JOHANNES KEPLER UNIVERSITY LINZ

Institute of Polymeric Materials and Testing

SCREENING VON FASERVERSTÄRKTEN POLYAMIDEN FÜR SPEICHERKOLLEKTORSYSTEME

Patrick R. Bradler, Joerg Fischer,
Gernot M. Wallner, Reinhold W. Lang

Institute of Polymeric Materials and Testing,
Johannes Kepler University Linz, Austria

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solpol

INTRODUCTION AND SCOPE

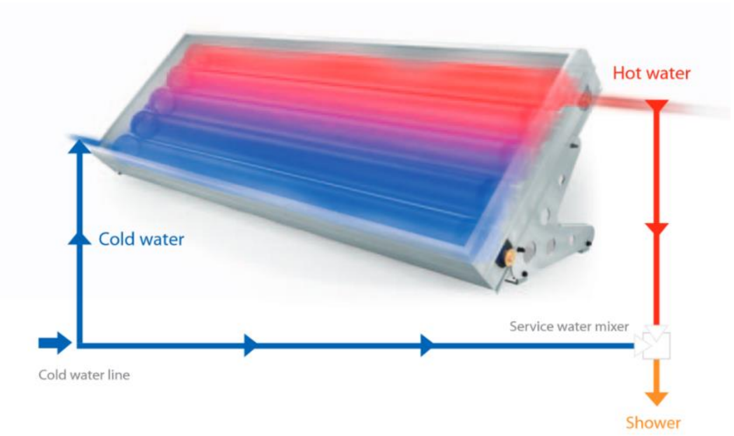
SolPol-4/5 (WP-03): *Solar-thermal Systems based on Polymeric Materials – Novel Materials and Test Methods*

Replacement of metals by polymeric materials to:

- reduce weight and increase ease of installation
- increase reliability and lifetime
- enable attractive design at improved cost/performance ratio

Relevant environmental conditions:

- temperature up to 95°C
- pressurized, water filled pipes with up to 6 bar (incl. oscillation)



mechanical properties and fatigue crack growth (FCG) behavior at application relevant temperatures

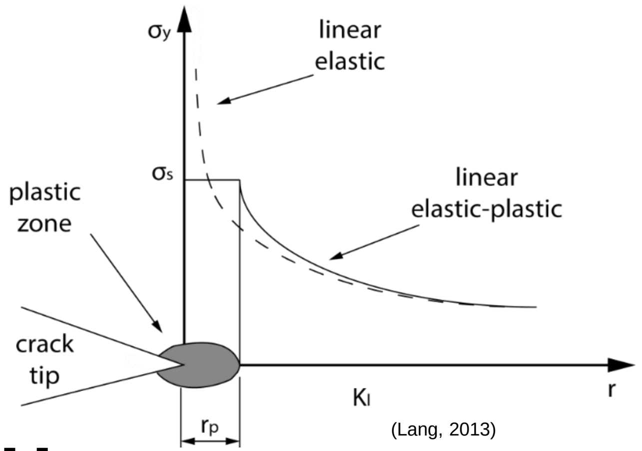
General Background – Region II

Fatigue crack growth (FCG) properties – basics

Basic assumptions of linear elastic fracture mechanics (LEFM)

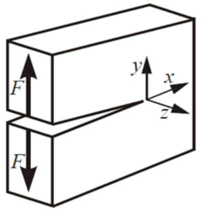
(stress based: stress intensity factor K)

- linear-elastic material behavior
- small plastic zones
- K describes the crack tip near-field



(Lang, 2013)

$$K_I = \sigma * \sqrt{\pi * a} * Y_I$$



(Richard and Sander, 2012) Mode I

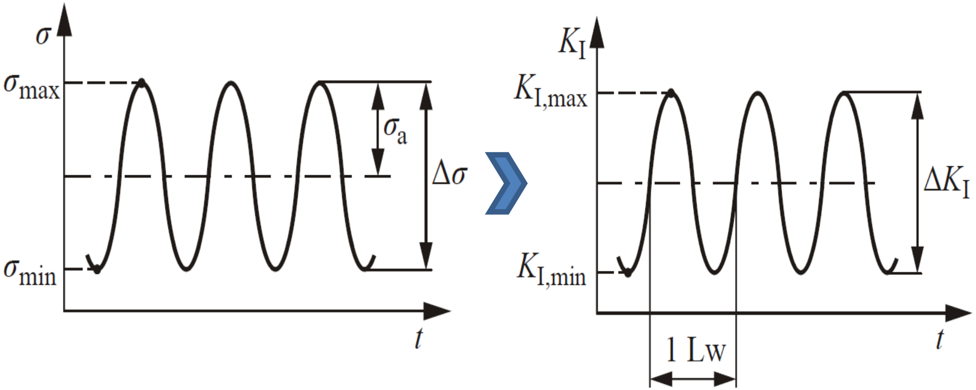
relevant for applications:

Loading Mode I

(tensile and bending loads of components, pressurized pipes)

GENERAL BACKGROUND – REGION II

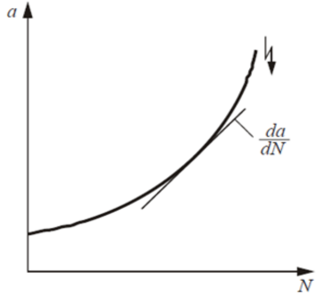
FCG properties – cyclic loading

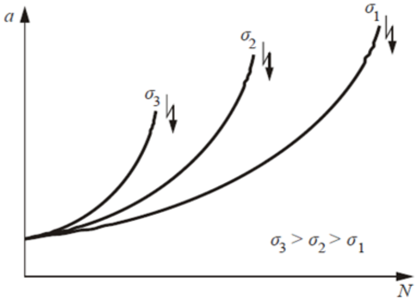


$$R = \frac{\sigma_{min}}{\sigma_{max}} = \frac{K_{I,min}}{K_{I,max}} = 0.1$$

f = 5 *Hz*

$$\Delta K_I = \Delta\sigma * \sqrt{\pi * a} * Y_I$$

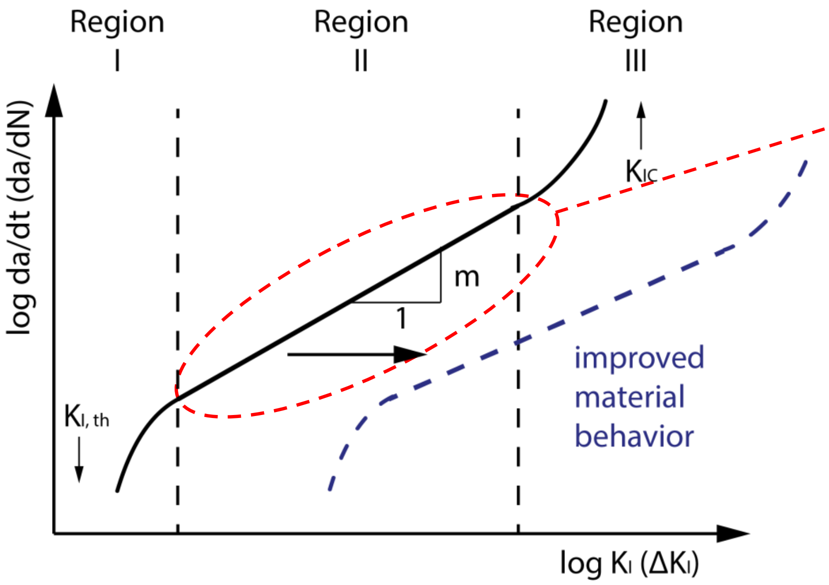




- crack length (a) increases with number of cycles (N)

GENERAL BACKGROUND – REGION II

FCG properties – crack growth kinetics



Paris-Law

$$\frac{da}{dN} = A \cdot \Delta {K_I}^m$$

Region I: lower limit (threshold)
Region II: stable crack growth
Region III: unstable crack growth and/or high plastic deformations

EXPERIMENTAL – MATERIALS

	Phenolic (P)			*Aminic (A)*			*Specific (S)*	
	Irganox 1098 (P1)	Bruggolen H164 (P2)	Irganox 1330 (P3)	Naugard Super Q (A1)	Naugard 445 (A2)	Bruggolen H204 (A3)	Stabilisator 9000 (S1)	Bruggolen H3360 (S2)
PA	Polyamide 66 (PA) GF 30 – matrix material							
PA-P1	1							
PA-P2		1						
PA-P3			1					
PA-A1				1				
PA-A2					1			
PA-A3						1		
PA-S1		0.4					0.6	
PA-S2								1
PPA	Polyphthalamide (PPA) GF 45							

EXPERIMENTAL – TEST METHODOLOGY

Compounding
&
specimen production

conditioned | unconditioned

Thermomechanical and fatigue testing

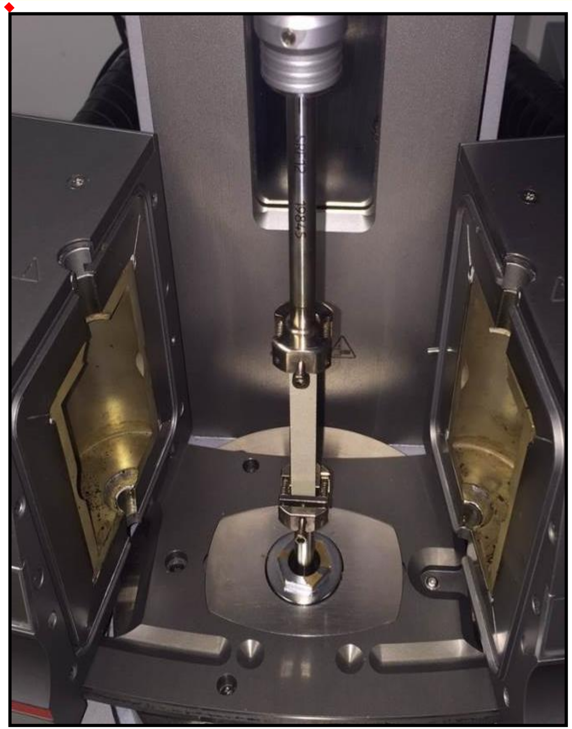
DMA

Fatigue Crack Growth (FCG)

95°C water	**80°C water**	**95°C air**	**23°C air**

EXPERIMENTAL – TEST METHODOLOGY – DYNAMIC MECHANICAL ANALYSIS

Anton Paar Physica MCR 502 Rheometer

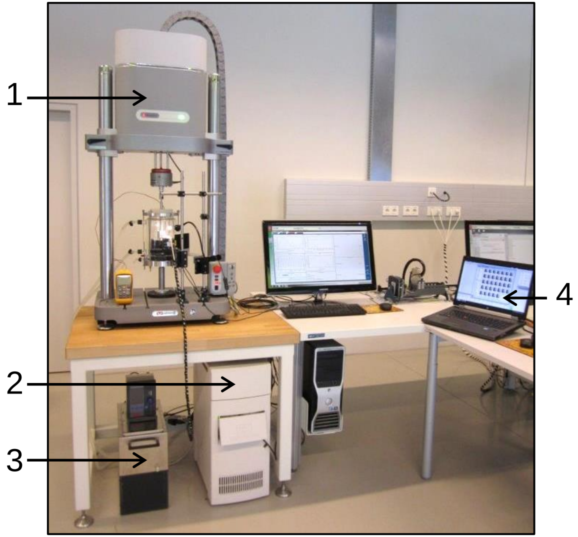


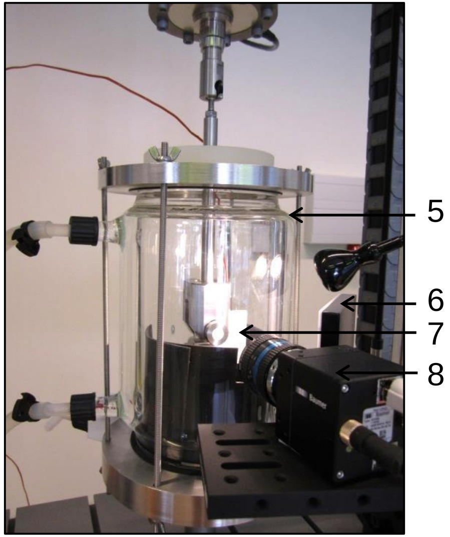
test parameters

- torsional mode
- deformation: 0.1 %
- frequency: 1 Hz
- temperature range: -60°C – 240°C
- heating rate: 3 K/min

EXPERIMENTAL – TEST METHODOLOGY – FATIGUE TESTS

Instron ElectroPuls E3000 with optical crack growth measurement





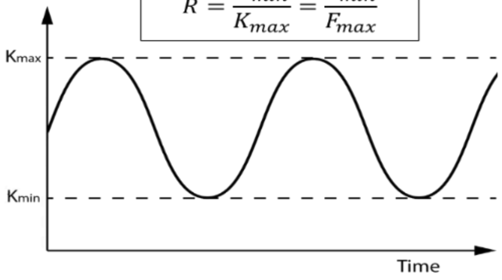
1 testing machine (Instron E3000)
2 machine controlling computer
3 temperature control system
4 camera controlling and data evaluation computer

5 glass containment
6 LED flashlight
7 specimen
8 camera

test parameters:

- frequency: 5 Hz
- R-Ratio: 0.1
- temperatures: 23°C, 80°C, 95°C

$$R = \frac{K_{min}}{K_{max}} = \frac{F_{min}}{F_{max}}$$



EXPERIMENTAL – TEST METHODOLOGY – FATIGUE TESTS

Data evaluation – CT specimen

measurement procedure:

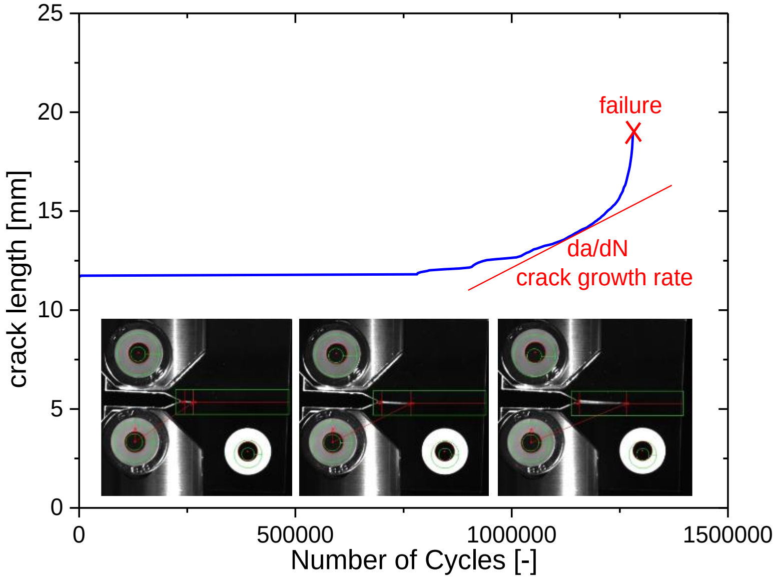
- trigger of the camera system using a real time machine
- image recording at F_{max}

data evaluation:

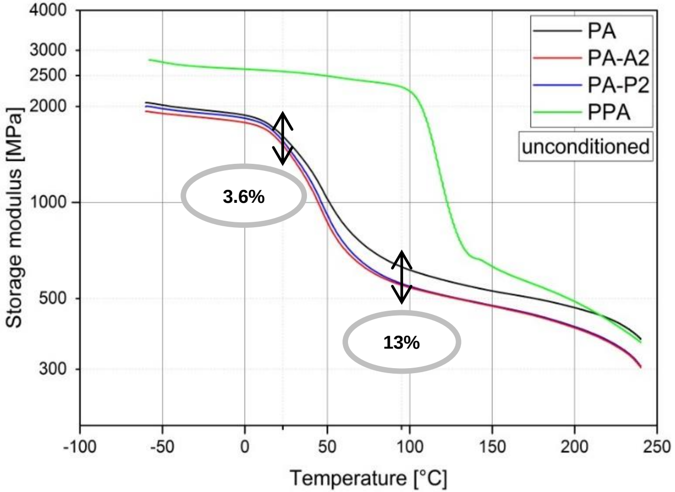
- image processing and crack length measurement using pixel comparison
- calculation:

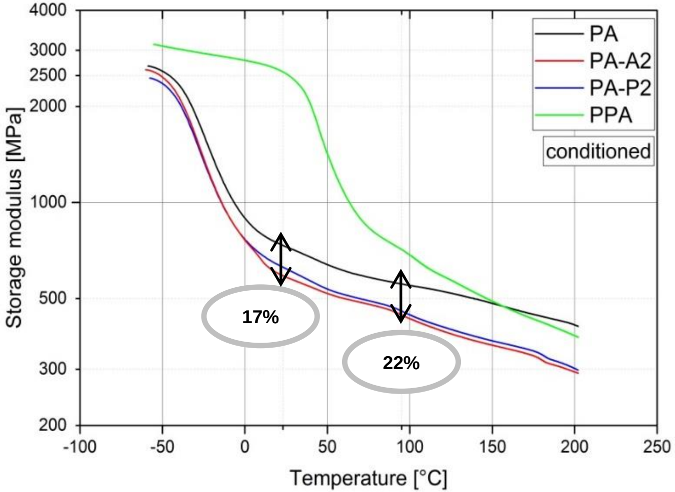
$$K_I = \frac{F}{B \cdot \sqrt{W}} \cdot f\left(\frac{a}{W}\right)$$

- fatigue crack growth (FCG) rate da/dN vs. stress intensity factor $K_{I,max}$



RESULTS – DYNAMIC MECHANICAL ANALYSIS





Storage modulus:

- PPA >> PA > PA-P2 > PA-A2
- higher deviation with increasing temperature

Glass transition temperature:

- PPA: 121°C
- PA / PA-P2 / PA-A2: 59°C / 56°C / 55°C

Storage modulus:

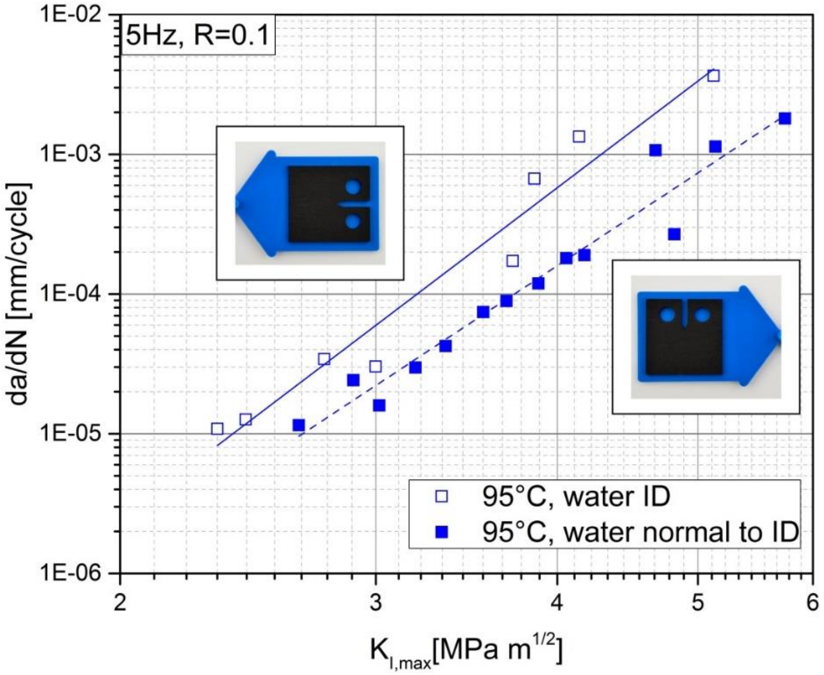
- PPA > PA types
- PA-A2 > PA-P2 at -50°C
- PA-A2 < PA-P2 above Tg
- significant change in deviation with increasing temperature

Glass transition temperature:

- PPA: 55°C
- PA / PA-P2 / PA-A2: -19°C / -22°C / -23°C

RESULTS – INFLUENCE OF ORIENTATION ON FCG-PROPERTIES

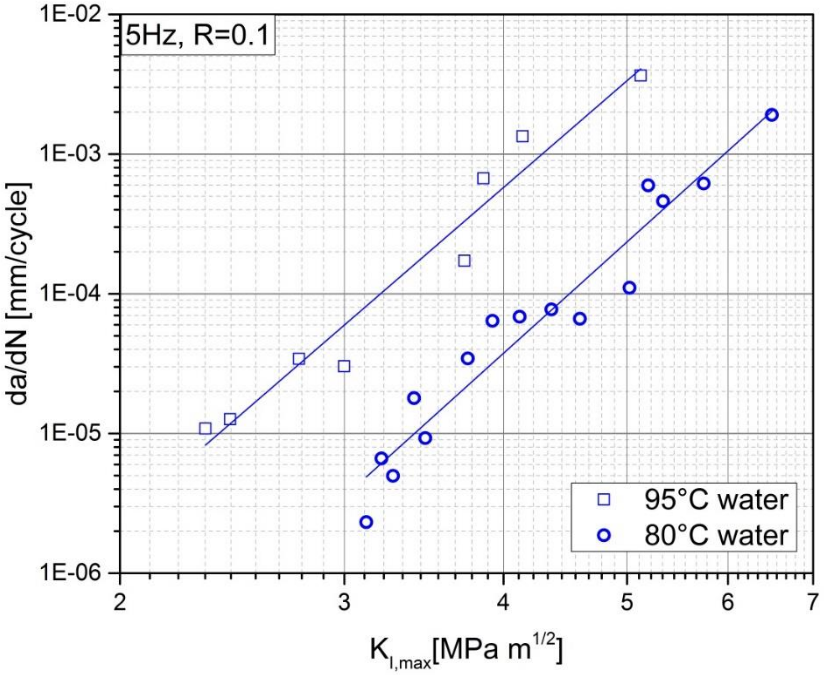
PA



- significant influence of melt injection direction (ID);
  caused by fiber orientation in force direction
- improved behavior for specimen normal to ID:
  factor 3.5 at K=4
- increasing improvement with higher K-values (lower slope)

RESULTS – INFLUENCE OF TEMPERATURE ON FCG-PROPERTIES

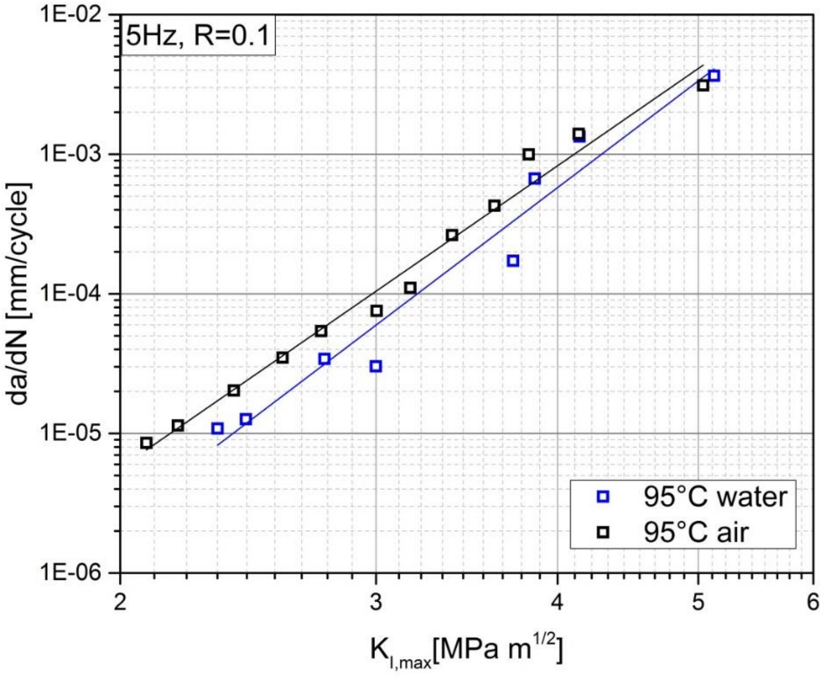
PA



- significant influence of temperature
- improved behavior at lower temperatures (80°C): factor 15 at K=4
- similar slopes

RESULTS – INFLUENCE OF TEST ENVIRONMENT ON FCG-PROPERTIES

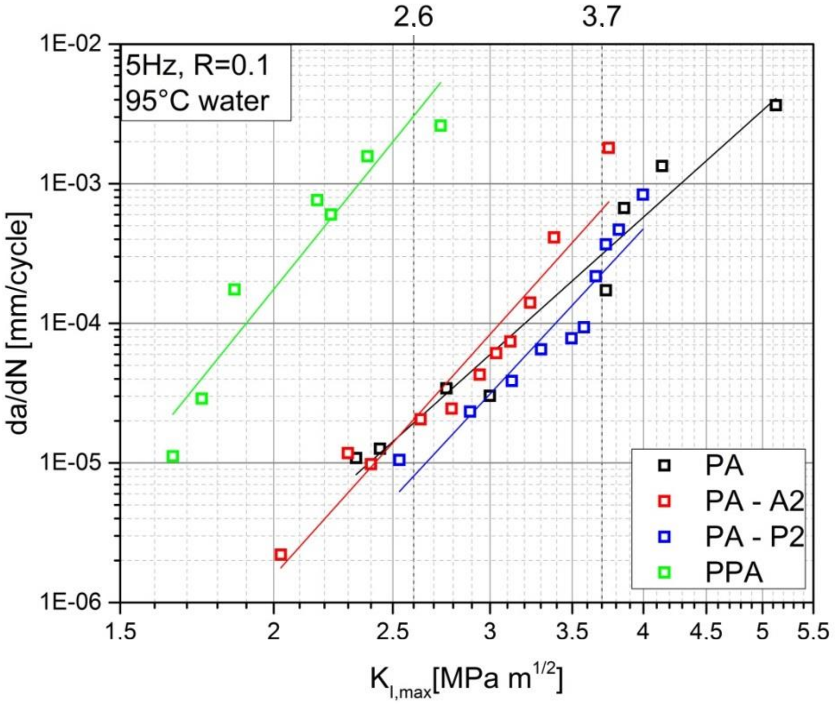
PA

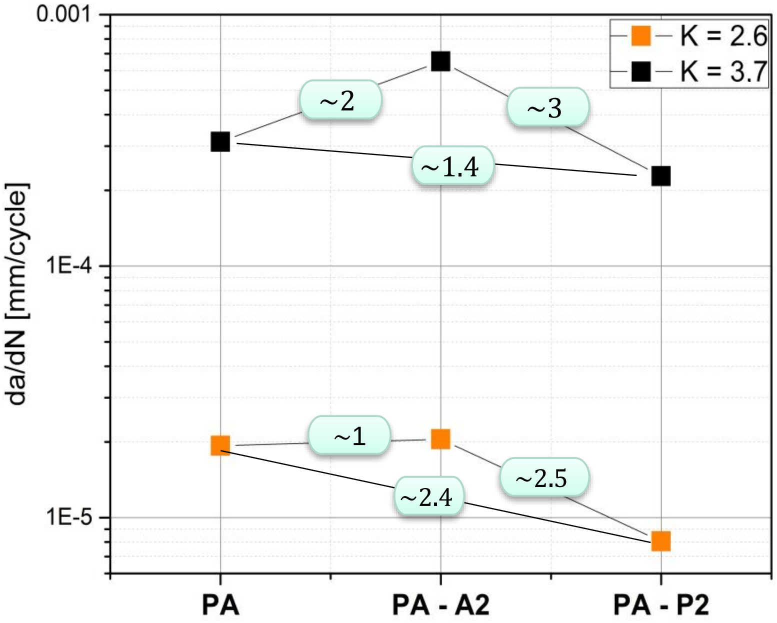


- minor influence of water
- slightly increased crack growth resistance in water
- slope for water environment slightly increased

RESULTS – INFLUENCE OF STABILIZER SYSTEMS ON FCG-PROPERTIES

PA, PA with amino based stabilizer, PA with phenol based stabilizer, PPA





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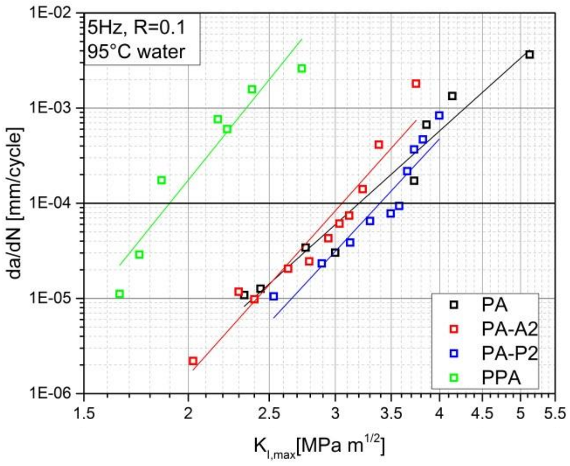
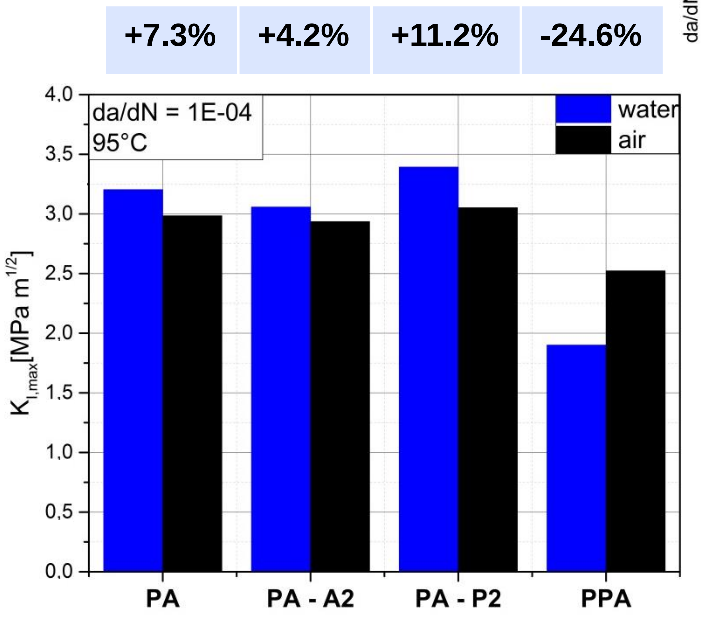
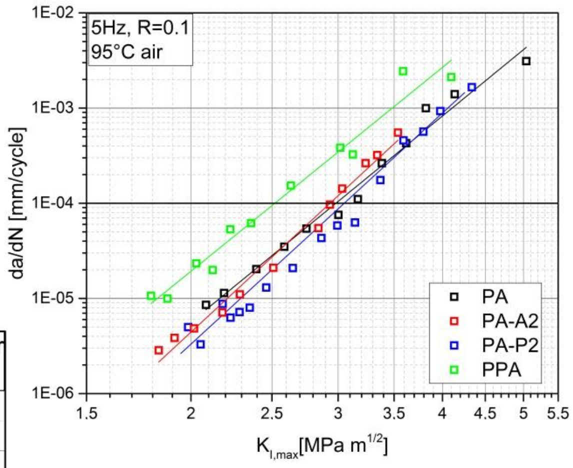
RESULTS – INFLUENCE OF STABILIZER SYSTEM ON FCG-PROPERTIES







SUMMARY

Dynamic mechanical analysis

- PPA exhibits highest storage moduli and T_g-values due to glass fiber content and morphology
- storage moduli for PA-types with different stabilizer systems:
  - PA > PA-P2 > PA-A2 at 95°C conditioned
  - higher deviation with increasing temperature due to fiber content
- similar T_g-values for PA-types with different stabilizer systems

Fatigue testing

- improved resistance for specimen normal to ID (factor 3.6)
- superior FCG behavior at lower temperatures (factor 15)
- slightly increased performance for specimen tested in water
- material ranking:

  PA-P2 > PA > PA-A2 >> PPA

ACKNOWLEDGMENT

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