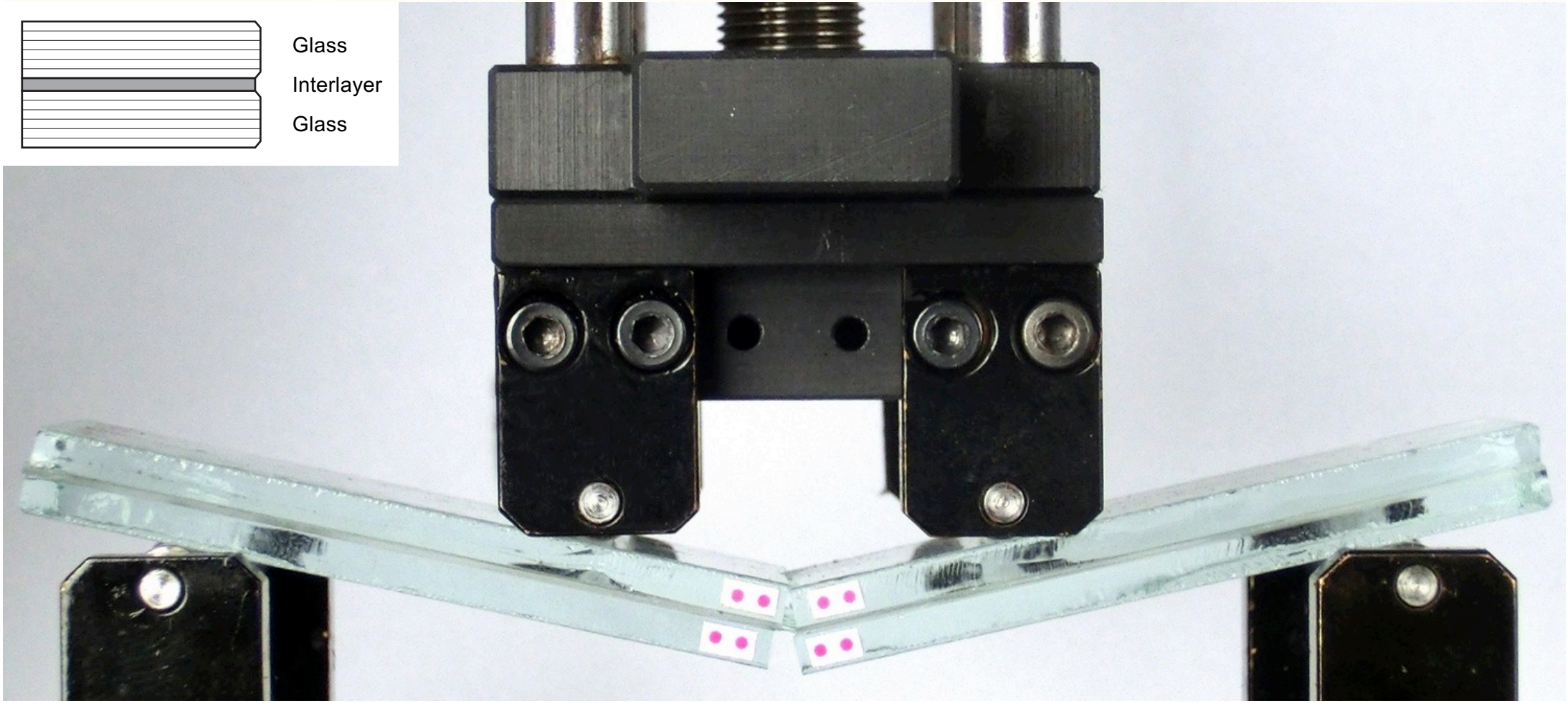
Glass

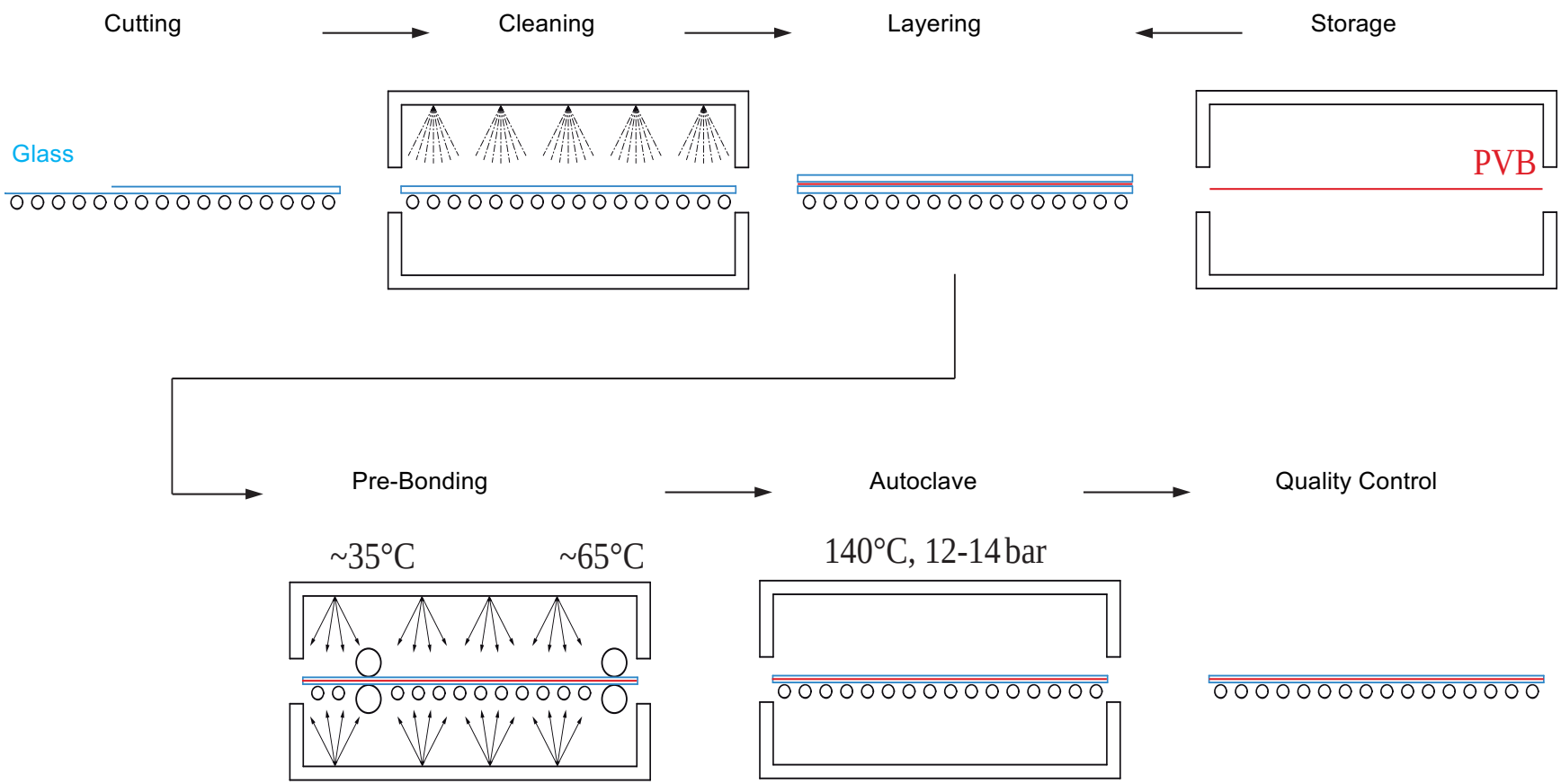
Interlayer

Glass



Laminated Glass

Manufacturing process



Laminated Glass

Ball drop test

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Laminated Glass Dimensions

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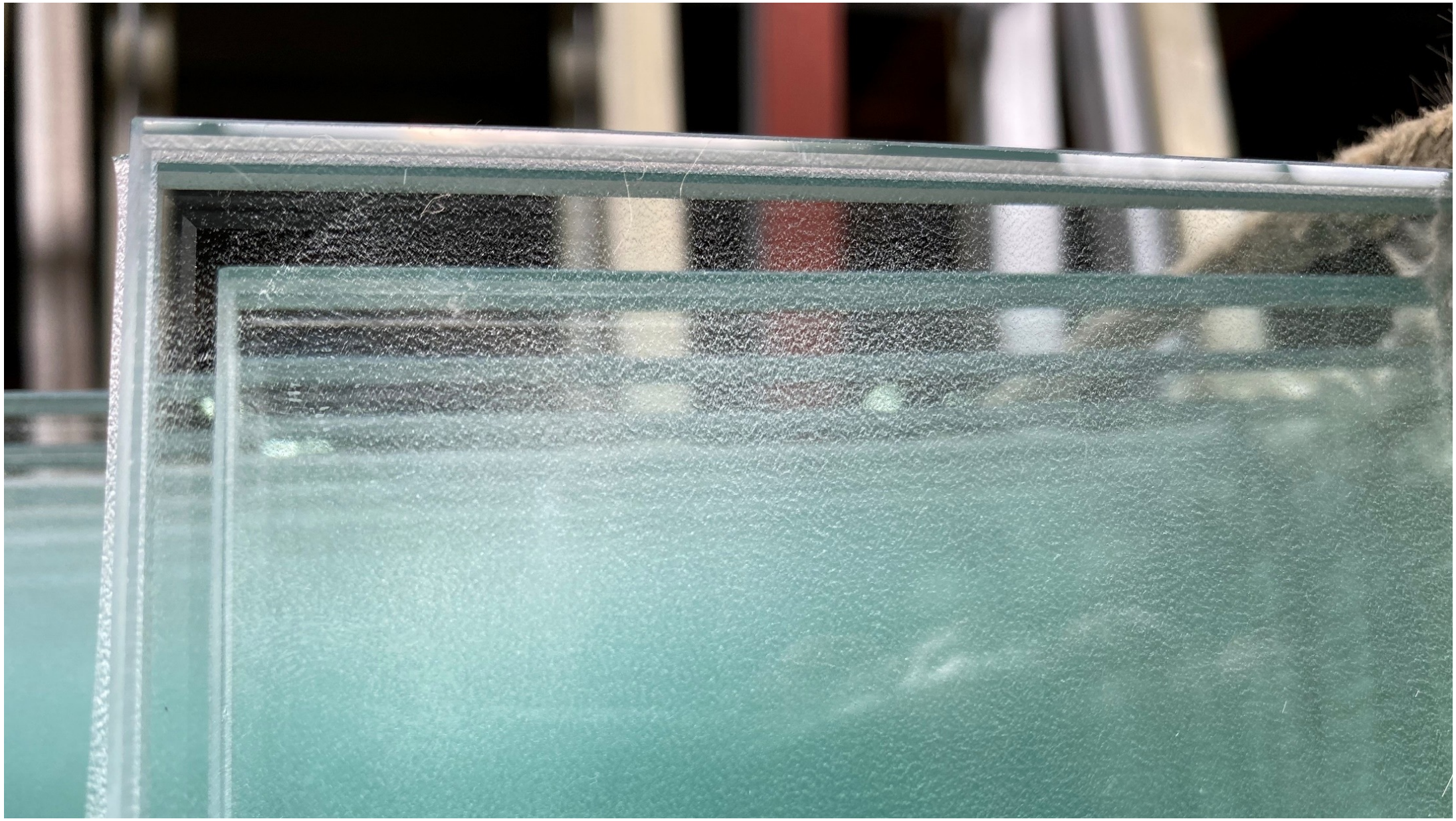
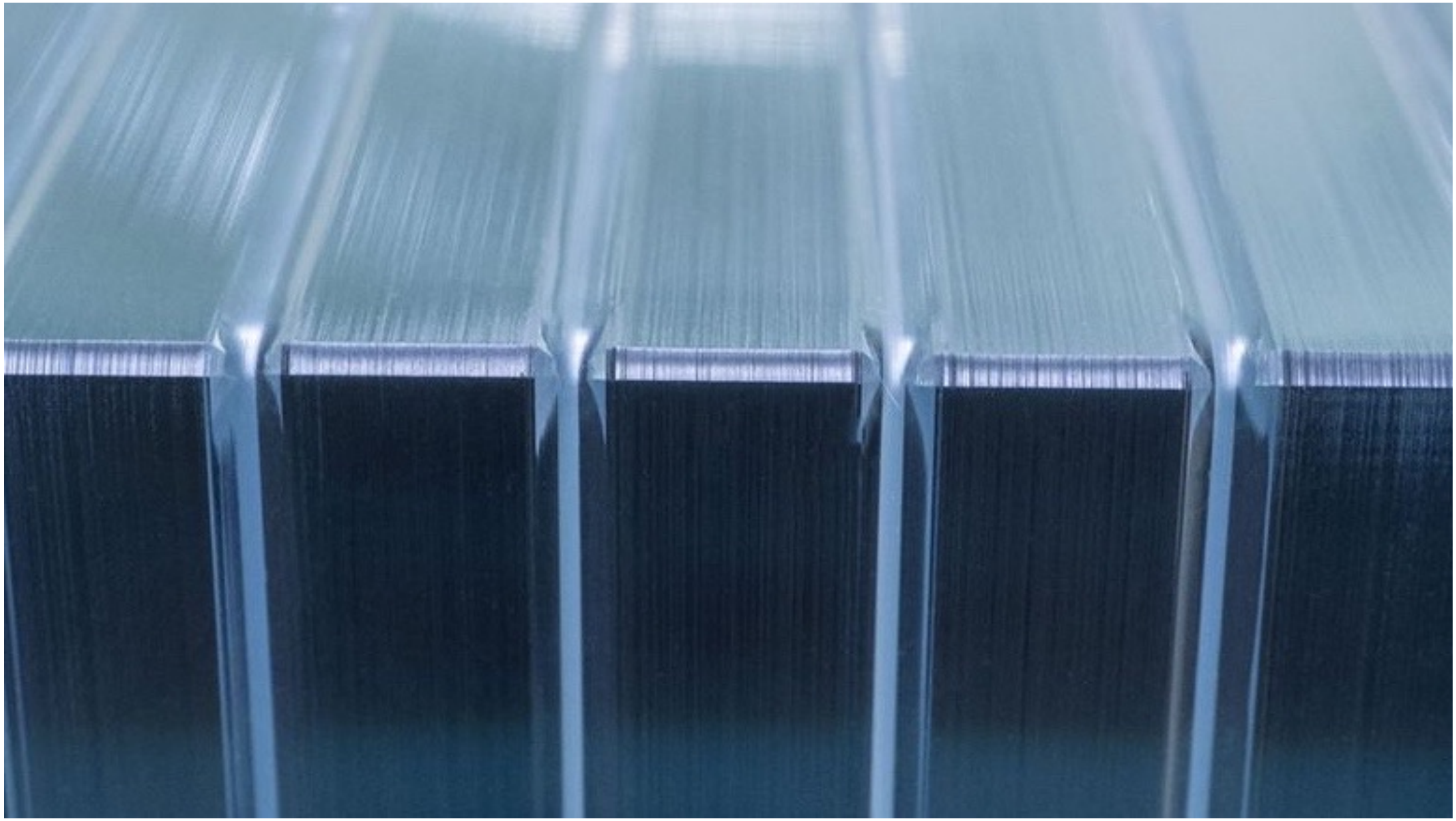
Today: 3.600 mm x 20.000 mm

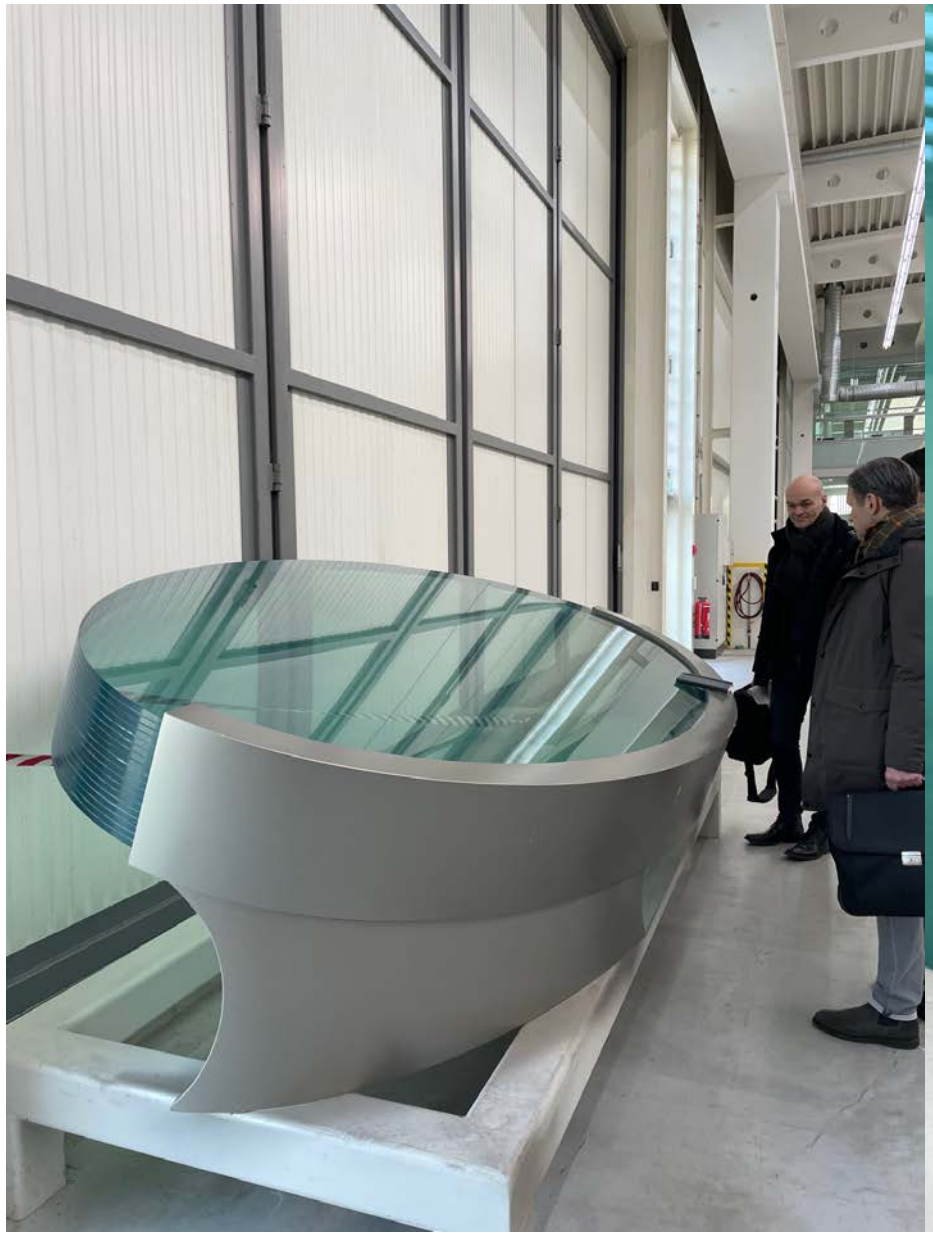
alaston

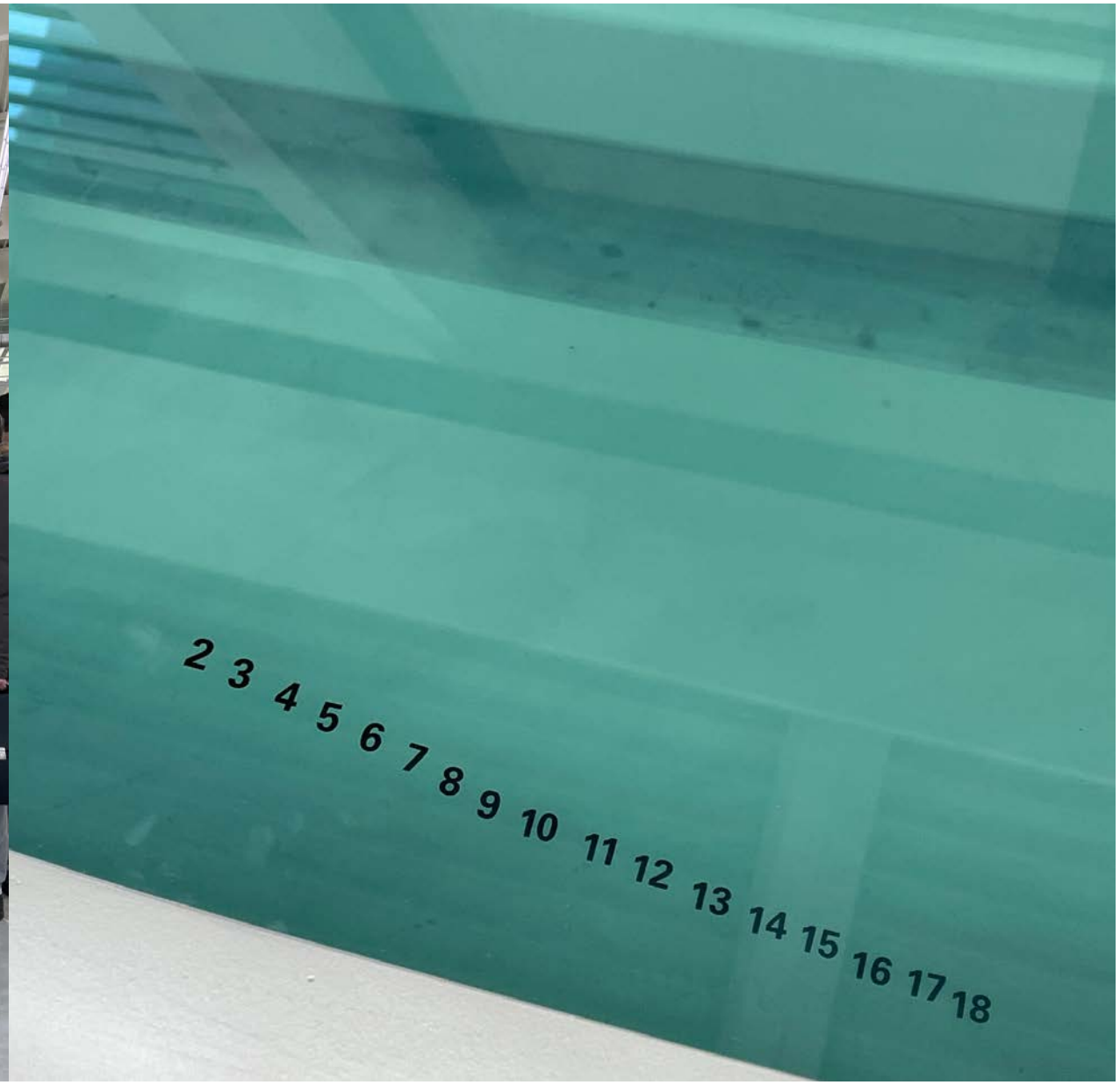
glaston



SCHOLZ



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Delamination

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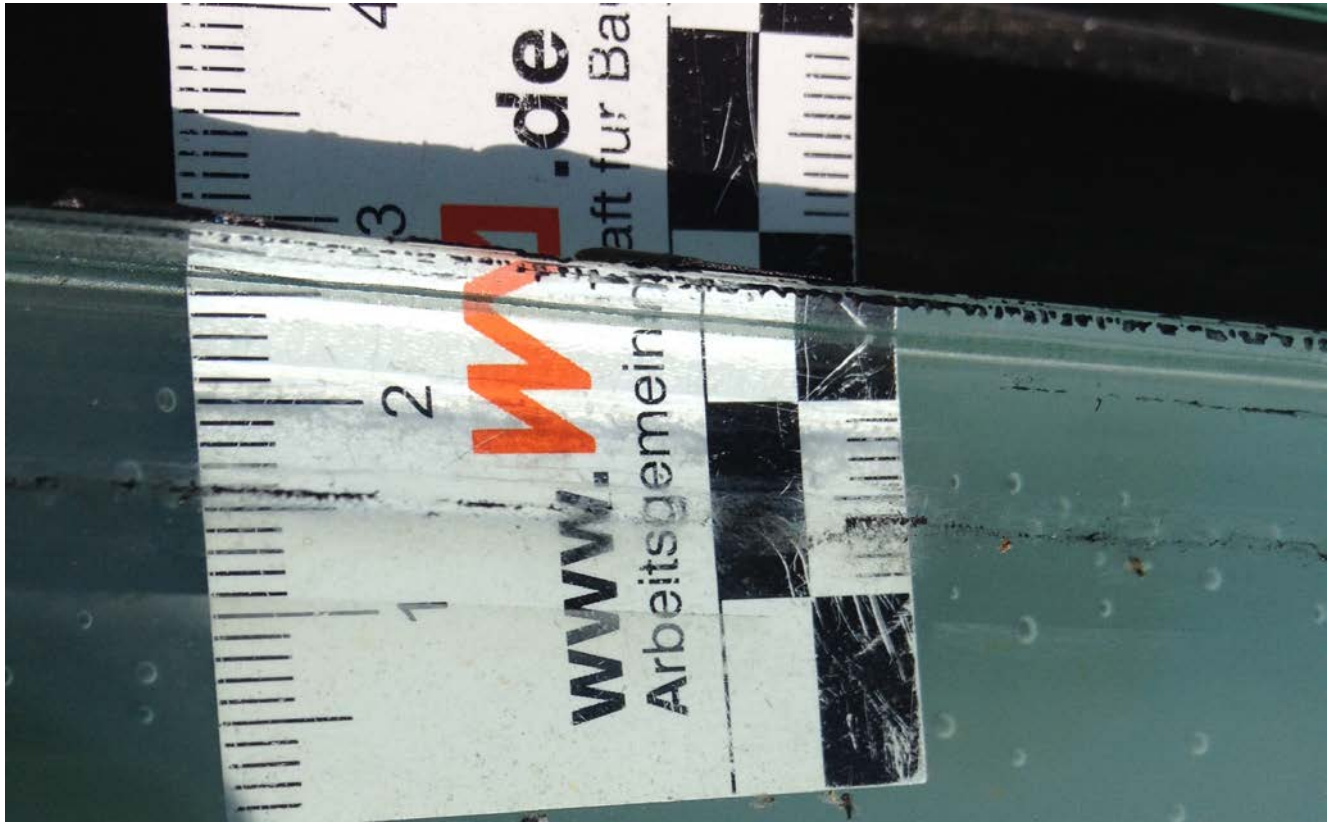

1 2 3 4 5 6 7 8 9
10 cm
www.WTA.de Wissenschaftlich-Technische
Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege e.V.

Glass Cube Leonardo, 2005
Architects: 3deluxe
Engineering: Schlaich Bergermann und Partner

Glass Cube Leonardo, 2022

Glass & Polymers Team 2023

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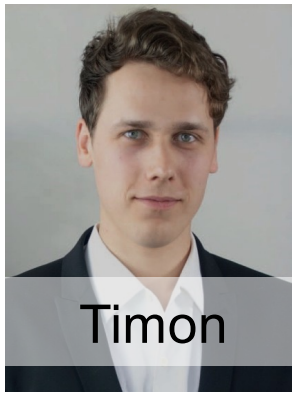

State Material Testing Agency (MPA) Darmstadt

Glass Structures & Engineering Journal

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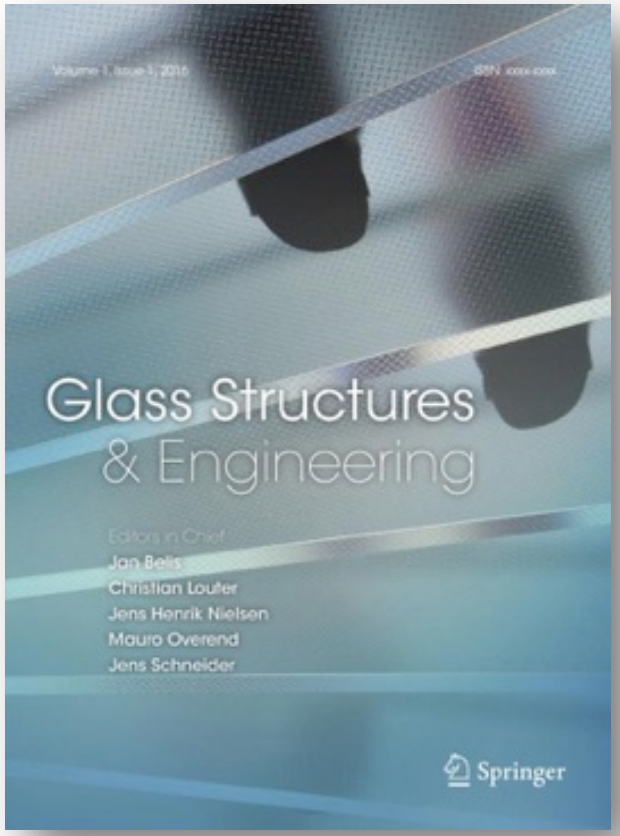

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Thank you for your attention.