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Improvement of hail test setup for larger hailstones

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ABSTRACT

Climate change is playing a major role in the increasing of severe weather phenomena, even more when we consider alpine environment, where hailstorms are more frequent and intense: in 2021 the damages due to storms and hailstorms amounted to 1,9 billion Euro only in Switzerland. This trend is subject of detailed scientific studies, aiming at the definition and validation of risk maps to forecast the frequency of events, with extended ranges up to 50 years, in order to choose the appropriate, robust products to reduce the insurance costs in higher risk areas. The hail damage is of particular relevance for photovoltaics, for this reason, a dedicated IEC working group for the definition of a new technical specification (IEC TS 63397) has been set up. The traditional hail test, foreseen at IEC level to qualify a PV module (IEC 61215-2, MQT17), is set to 25mm of diameter and 80 km/h (22 m/s) of speed. In Switzerland, due to the particular conditions of the environment, the applied standard, issued by VKF (Vereinigung Kantonaler Feuerversicherungen) is more demanding, setting minimum requirement at 30 mm but in practical terms, raising it to 40 mm and more. In this framework, SUPSI PVLab, the only ISO 17025 accredited test laboratory for PV modules in Switzerland, is working on improvements of the hail test stand, to reach up to 100mm of diameter and 166 km/h of speed, in order to grant sufficient test margins for the module manufacturers to evaluate the robustness of their products.

Normatives

GENERAL REQUIREMENTS

The VKF (APIB) test specifications are used for the determination of the hail impact resistance of building components on the basis of consistent, product-neutral testing and classification methods. They include the generally valid guidelines for the execution of a hail impact resistance test (APIB Test Specification No. 00a - GENERAL SECTION A, Part A), binding instructions on the documentation of the test set-up and the results achieved (APIB Test Specification No. 00b - GENERAL SECTION B, Part B), as well as supplementary specifications relevant to specific building components.

The standard SIA 261/1 (2003), Art. 6.2.4 refers to the Swiss Hail Impact Protection Register of the CFIA. Published in the Hail Impact Protection Register for the building components entered are the hail impact resistance classes achieved in the hail impact resistance test for all the component functions required in the component-specific test specifications. The Swiss Hail Impact Protection Register of the CFIA should make it easier for users to select a product that has been tested and classified. It has a similar structure to the Swiss Fire Protection Register of the CFIA.

Classification VKF and IEC

The VKF definition of a hail impact resistance class (HW n) is based on the diameter of a hailstone:

- Hail resistance class 1 (**HW 1**) is defined by the kinetic energy at impact of a hailstone with a diameter of **10 mm**
- Hail resistance class 2 (**HW 2**) is defined by the kinetic energy at impact of a hailstone with a diameter of **20 mm**
- Hail resistance class 3 (**HW 3**) is defined by the kinetic energy at impact of a hailstone with a diameter of **30 mm**
- Hail resistance class 4 (**HW 4**) is defined by the kinetic energy at impact of a hailstone with a diameter of **40 mm**
- Hail resistance class 5 (**HW 5**) is defined by the kinetic energy at impact of a hailstone with a diameter of **50 mm**

For the hailstones of 10 to 50 mm diameter the following Class boundaries, in terms of impact kinetic **energy**, mass and velocity are defined, including the intermediate values for the projectile diameters 25 mm, 35 mm, 45 mm, 55 mm, 65 mm and 75 mm (from Appendix B -Table 4 of the VKF reference standard), and the values for the larger projectile sizes (60 mm, 70 mm and 80 mm - from Appendix B -Table 3 of the VKF reference standard). The impact energies as defined in in the international IEC and European standardization are shown as well:

Hail resistance **CLASS**	Hailstone **diameter**	G_{min} - **min. mass**	G_{MAX} - **MAX mass**	v_R - **Velocity** on impact	**Impact energy** - min. limit E_{min}	**Impact energy** - MAX limit - E_{MAX}
	[mm]	≥ [g]	≤ [g]	[m/s]	≥ [J]	≤ [J]
HW1	**10**	0.43	0.51	13.77	0.04	0.09
	15	1.46	1.71	16.87	0.22	0.37
HW2	**20**	3.46	4.04	19.48	0.69	1.0
	25	6.76	7.90	21.77	1.69	2.3
HW3	**30**	11.68	13.65	23.85	3.50	4.4
	35	18.55	21.67	25.76	6.5	7.9
HW4	**40**	27.70	32.35	27.54	11.1	13.2
	45	39.43	46.06	29.21	17.7	20.9
HW5	**50**	54.09	63.18	30.79	27.0	31.5
	55	72.00	84.10	32.30	39.5	45.9
	60	93.47	109.18	33.73	56.0	64.7
	65	118.85	138.81	35.11	77.1	89.0
	70	148.43	173.38	36.44	104	120
	75	182.57	213.25	37.72	137	157
	80	221.57	258.80	38.95	177	204

VKF definition of a hail impact resistance class

min	DIAM.	max	min	MASS	max	min	VEL.	Max	min	ENERGY	Max
	[mm]			[g]			[m/s]			[J]	
23.75	**25**	26.25	7.15	**7.53**	7.91	22.31	**23.0**	24.15	1.78	**2.0**	2.31
33.25	**35**	36.75	19.67	**20.7**	21.74	25.84	**27.2**	28.56	6.57	**7.7**	8.86
42.75	**45**	47.25	41.71	**43.9**	46.10	29.17	**30.7**	32.24	17.74	**20.7**	23.95
52.25	**55**	57.75	76.19	**80.2**	84.21	32.21	**33.9**	35.60	39.51	**46.1**	53.35
61.75	**65**	68.25	125	**132.0**	139	34.87	**36.7**	38.54	76.22	**88.9**	102.91
71.25	**75**	78.75	193	**203.0**	213	37.53	**39.5**	41.48	136	**158**	183

EN-IEC 61215-2:2021 hail test parameters

Basic principles of VKF hail resistance test

Natural hailstones can assume different shapes. In principle, however, spherical projectiles made of transparent, optically clear ice (produced by different methods) are used for testing. The ice quality is periodically checked by the testing house, by means of inter-laboratory tests.

The test parameters are deliberately selected so that, in comparison with natural hailstones, the projectiles travel at a higher speed. By doing this, it could be ensured that the hailstones that occur in nature would, most probably, have a lower impact kinetic energy than those used for testing. For the determination of the physical data in the nature and in the testing laboratory, the following equations are used:

Calculation of kinetic **energy**:

$$E_H = \frac{m_H \cdot v_A^2}{2}$$

E_H : impact energy of hailstone [J]
m_H : mass of hailstone [kg]
v_A : speed on impact (“velocity”) [m/s]

Calculation of the **mass** of the hailstone:

$$m_H = V_H \cdot \rho_{Eis} = \frac{4 \cdot \pi \cdot \left(\frac{d_H}{2}\right)^3}{3} \cdot \rho_{Eis}$$

m_H : mass of hailstone [kg]
V_H: volume of hailstone [m³]
ρ_{Eis} : ice density [kg/m³]
d_H: diameter of hailstone [m]

Calculation of the **velocity** on impact:

The speed on impact according to SIA 261/1 (referred also as "velocity of fall" in SIA 261/1) is calculated from the diameter of the hailstone, density of the ice and density of the air, gravitational acceleration and air drag coefficient:

$$v_{max} = \sqrt{\frac{4 \cdot \rho_{Eis} \cdot d_H \cdot g}{3 \cdot \rho_{Luft} \cdot c_w}}$$

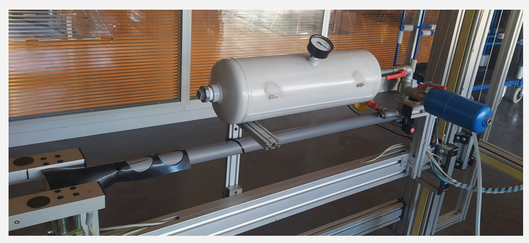
v_{max} : maximum speed on impact (“velocity”) [m/s]
ρ_{Eis} : ice density [kg/m³]
ρ_{Luft} : air density [kg/m³]
d_H : diameter of hailstone [m]
g : gravitational acceleration = 9.81 [m/s²]
c_w : air drag coefficient of a sphere with a slightly rough surface [-]

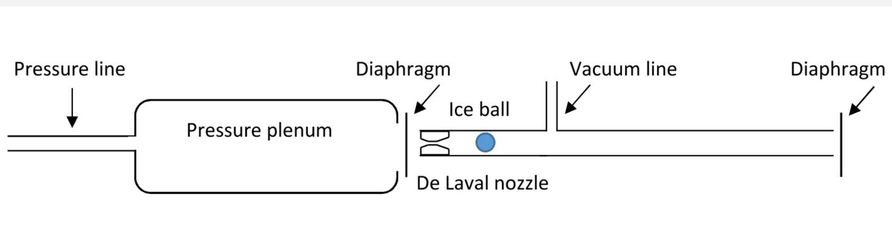
Values assumed for the evaluation of impact kinetic energy:
ρ_{Eis} = 870 [kg/m³] - density of projectile
ρ_{Luft} = 1.2 [kg/m³] – air density at ambient temperature =20°C, 1 atm.
c_w = 0.5 [-] air drag coefficient of a sphere with a slightly rough surface

Methods, results and improvements achieved

- Study about the possibility to increase the capability of hail test setup to shoot at 70, 80, 90 and 100mm, in order to give margin to the manufacturers to understand effective behaviour under extreme events.
- Need to increase the air speed out of the compressive air cannon in order to control the speed of 110-450g of ice: VKF standard is more stringent than IEC standard for what concern limits on impact energy.
- Use of schematic for “ultra sonic ping pong ball” with 3D printed “De Laval” nozzle and Venturi valve to create vacuum: ⇨ Not OK. Insufficient pressure and heavy weight of the projectile are limits.
- Increase of valves’ diameter to have larger flow on the new, larger cannons of 70, 80, 90 and 100mm, simplification of setup: ⇨ OK. Speed limit of 64.8 m/s with 70mm hail, well above the needs.
- Ice ball silicon moulds not OK for the production of repeatable ice balls, the use of larger aluminium moulds is under investigation.

- Successful test for use of accredited hail test up to 70 mm, above the previous limit of 60mm. Margins to be further explored.





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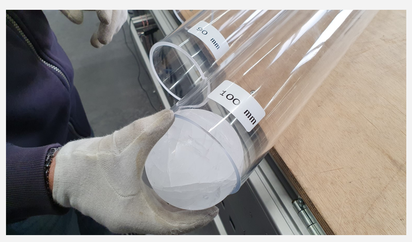

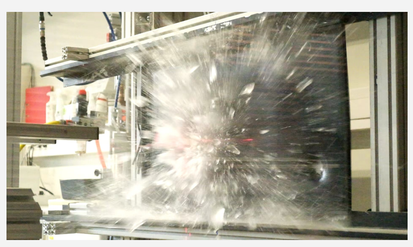

Experiment with 3d printed parts, experimental setup and schematic of ultra sonic system.

New test setup,cannon for larger diameters, silicone moulds for larger ice-balls, comparison with real hailstone in July 2021, Canton Luzern, impact of 100mm on module