Future-proof materials for electromobility
Details on weld lines, flame retardancy & corrosion behavior

Zukunftsfähige Werkstoffe für die Elektromobilität
Details zu Bindenähten, Flammschutz & Korrosionsverhalten

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Dr. Bianca Fischer und Frank Budde

AKRO COMPOUNDS

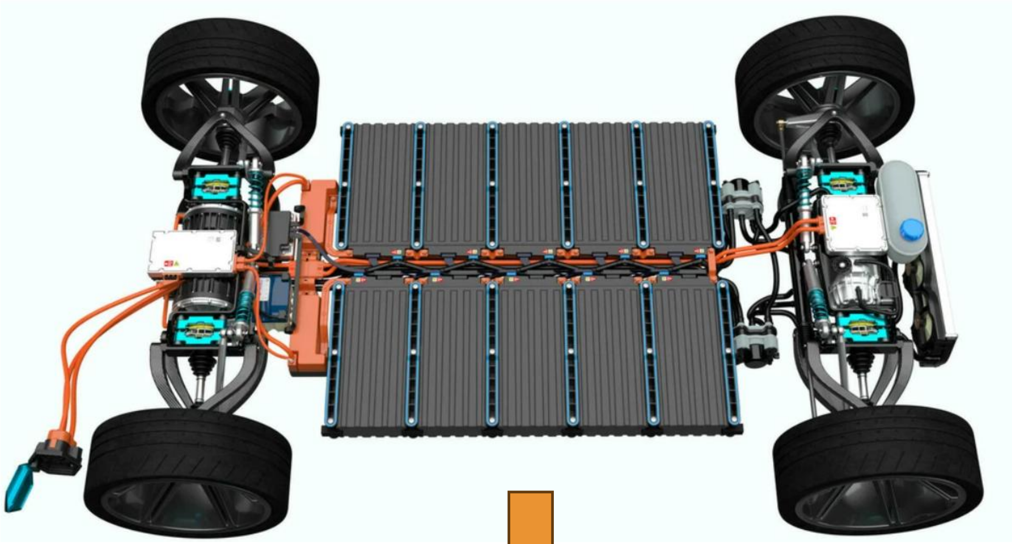
Agenda

- starting point
- Overmolded busbars
  - weld lines
    - examples
  - other failure modes

- comparison of dielectric strength values
- thermal runaway requirements
- corrosivity of flame-retardant materials

Starting Point

What business opportunities are there after the end of the combustion engine?

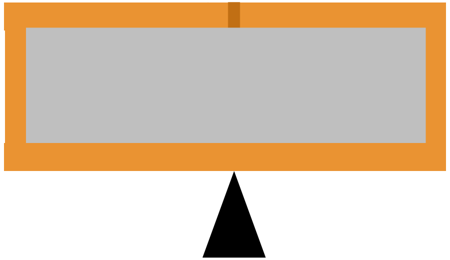


Leading the electrical energy,
e.g. **busbars**

thermal management,
e.g. new water/glycols

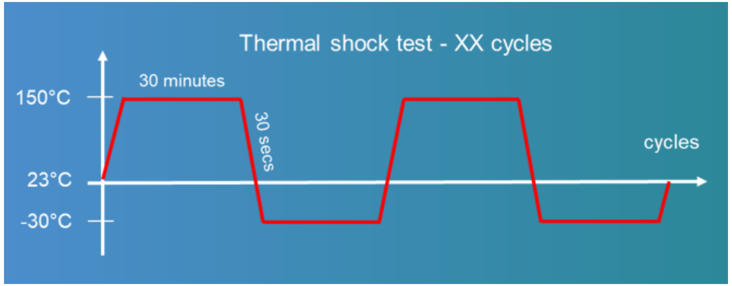
Overmoulded Busbars

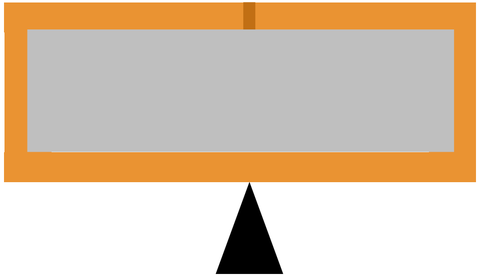
weld lines



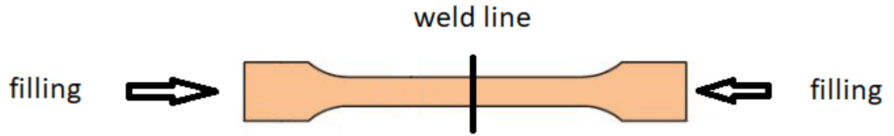
application: busbars, test procedure

between 200 and 2000 cycles





Is there an easier way for material choice?



thermal elongation

$$\delta L = L_0 \cdot \alpha \cdot (T_1 - T_0)$$

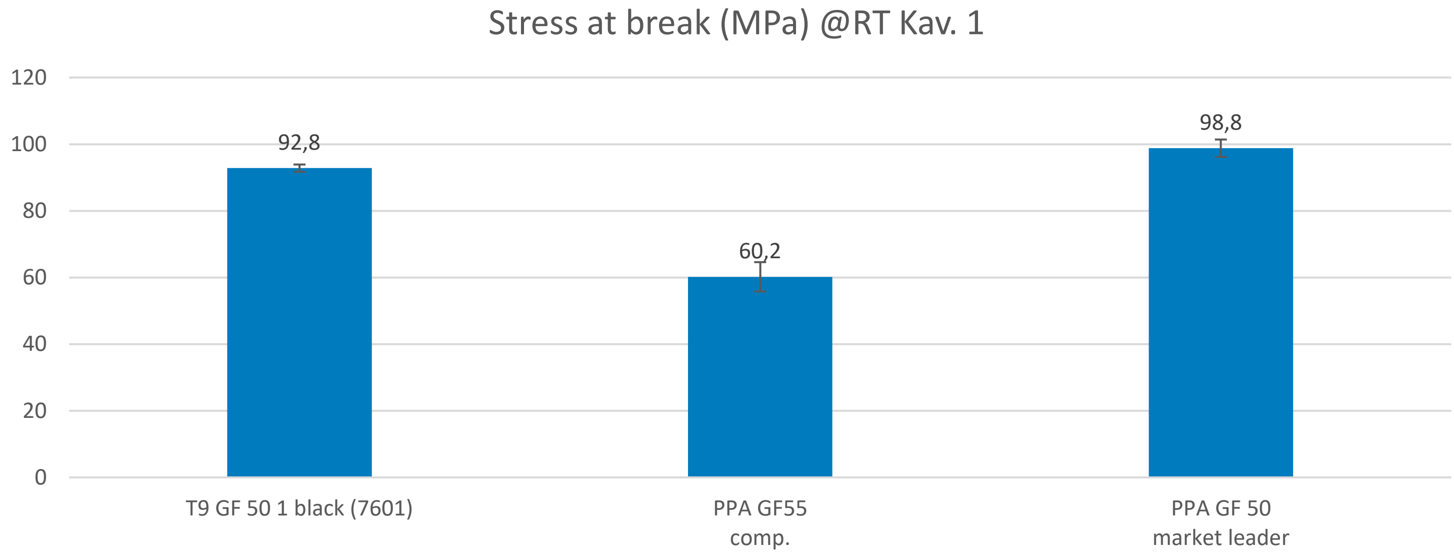
Where,
δL = change in length
L0 = original length
α = coefficient of thermal expansion
T1 = final temperature
T0 = initial or reference temperature

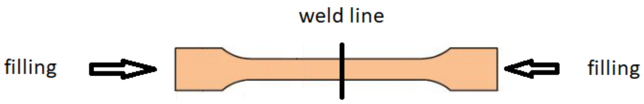
application: busbars

Which PPA GF50 is the best?

Competitors

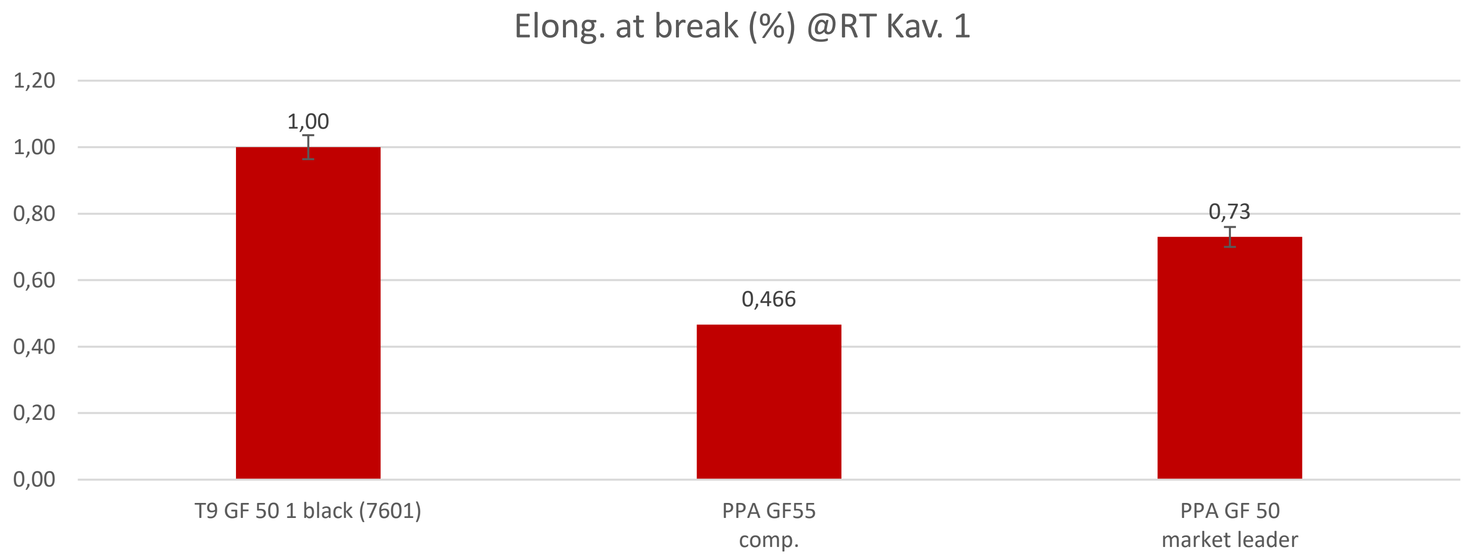
properties to competitors PPA

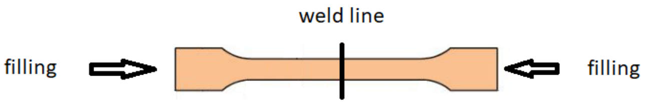




all tests are d.a.m.

properties to competitors PPA

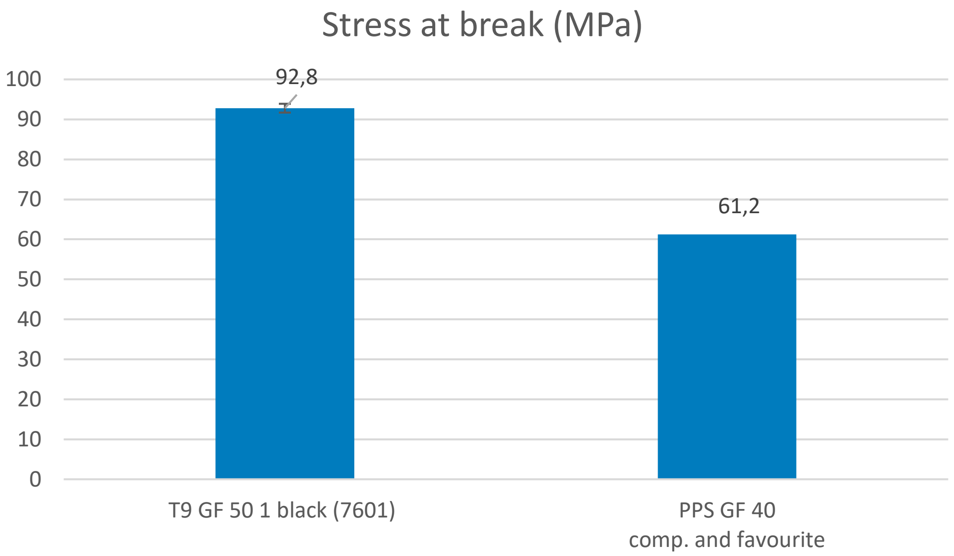


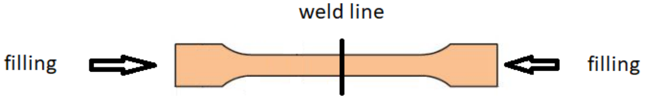


application: busbars

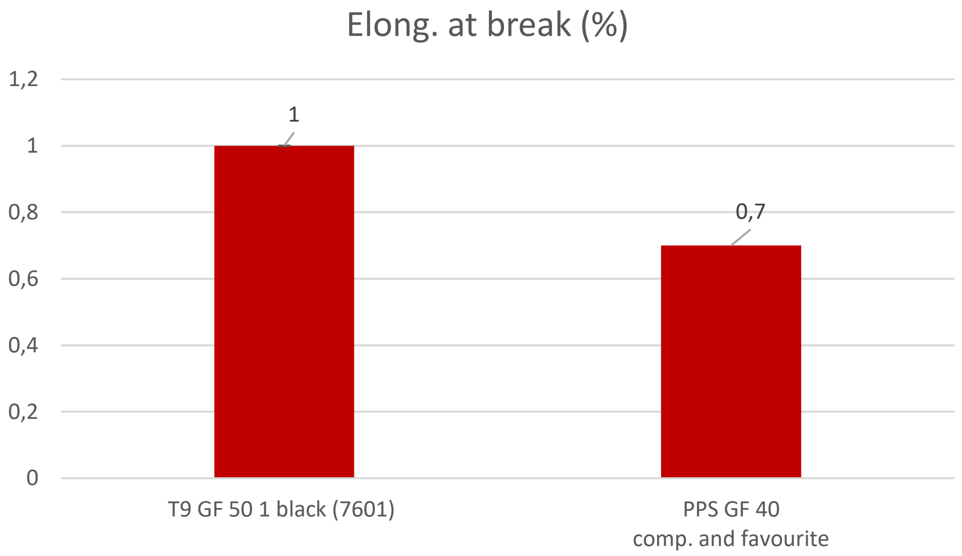
Is PPS better in weld line strength or strain?

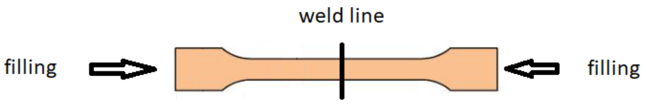
application: busbars





application: busbars

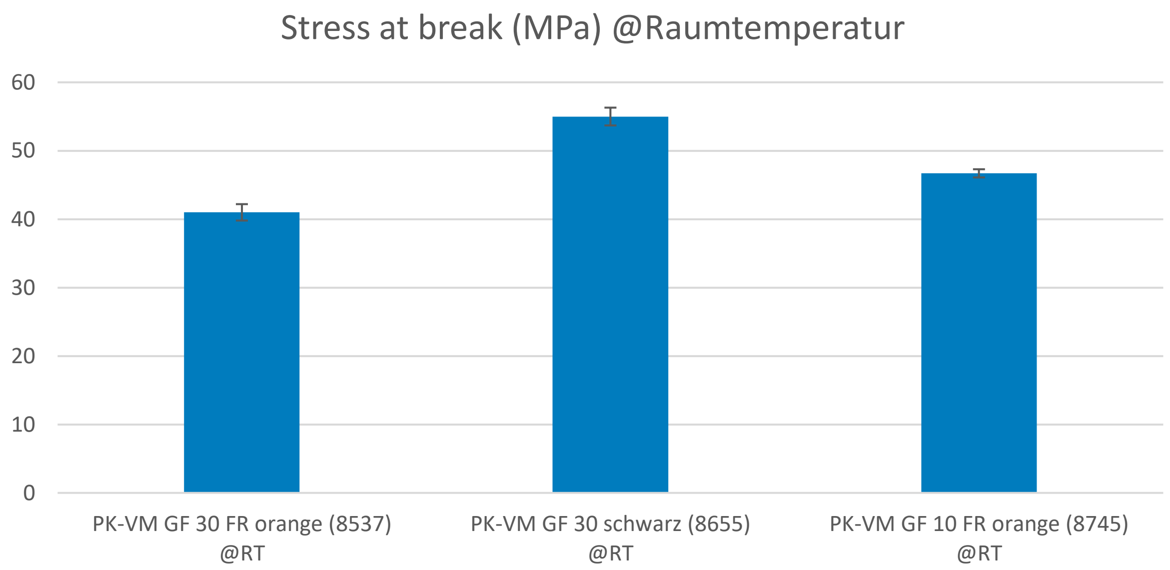


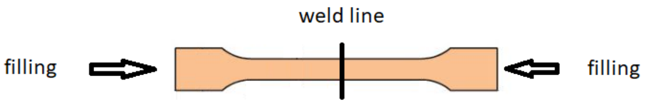


application: busbars

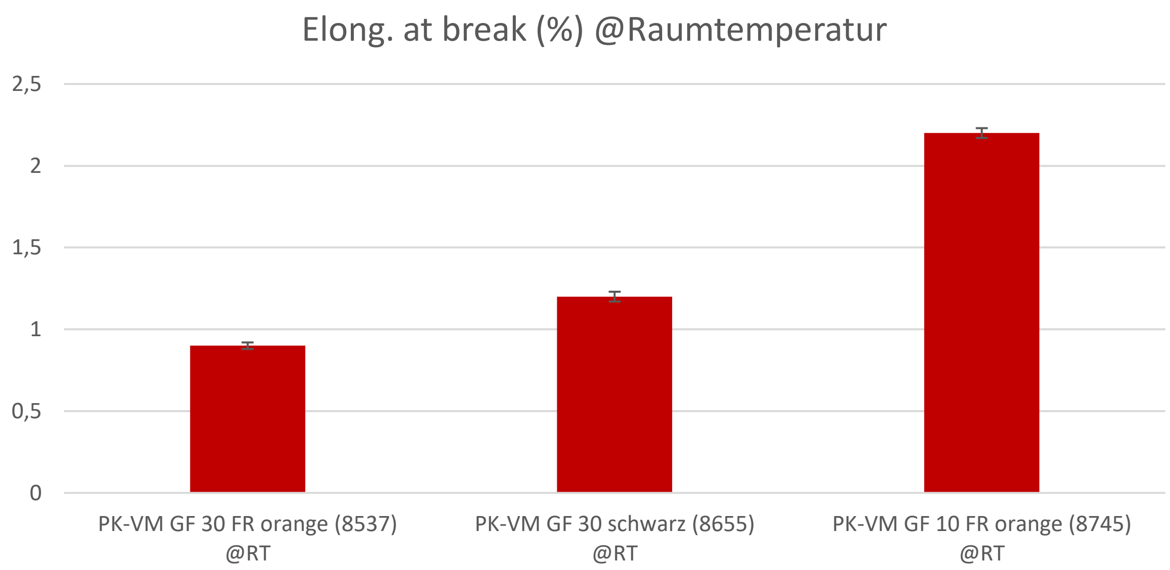
Influence of flame retardant on weld line properties

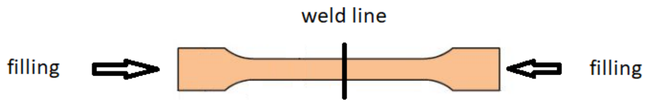
PK and flame retardant





PK and flame retardant





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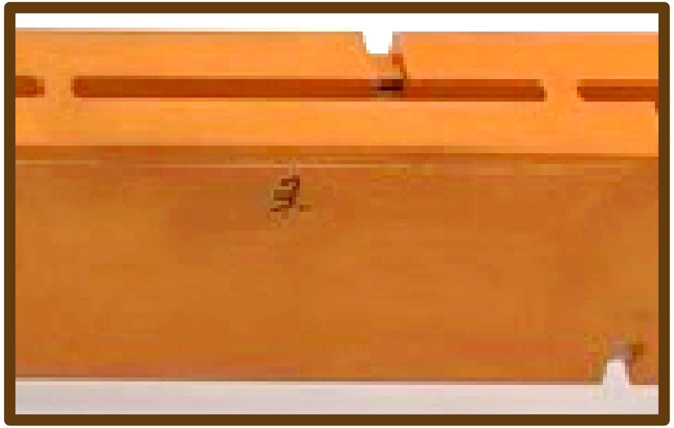
other failure mode
90° to fibre orientation



CTE in fibre orientation, PK-VM GF 30 orange (8537)

	A	B	C	D	E	F	G	H	I	J	K
1	**Temperature (°C)**	**Dimension change (µm)**	**zero point**	**strain [%]**	**CTE**	**CTE [10^-6*1/K]**		**CTE copper [10^-6*1/K]**		**relative strain**	
2	-40,97113	-1,869055	-6,824839	-0,0411	-1,1411E-05	-11,4105608		16,5		near to zero	
1657	20,00241	4,955784	0								
4375	120,1344	16,04778	11,091996	**strain [%]**	**CTE**	**CTE [10^-6*1/K]**		**CTE copper [10^-6*1/K]**		**relative strain**	
4376	120,1659	16,05358	11,097796	0,1113	1,1133E-05	11,1327528		16,5		near to zero	
4377	120,2006	16,05428									

In fiber direction, the coefficients of thermal expansion of the plastic and copper are nearly identical, both from room temperature to -40°C and from room temperature to 120°C. The differences are negligible.

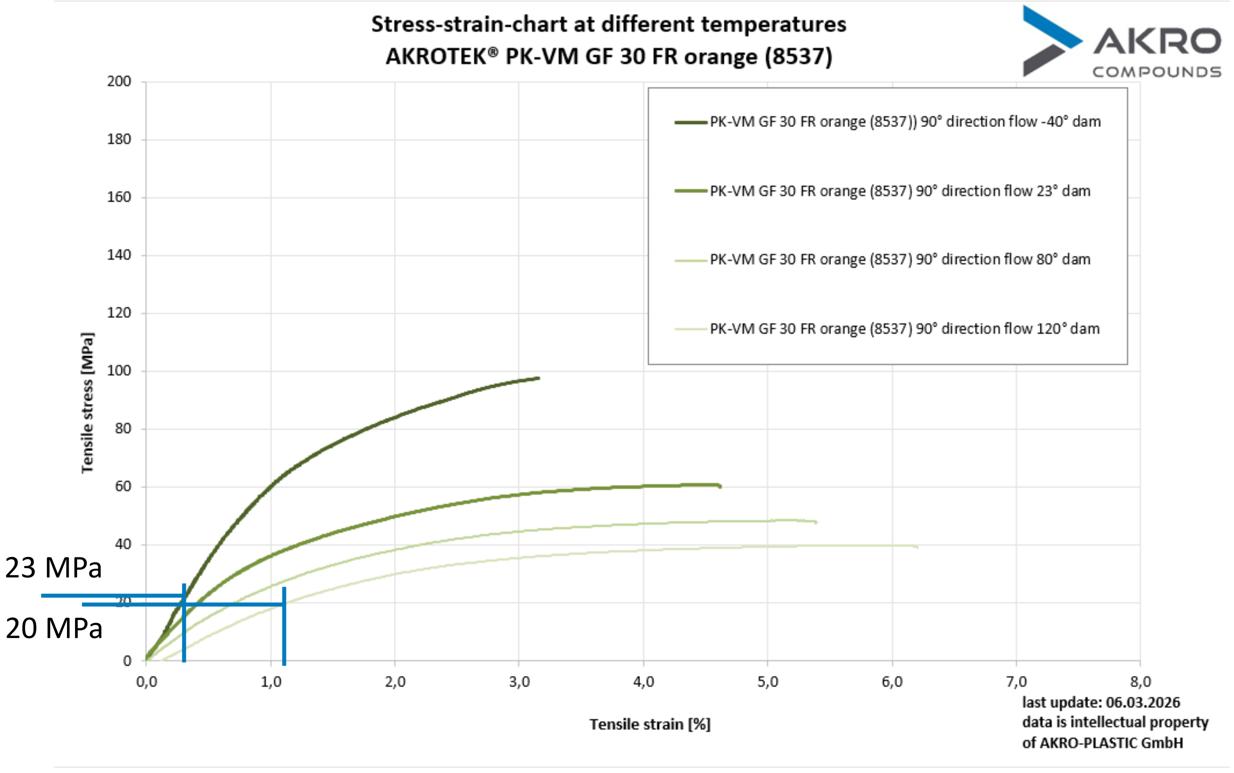
CTE, perpendicular to fiber direction, (8537)

	A	B	C	D	E	F	G	H	I	J	K
1	**Temperature (°C)**	**Dimension change (µm)**	**zero point**	**strain [%]**	**CTE**	**CTE [10^-6*1/K]**		**CTE copper [10^-6*1/K]**		**relative strain [%]**	
2	-40,1459	-31,04415	-41,9326	-0,4206	-7,01078E-05	-70,1078052		16,5	Kupfer	**-0,322**	
1634	19,9964	10,88845	0								
4347	119,9897	141,6678	130,77935	**strain [%]**	**CTE**	**CTE [10^-6*1/K]**		**CTE copper [10^-6*1/K]**		**relative strain [%]**	
4348	120,0254	141,7239	130,83545	1,3125	0,000131248	131,247567		16,5	Kupfer	**1,147**	
4349	120,069	141,7786									

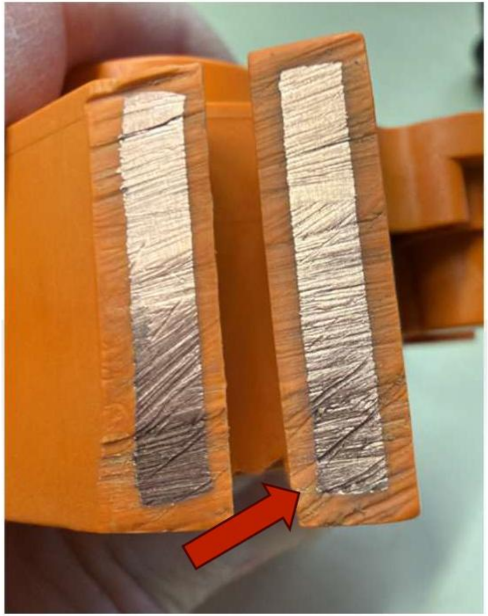
Perpendicular to the fiber orientation, there is a strain difference of approximately 0.32% from room temperature (RT) to -40°C. Since this expansion/contraction is restricted by the copper insert, thermal stress occurs. From RT to 120°C, there is a strain difference of approximately 1.15%. Outward expansion is not restricted; therefore, we assume that no significant thermal stress occurs here. However, delamination between the plastic and metal could occur.

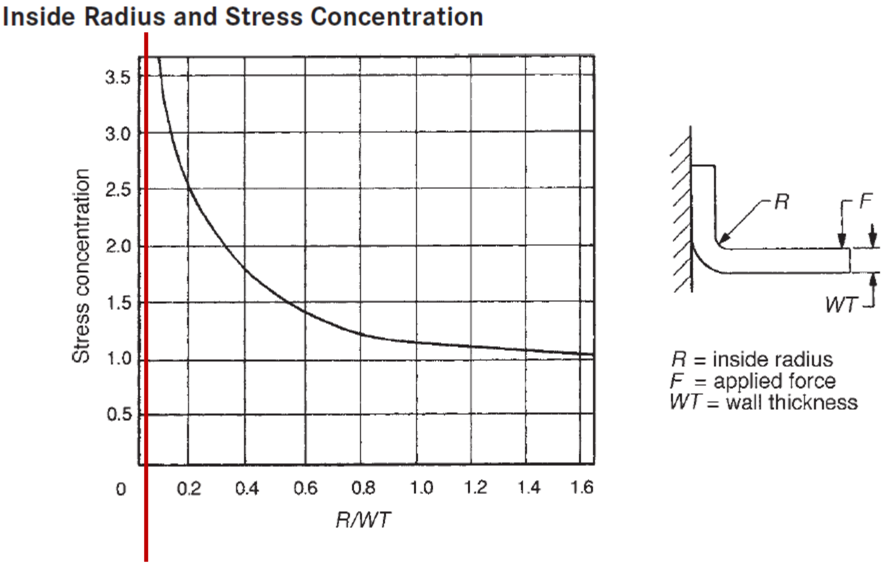
Estimated thermal stresses at PK-VM GF 30 FR

The thermal stress at -40°C is approximately 23 MPa.
Maximum tensile strength:
97 MPa



stress concentration factor





The sharp-edged copper insert results in a stress concentration factor which, according to this diagram, is approximately 4 to 5.

Are there any alternatives to the PK GF 30 FR ???

AKROLOY® PRELIMINARY

PARA GF 35 1 FR orange (8039)

PARA GF35 FR(40)

AKROLOY® PARA GF 35 1 FR orange (8039) is a 35% glass fibre reinforced, flame-retardant and heat-stabilized polyarylamide with very high rigidity and strength, colored similiar to RAL 2003. The material is based on a flame retardant system that is free of red phosphorus, PFAS, zinc borate and melamine. The product has high flowability, excellent surface quality and low warpage. Applications include components that require a low creep tendency, even in a conditioned state, or excellent arc resistance. It is therefore also suitable as a replacement for components made of duroplastic materials. It is also the perfect candidate for thermal runaway requirements.

Features

electrically neutral · flame retardant · surface modified · reduced moisture · easy flow · E-Mobility

Properties

Modulus	Strength	Impact
14.500 MPa	200 MPa	60 kJ/m²

Properties · Documents · Processing · Diagrams · Applications

Mechanical Properties

Tensile modulus ISO 527-2	1 mm/min | d.a.m. 1 mm/min | conditioned	14500 MPa 14500 MPa
Tensile stress at break ISO 527-2	5 mm/min | d.a.m. 5 mm/min | conditioned	200 MPa 185 MPa
Tensile strain at break ISO 527-2	5 mm/min | d.a.m. 5 mm/min | conditioned	2,0 % 1,7 %

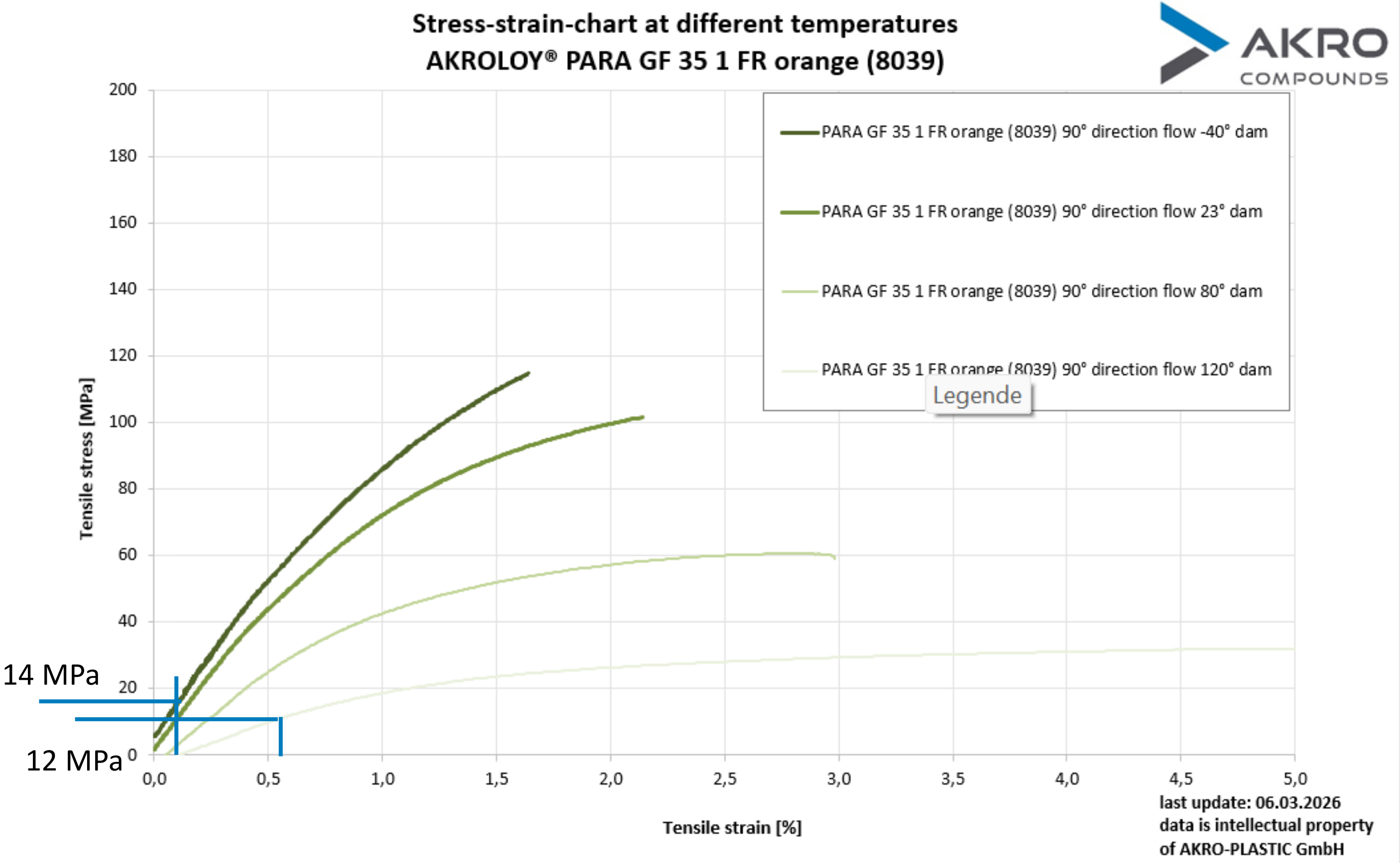
CTE, perpendicular to fiber direction, Akroloy PARA GF 35 1 FR

Temperature (°C)	**Dimension change (µm)**		Dehnung [%]	Ausdehnungsk	Ausdehnungskoeff [10^-6*1		Ausdehnungskoeff [10^-6]		Dehnung relativ
-42,00197	-40,55116	-24,24458	-0,1473	-3,95944E-05	-39,5943651		16,5	Kupfer	**0,14%**
-41,97122	-40,6492	-24,34262							
-41,9371	-40,57869	-24,27211							
20,01701	-15,26896	0							
120,0077	60,40649	75,67545	Dehnung [%]	Ausdehnungsk	Ausdehnungskoeff [10^-6*1		Ausdehnungskoeff [10^-6]		Dehnung relativ
120,0484	60,41499	75,68395	0,7416	7,41607E-05	74,1606894		16,5	Kupfer	**0,58%**
120,0861	60,42999								

Perpendicular to the fiber orientation, there is a difference in strain from RT to -40°C of approximately 0.14%.

Estimated thermal stresses at PARA GF 35 1 FR

The thermal stress at -40°C is approximately 14 MPa.
Maximum tensile strength: 115 MPa



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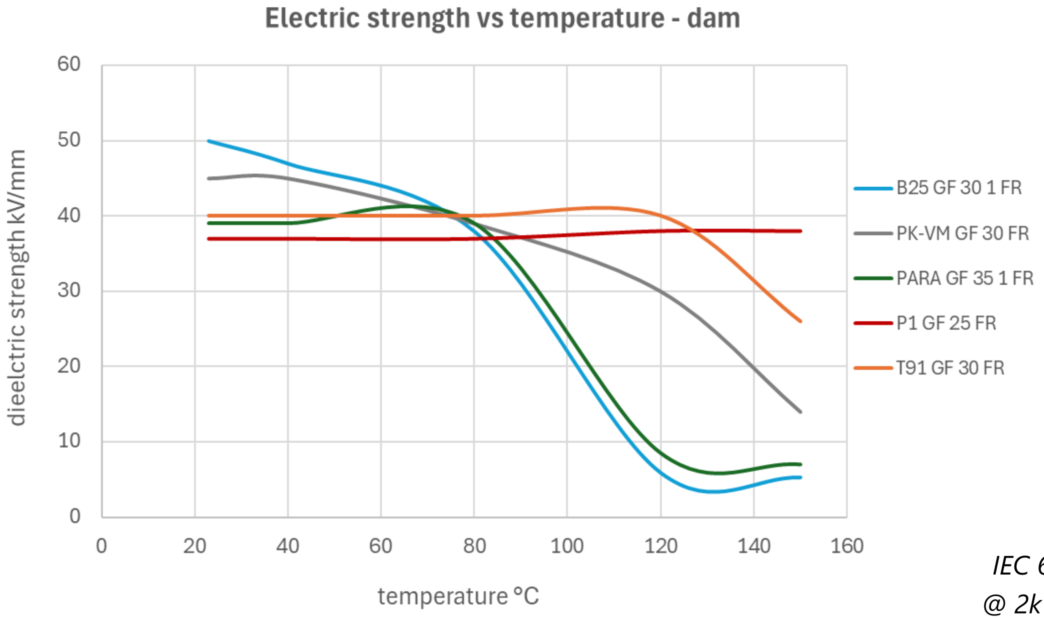
- corrosivity of flame-retardant materials

Dielectric strength vs temperature of different polymers - dam

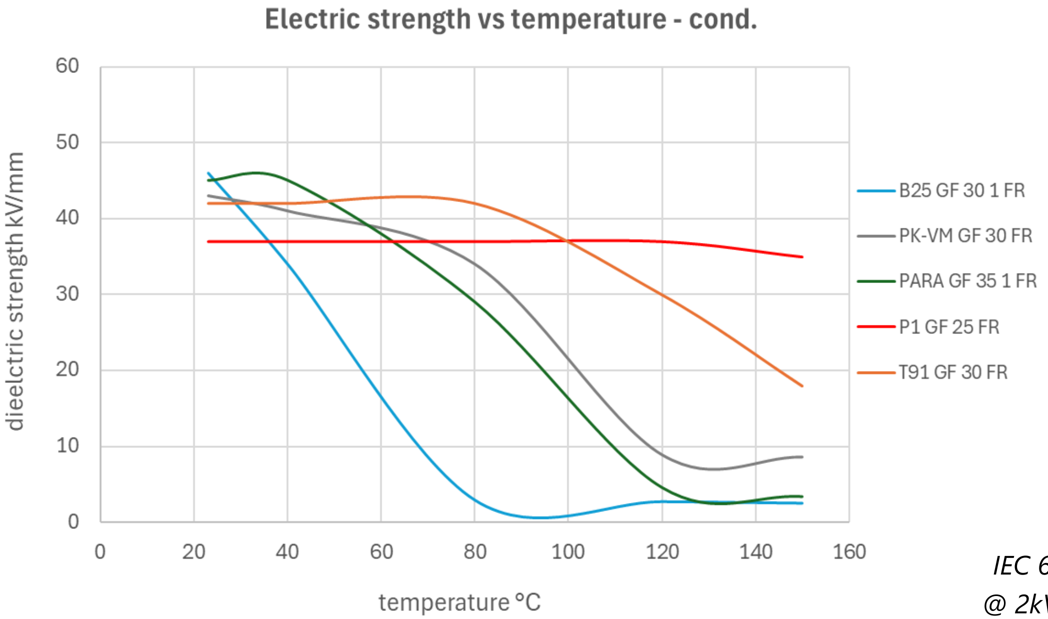


IEC 60243-1:2013, 1mm thick plates @ 2kV/s rise, AC 50 Hz

Insulation properties strongly depend on

- polarity of polymer, temperature & degree of moisture uptake

Dielectric strength vs temperature of different polymers – cond.



IEC 60243-1:2013, 1mm thick plates @ 2kV/s rise, AC 50 Hz

- for your application required value at highest T & max moisture content need to be known

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Determination of thermal runaway performance

- direct flame test without particle spread – **500W flame test**

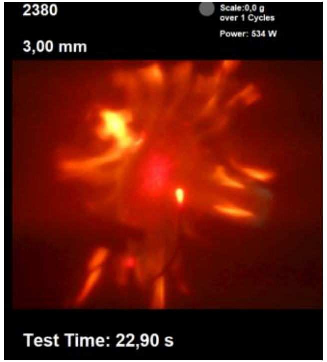
  ~ 1100 - 1200 °C, 10 min, temperature sensor on non-flame side

  temperature increase on non-flame side measured

Determination of thermal runaway performance

- direct flame test without particle spread – **500W flame test**
  ~ 1100 - 1200 °C, 10 min, temperature sensor on non-flame side
  temperature increase on non-flame side measured

- direct flame & particle spread – **torch & grit test**
  15s **torch** (500W flame → 1300 °C) & 5s **grit** (aluminium oxid particles) → 1 cycle
  amount of passed cycles determined



Determination of thermal runaway performance

- direct flame test without particle spread – **500W flame test**
  ~ 1100 - 1200 °C, 10 min, temperature sensor on non-flame side
  temperature increase on non-flame side measured

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  15s **torch** (500W flame → 1300 °C) & 5s **grit** (aluminium oxid particles) → 1 cycle
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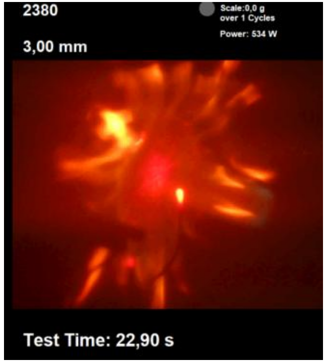
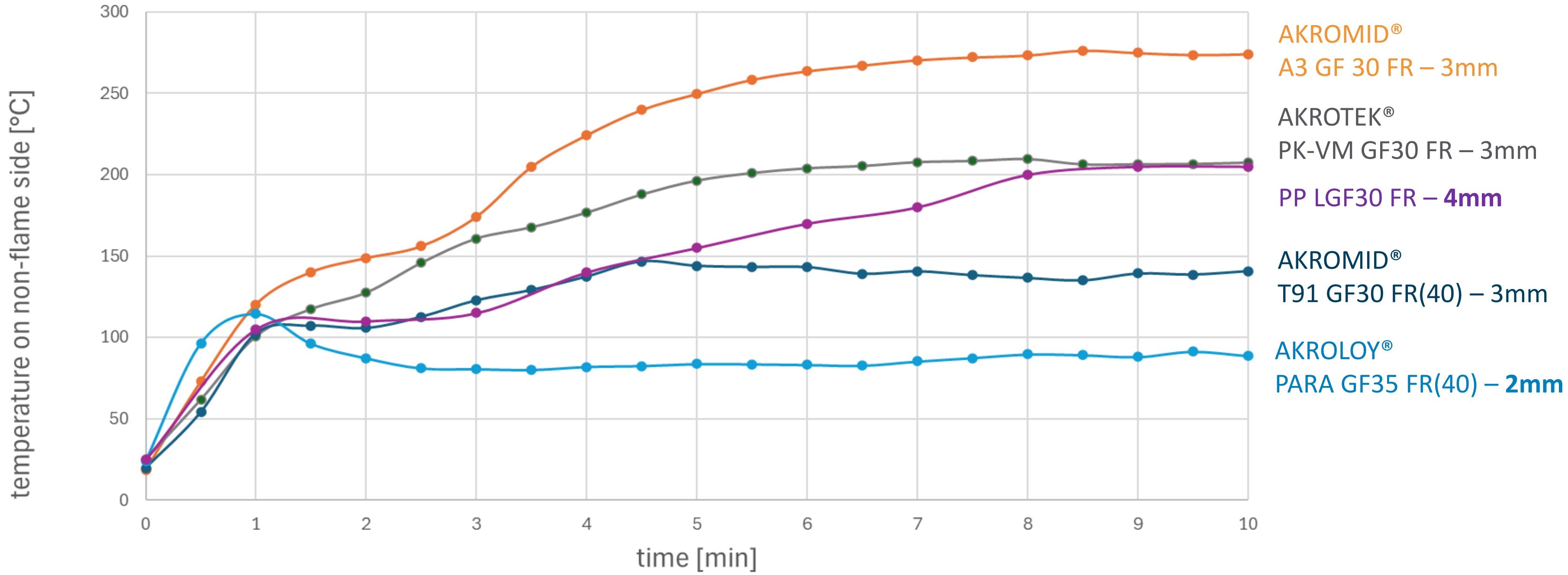


- heat without direct flame and without particle spread – **cone calorimeter test**
  50 kW/m² radiation
  peak and total amount of heat relase and smoke production determined

500W flame test - temperature increase on non-flame side



- AKROLOY® PARA GF 35 1 FR shows lowest temperature increase on non-flame side at only **2mm** thickness → very high thermal insulation behaviour!

Visual inspection after 10 min @ 1200 °C

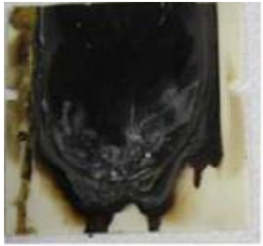
AKROMID®
A3 GF 30 FR
3mm thickness

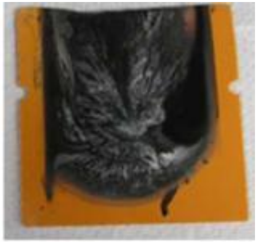
AKROTEK®
PK-VM GF 30 FR
3mm thickness

AKROMID®
T91 GF 30 FR
3mm thickness

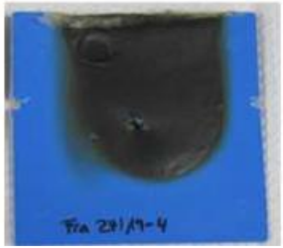
AKROLOY®
PARA GF 35 1 FR
2mm thickness

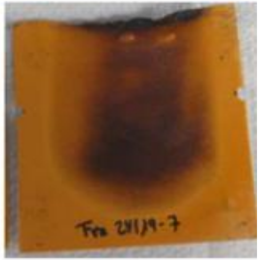
front side





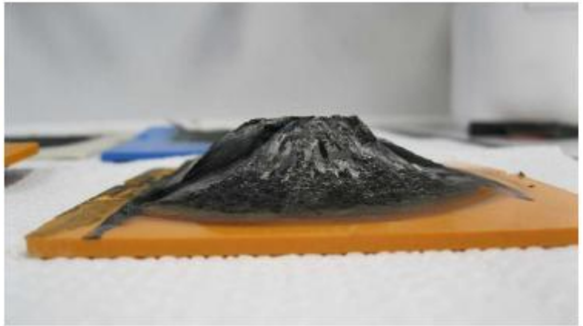
reverse side





Intumescent layer bulid-up during test

AKROMID® T91 GF 30 FR



AKROLOY® PARA GF 35 1 FR

AKROLOY® PARA GF 35 1 FR builts up an strong intumnescence layer

→ excellent thermal insulation of material – temperature increase on reverse side does not exceed 115 °C

→ plate is still completely flat after test / no deformation occured

Torch & Grit test

Torch & Grit test

	AKROTEK® PK-VM GF 30 FR	AKROMID® T91 GF 30 FR	AKROLOY® PARA GF 35 1 FR
Burn through time in s @ 3mm	100	97	**121**
Passed cycles @ 3mm	5	4	**6**
Burn through time in s @ 2mm	46	55	57
Passed cycles @ 2mm	2	2	2

- AKROLOY® PARA GF 35 1 FR passes 6 cycles of Torch and Grit test at 3mm thickness!

Cone calorimeter test with 50 kW/m² radiation

	Heat release rate (peak) [kW/m²]	Total heat release [MJ/m²]	Total smoke production [m²]
AKROMID® A3 GF 30 FR	173	71	13,4
AKROTEK® PK-VM GF 30 FR	108	40	10,4
AKROMID® T91 GF 30 FR	194	57	16,3
AKROLOY® PARA GF 35 1 FR	87	46	9,5
AKROTEK® PPS GF 40	518	54	10,8

- AKROLOY® PARA GF 35 1 FR shows lowest peak of heat release rate in combination with lowest smoke production → very good properties for thermal insulation material inside the battery

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Corrosion issue during processing of FR(40) compounds

- especially FR compounds with organic phosphorous as FR additive (FR(40)) can lead to corrosion during processing
- the FR additive releases acid that corrodes steel inside the injection moulding machine
- the degree of corrosiveness depends on polymer, processing parameters & moisture content
- you can´t avoid it but you can adapt processing parameters & use more corrosion resistant steel or a special coating

„Hagelschaden“

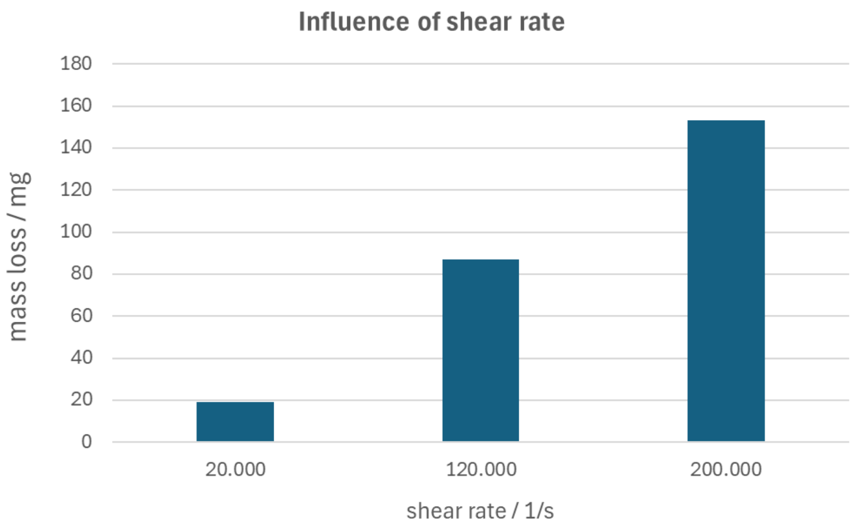
Corrosiveness measurement at AKRO-Plastic GmbH

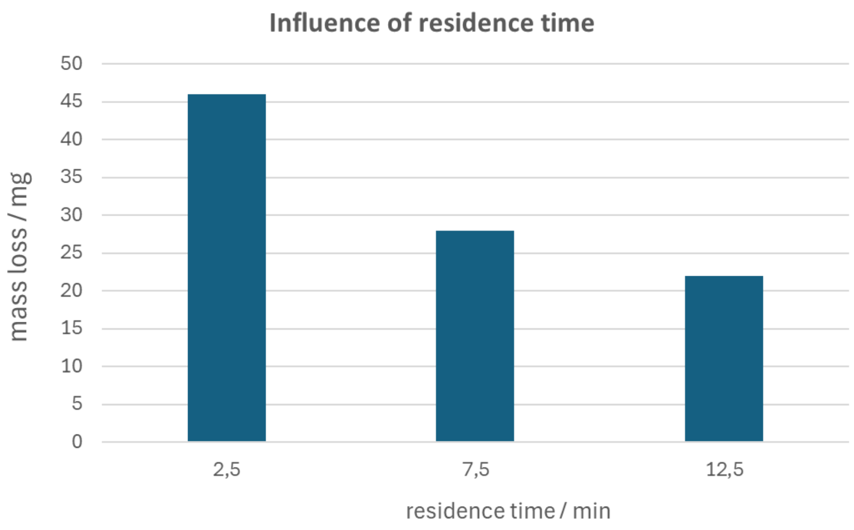
- ENGEL victory 300 injection moulding machine equipped with a 70 mm screw & a special nozzle
- plates out of steel 1.2379 (hardened), channel width of 6mm & height of 0,4mm
- for one trial 20 kg of material are processed and after that weight loss of plates is determined
- for processing parameter study AKROMID® A3 GF 30 1 FR was used

Corrosion nozzle with pair of small plates

Corrosiveness measurement at AKRO-Plastic GmbH

- ENGEL victory 300 injection moulding machine equipped with a 70 mm screw & a special nozzle
- plates out of steel 1.2379 (hardened), channel width of 6mm & height of 0,4mm
- for one trial 20 kg of material are processed and after that weight loss of plates is determined
- for processing parameter study AKROMID® A3 GF 30 1 FR was used





Corrosiveness of different FR compounds

Compound	Material Group	Residual humidity	Material temp.	Material loss
AKROMID® A3 GF 30 1 FR	**PA66 GF 30 FR(40)**	0,06 %	295 °C	153 mg
AKROMID® B25 GF 30 1 FR	**PA6 GF 30 FR(40)**	0,07 %	280 °C	109 mg
AKROMID® C3 GF 30 1 FR	**PA66 + PA6 GF 30 FR(40)**	0,06 %	290 °C	116 mg
PRECITE® P1 GF 25 FR	**PBT GF 25 FR(40)**	0,02 %	260 °C	97 mg
AKROMID® T91 GF 30 FR	**PA9T GF 30 FR(40)**	0,06 %	330 °C	144 mg

- all measurements done with a shear rate of 200.000 1/s (worst case)
- difference in corrosiveness is visible for different compounds
- it is better to use a PA6 instead of a PA66 if possible!

Take the chance to experience the method live in our competence center