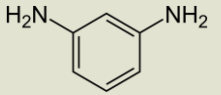
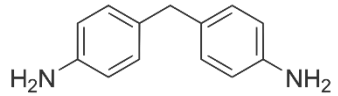
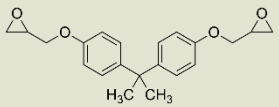
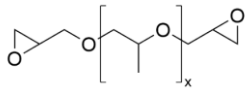
Tough epoxy systems

CHART Update
23.09.2021

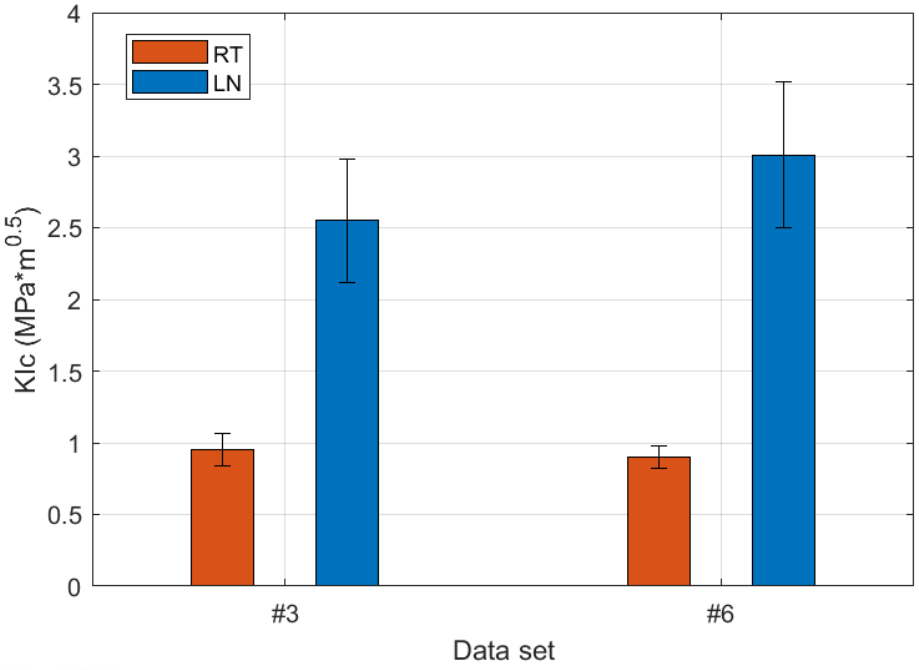
Pascal Studer
Laboratory for Soft Materials

Recap

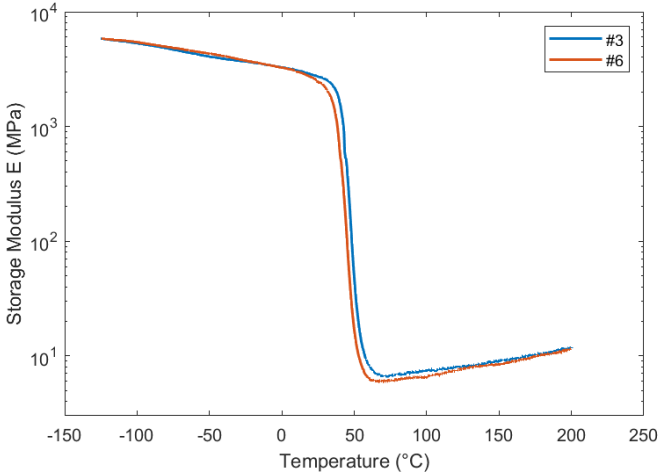
- Good toughness → Approaching MY750 values
- Pot life > 4h
- Low viscosity

#3 Wt. %	#6 Wt. %	Component
-	12.5	
21	-	
15.7	18.2	
63.3	69.4	

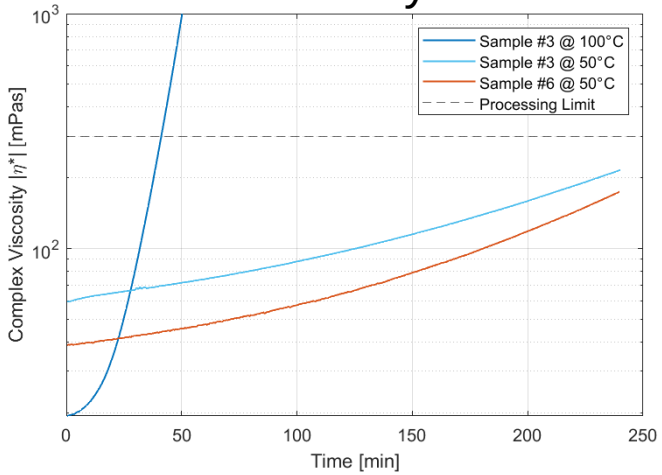
SENB



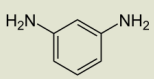
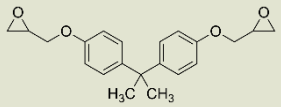
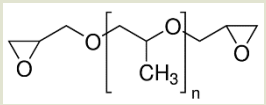
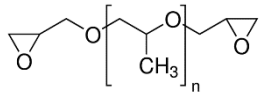
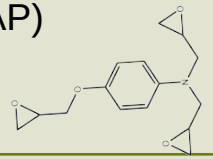
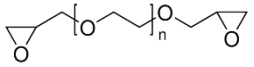
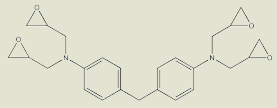
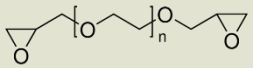
DMTA



Viscometry



Systematic study – System & Objectives

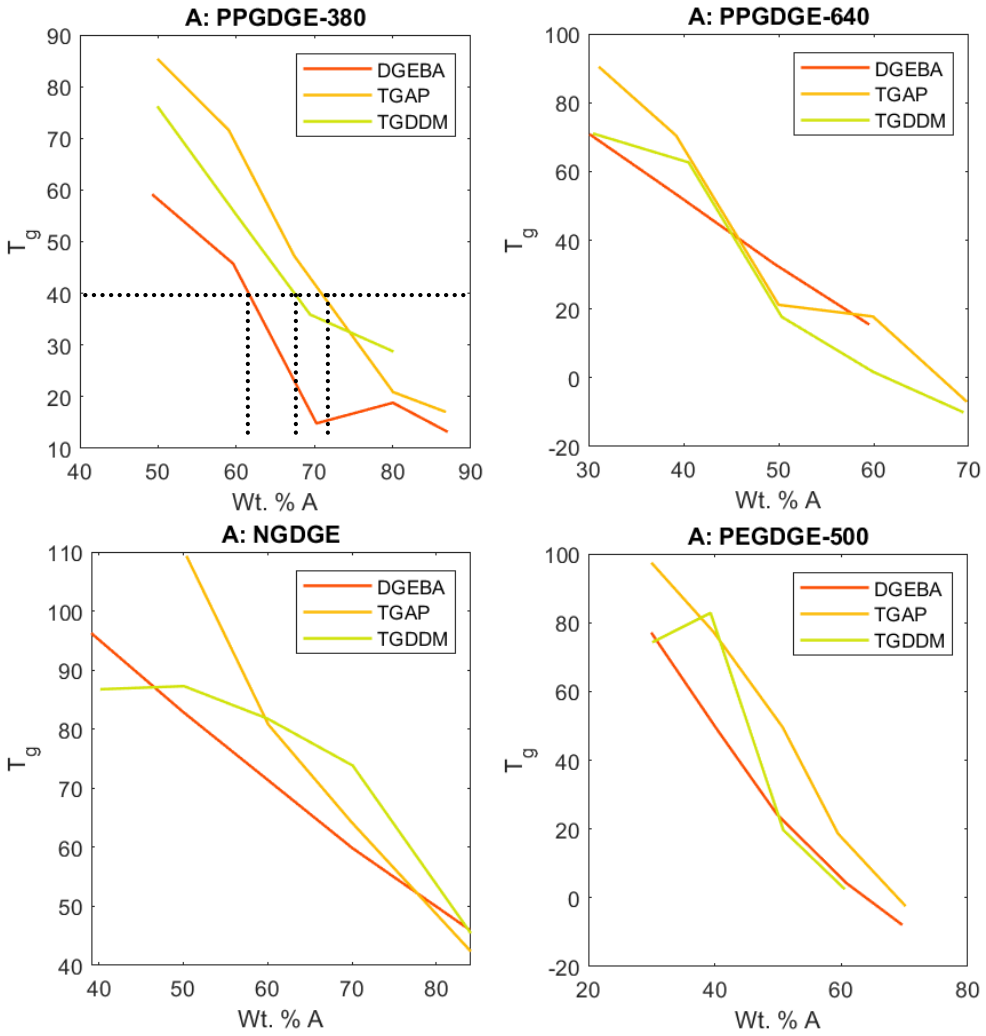
Comp. C Amine	Comp. B Epoxide	Comp. A (f = 2) Epoxide, flexible chain
Meta-phenylene diamine (MPD) f = 4 	Bisphenol A diglycidyl ether (DGEBA) f = 2 	Poly(propylene glycol) diglycidyl ether 380 g/mol (PPGDGE-380) 
		Poly(propylene glycol) diglycidyl ether 640 g/mol (PPGDGE-640) 
	Triglycidyl p-aminophenol (TGAP) f = 3 	Poly(ethylene glycol) diglycidyl ether 400 g/mol (PEGDGE-400) 
	Tetraglycidyl methylenedianilline (TGDDM) f = 4 	Poly(ethylene glycol) diglycidyl ether 500 g/mol (PEGDGE-500) 
		Neopentyl glycol diglycidyl ether (NGDGE) 

- Relate structural parameters (crosslink density, deformability,…) to toughness
- Each composition is a combination of A, B, C
  - Stoichiometric
  - One degree of freedom (I use **wt. % A**)
- Increase toughness even more
  - Maximize wt. % A, so that Tg = 40 °C & see which is most effective

Systematic study – Results of prestudy

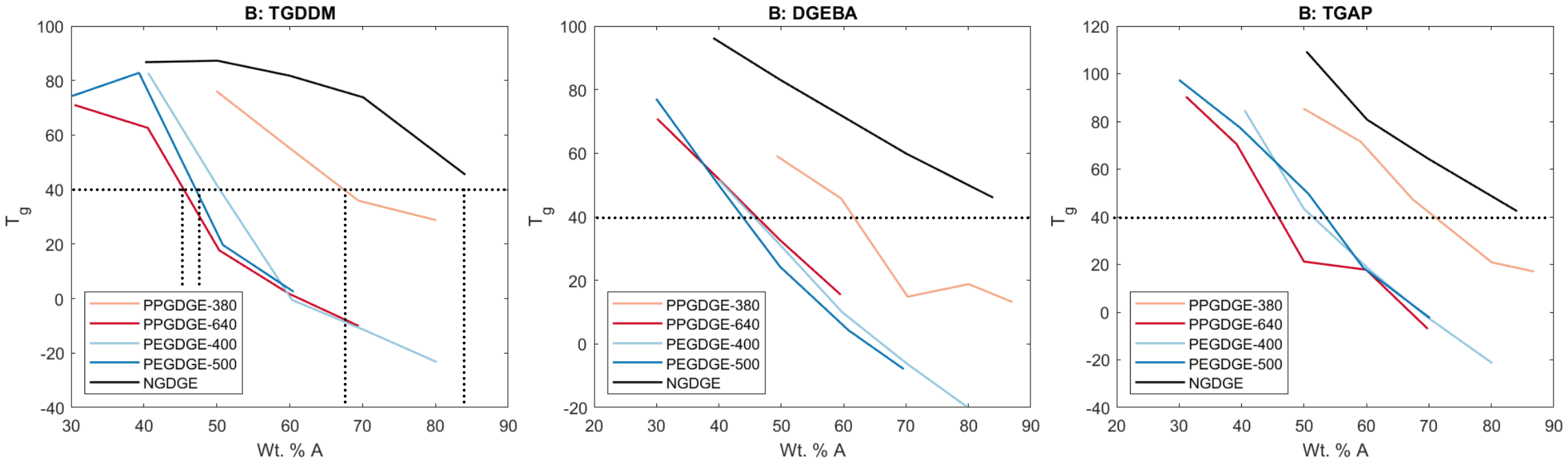
- Plots of Tg vs Wt. % component A
  - Fixed component A
  - Variable component B (f = 2, 3, 4)

- Findings
  - TGAP (f=3) seems to increase Tg the most, thus allowing to increase wt. % A
  - No advantage of TGDDM (f=4) over TGAP (f=3)
  - Effect not large



Systematic study – Results of prestudy

- Here, different molecular weights (Comp. A) are plotted together
- Findings
  - Higher molecular weight → Tg decreases faster

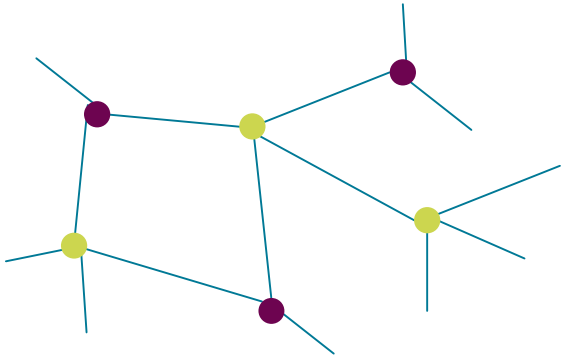


Systematic study – Calculations

- Calculation of the crosslink density (under full conversion)

$$v_e = \frac{3}{2}C_3 + \frac{4}{2}C_4 + \frac{5}{2}C_5 + \ldots = \sum_{f=3}^{\infty} C_f$$

C_f : Concentration of reactant of functionality f [moles/cm3]
v_e : Elastically active crosslinks [moles/cm3]

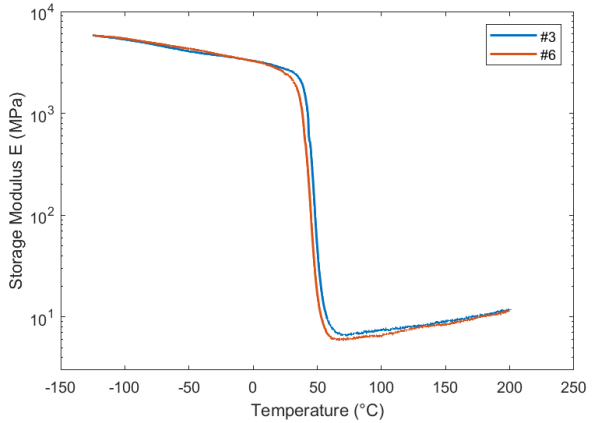


- Calculation of the corresponding rubbery elastic modulus (for small strains)

$$E = 3gv_eRT$$
$$g = (f_c - 2)/f_c$$

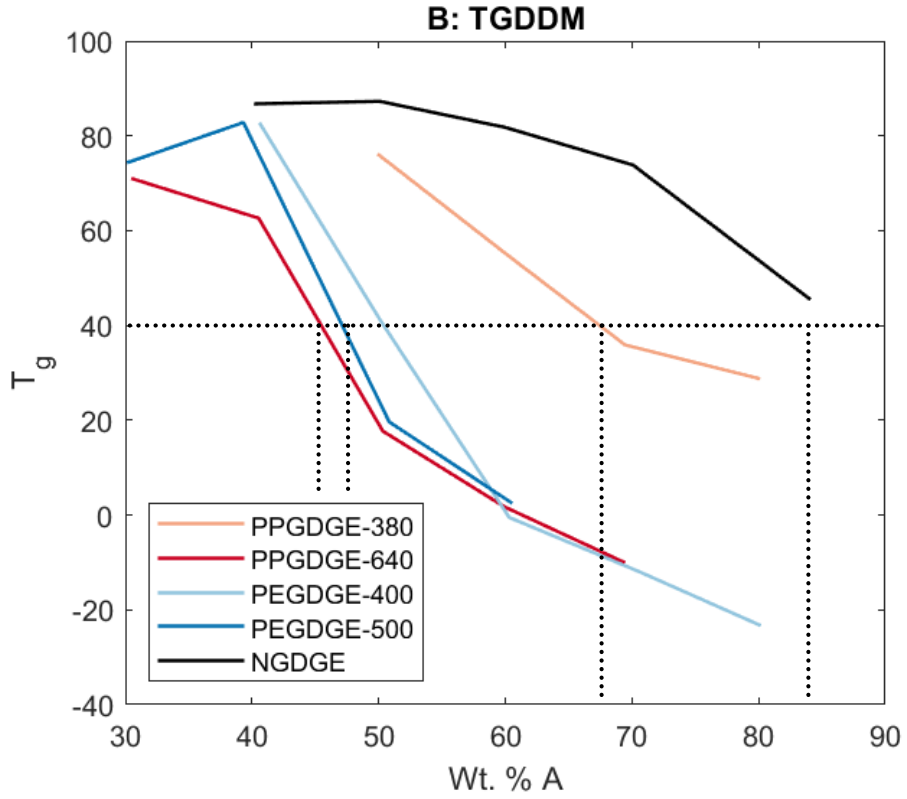
g : Prefactor accounting for crosslink mobility
R : Gas constant
T : Temperature
f_c : Average crosslink functionality

- Compare measured E, dE/dT with calculated value



Systematic study – Outlook

- Mechanical Testing: 27. Sept – 8. October
  - Toughness
  - DMTA
  - Compression
  - Tensile (above Tg)
- Investigation topological parameters - toughness
- Providing best formulations for PSI
  - All components are from Sigma-Aldrich



Acknowledgements

- ETH Zürich
  - Prof. Vermant, co-supervisor for discusssions and support
  - Soft Materials Group for support
  - Xavier Guichard and Dr. Alessandro Lauria for synthesis and discussions on Gd_2O_3 nanoparticles
- PSI
  - Dr. Bernhard Auchmann, Dr. André Brem and Dr. Michael Daly for discussions and experimental support
- CERN
  - Dr. Davide Tomassini for discussions
- Funding by CHART (Swiss accelerator research and technology)
  - Collaboration between ETH, PSI, CERN, EPFL
  - Developing technology for the FCC (future circular collider) planned for 2060

CHART
Swiss Accelerator Research and Technology