Anisotropy in Natural Fibres and its Influence on Composite Performance

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Thermoplastic Composites Growth

- Strong continuing growth
- Attractive & Improving Performance to Price Ratio
  - "Clean" processing - no chemistry
  - Intrinsically recyclable

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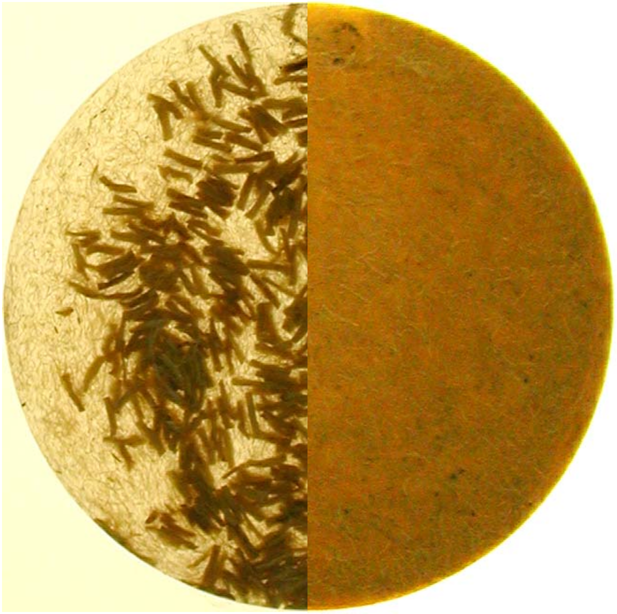
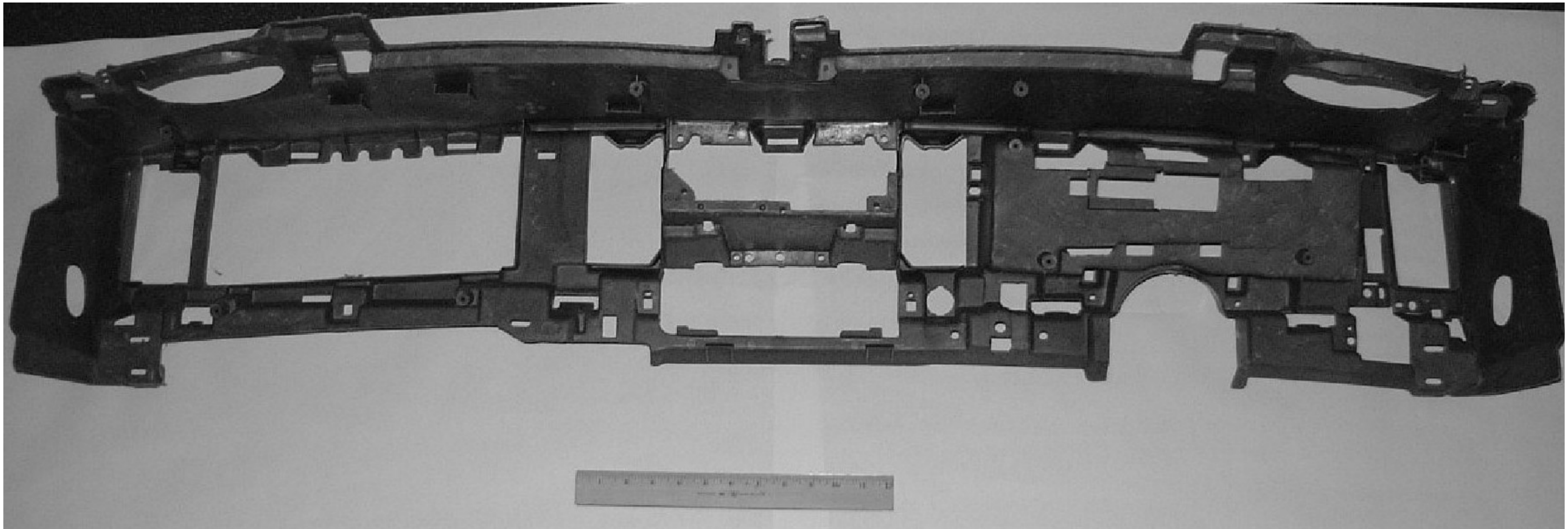
Natural Fibre Reinforced Polypropylene





Why Natural Fibre Composites ?

There is a growing interest in the use of Natural Fibre as a reinforcement for composites in many applications.
Some typical fibre properties are shown in the Table below

	Flax	Sisal	Jute	Glass
Modulus (GPa)	27-70	17-28	20-55	72
Strength (GPa)	0.3-0.9	0.1-0.8	0.2-0.9	>1.5
Density	1.5	1.3	1.3	2.6

$$E_C = \eta_0 \eta_L V_f E_f + V_m E_m$$

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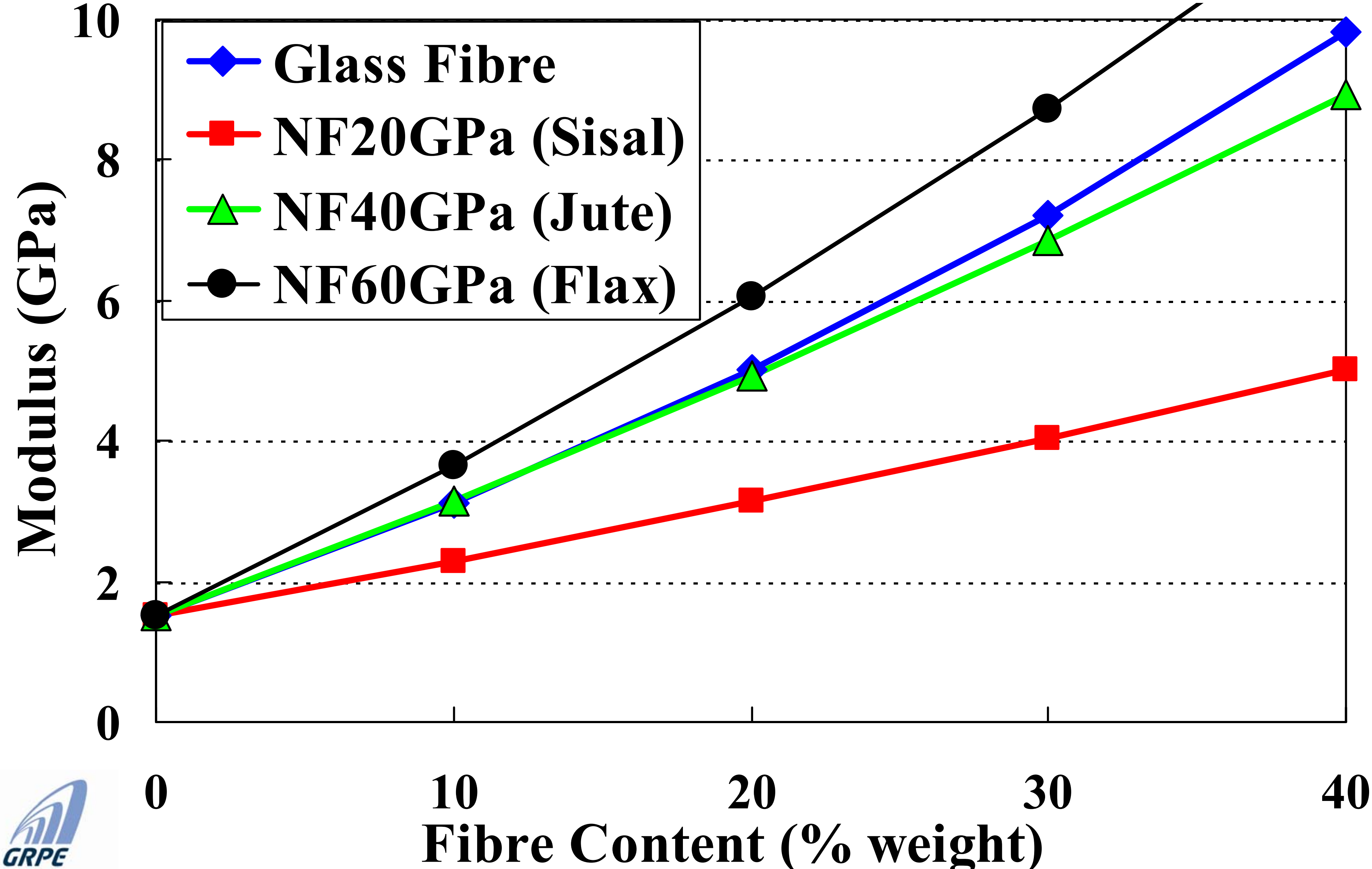
RoM Prediction Composite Modulus



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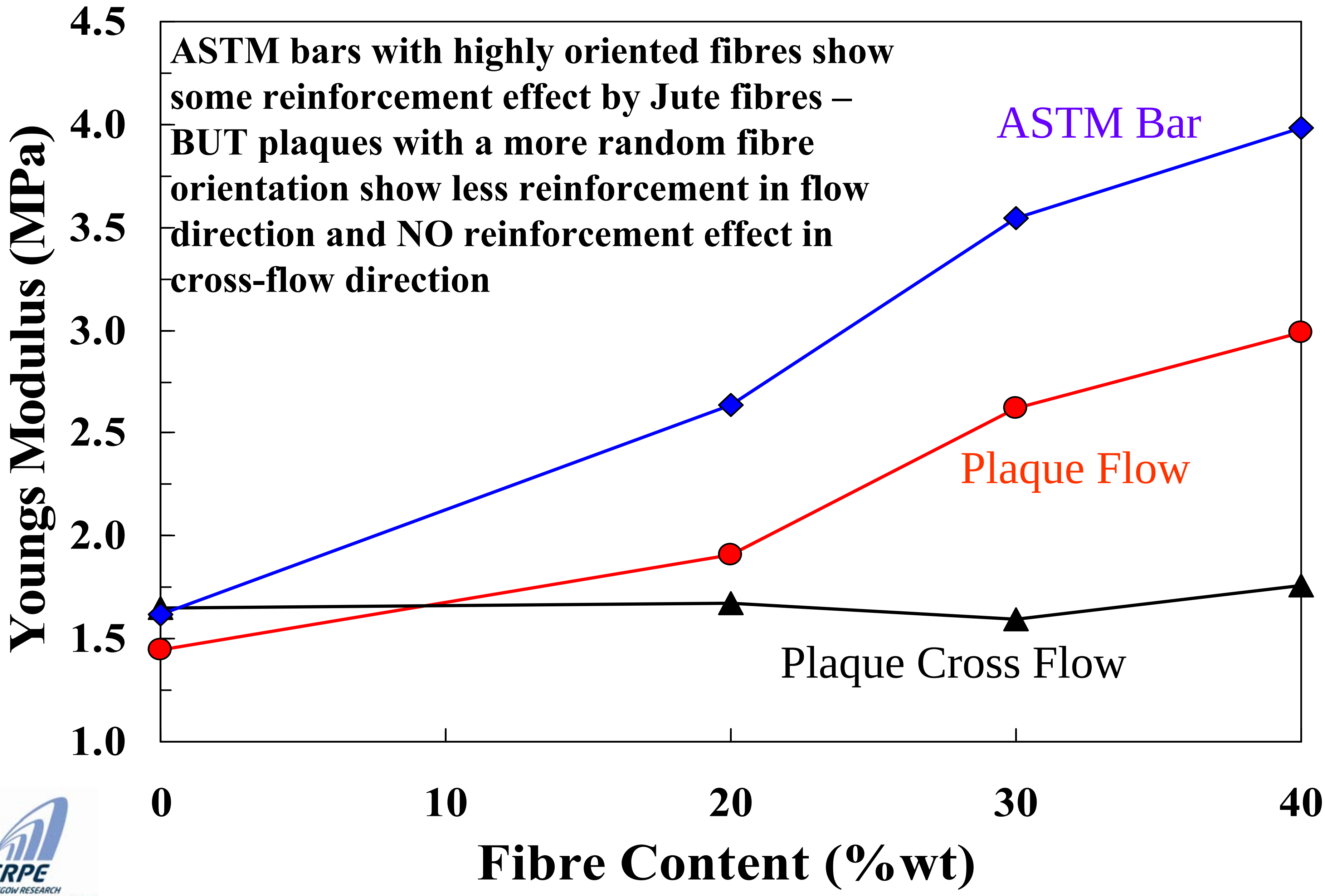
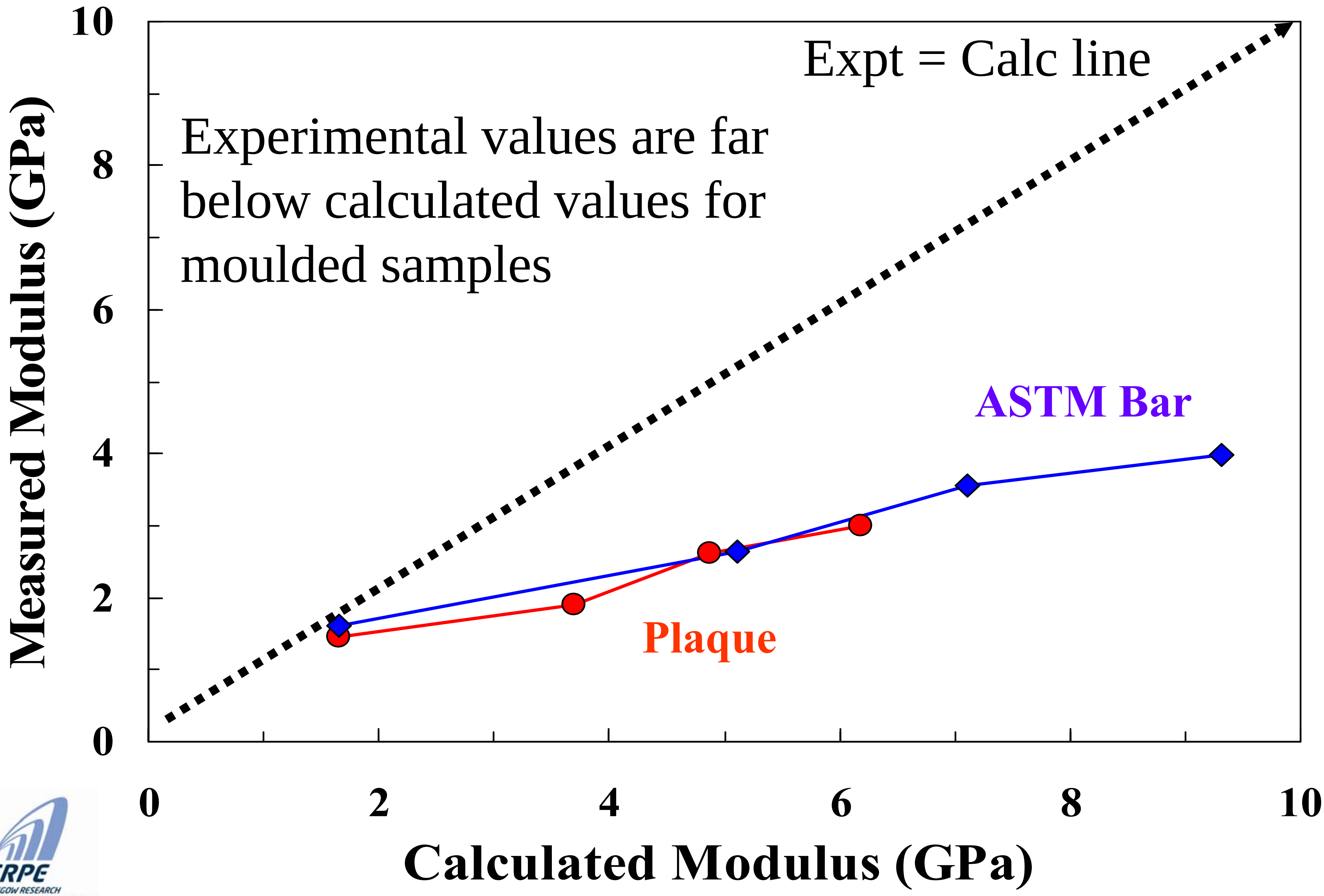
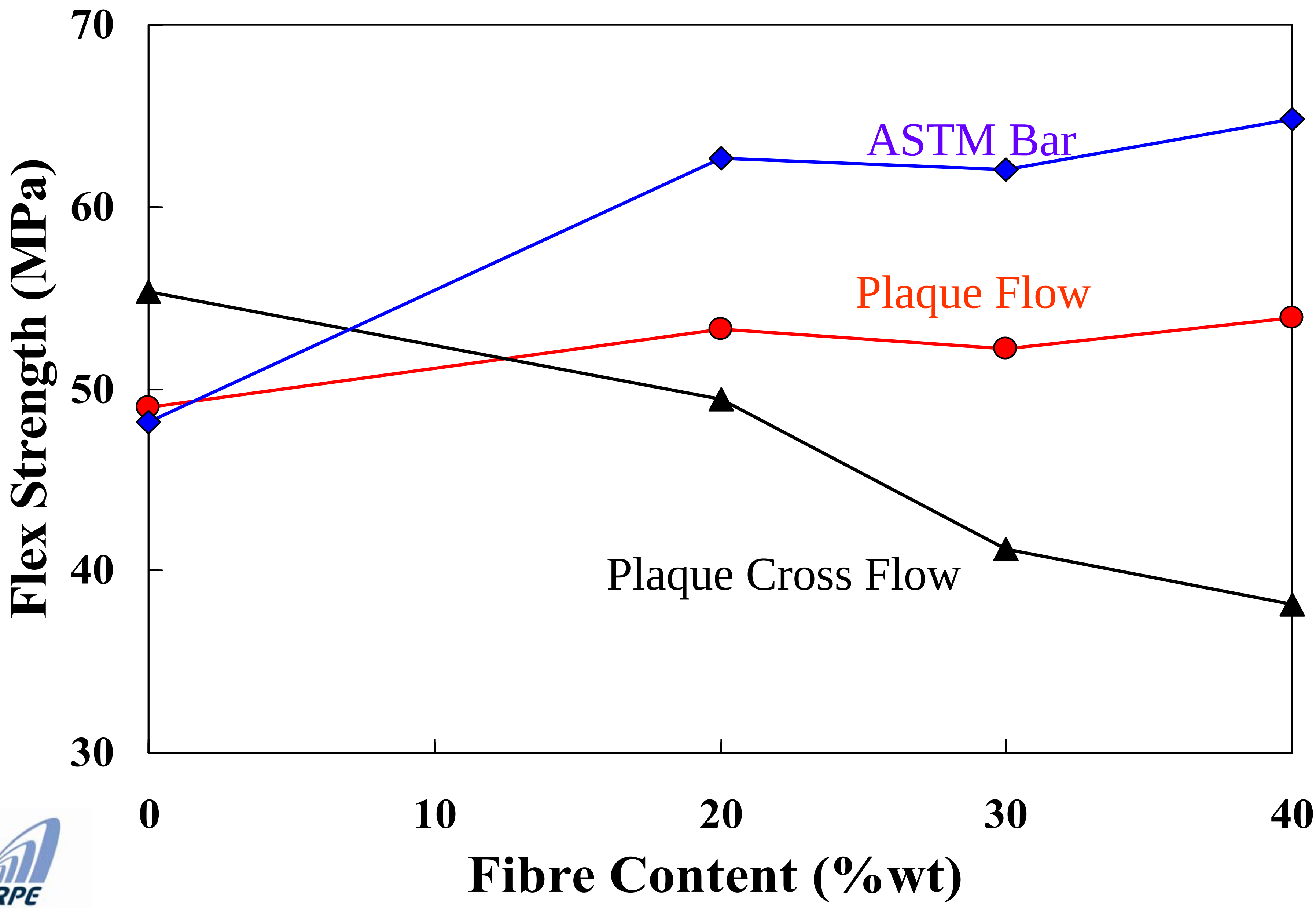
Modulus of Injection Moulded Jute-PP



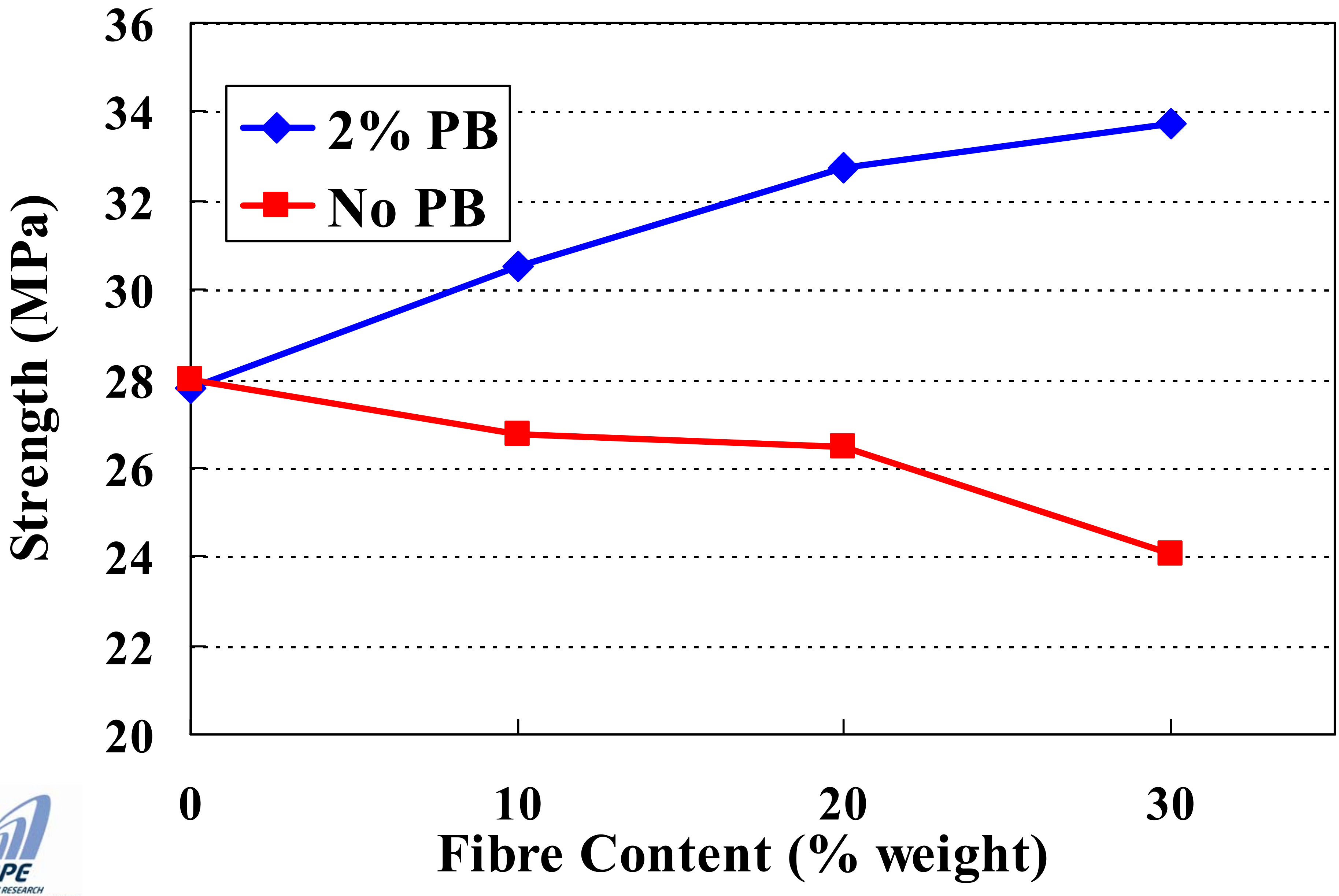
Jute-PP Modulus Experiment vs Calculated



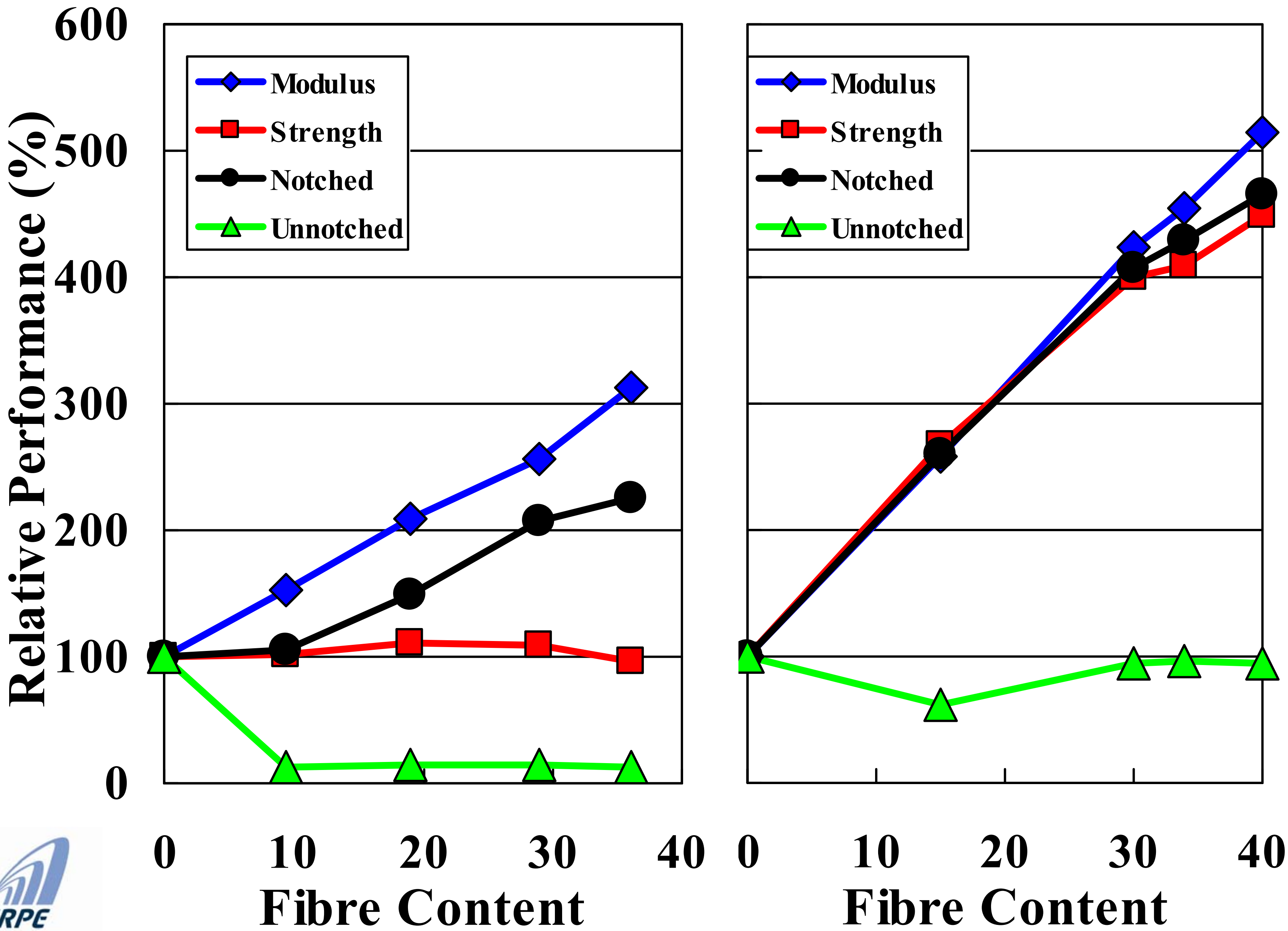
Jute-PP Flexural Strength



Jute-PP Tensile Strength



Comparison 'Long' NF vs GF



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Poor NF Performance – First reactions

- In general, cellulose based natural fibres have highly polar surfaces rich in –OH groups coated in natural waxes. Many polymer matrices (especially polyolefins) are much less polar.

- Therefore poor interaction
  - Poor wetting
  - Poor adhesion

- Solution must be surface treatments and silane coupling agents !

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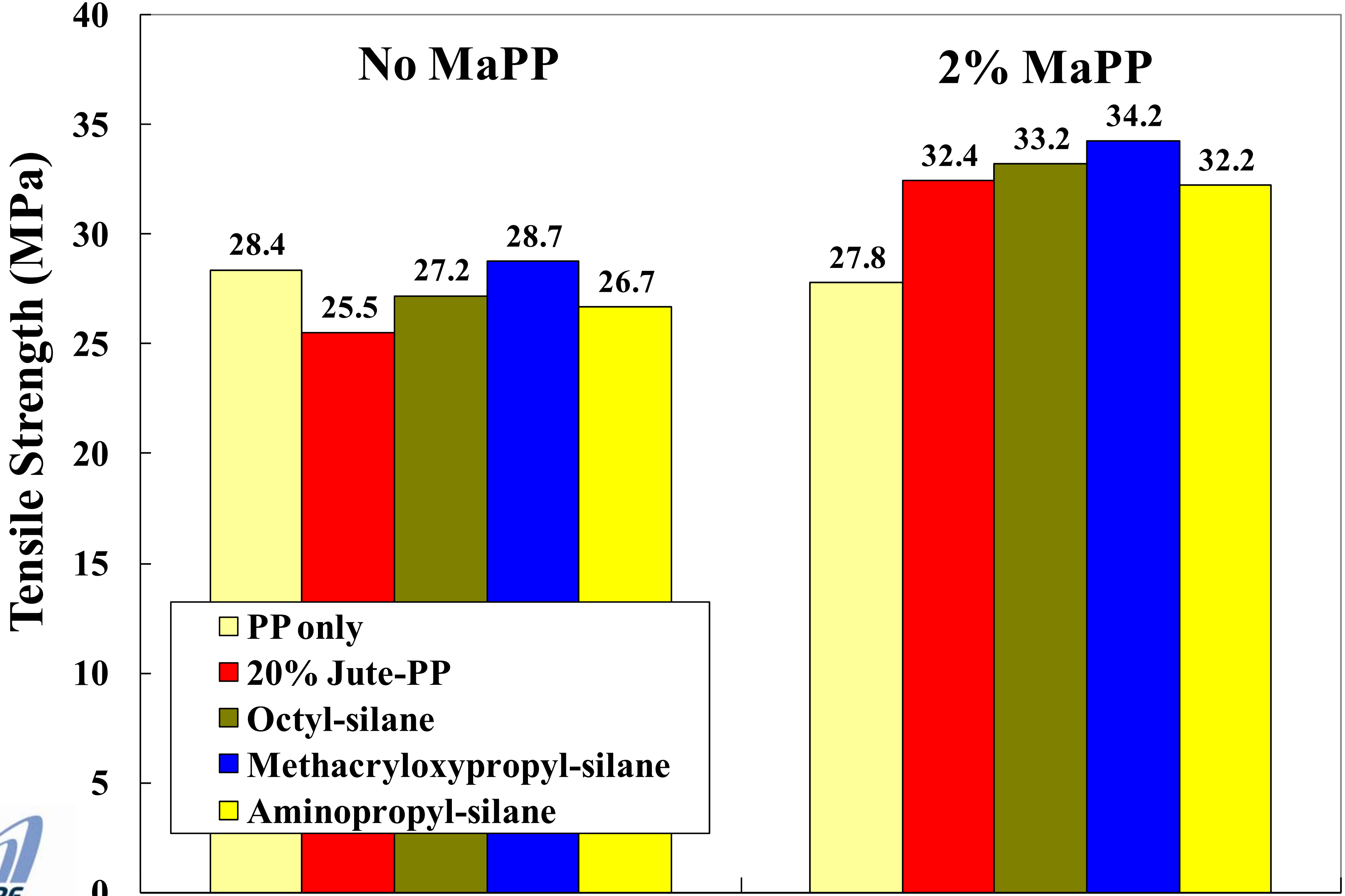
Silane-MaPP ‘adhesion’ effects 20% Jute-PP



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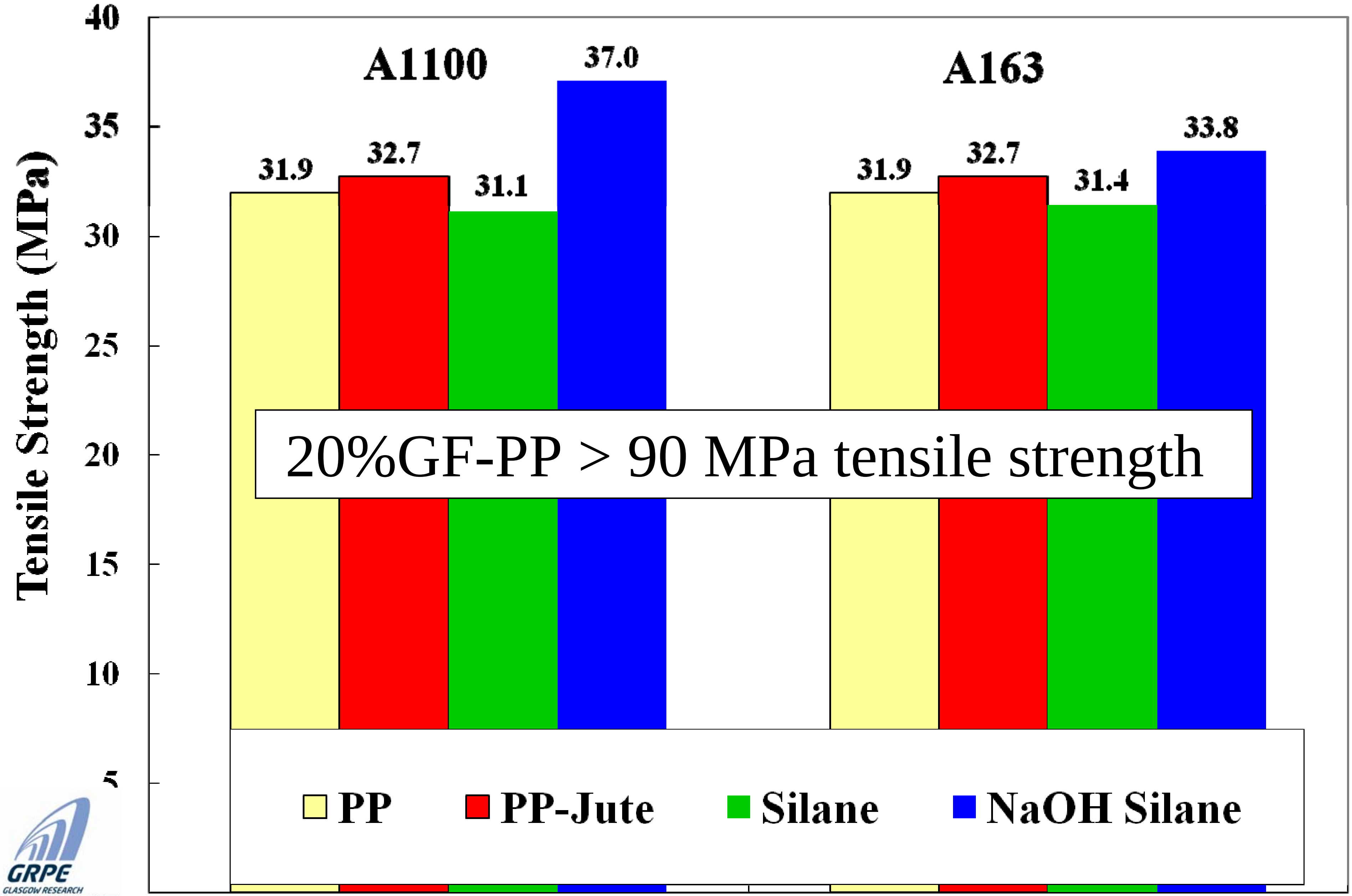
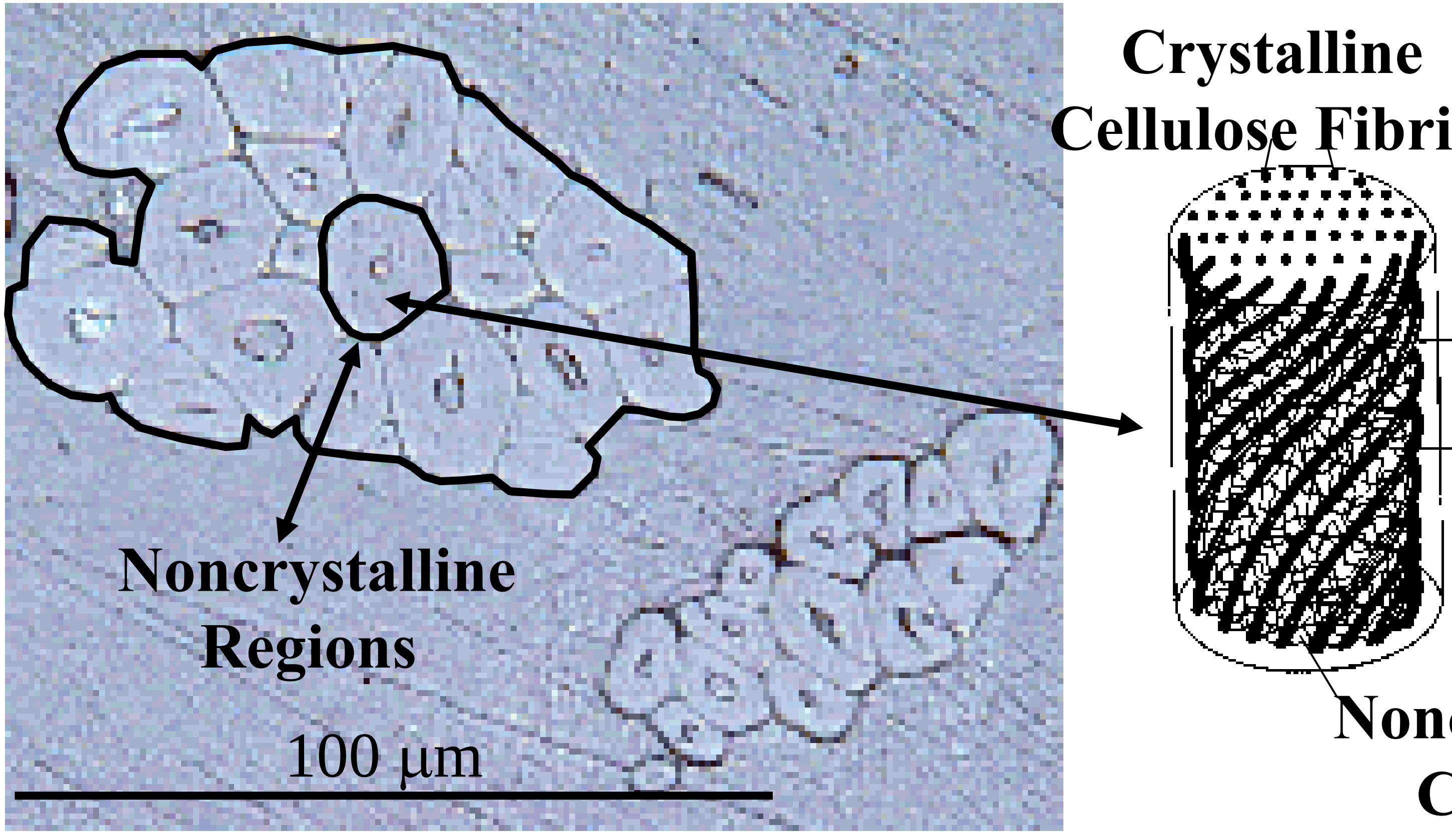
Silane-NaOH 'adhesion' effects 20% Jute-PP



Anisotropic Natural Fibre Structure



Property Anisotropy of Jute Fibre

	Temperature (°C)				
	-50	**-25**	**0**	**25**	**50**
E_{1f} (GPa)	42.8	41.9	40.3	39.4	38.9
E_{2f} (GPa)	8.2	7.8	6.6	5.5	3.8
E_{2f} /E_{1f}	**0.19**	**0.19**	**0.16**	**0.14**	**0.10**
G_{12f} (GPa)	4.9	4.7	4.7	3.5	3.3
ν_{12f}	0.19	0.16	0.14	0.11	0.08
ν_{21f}	0.04	0.03	0.02	0.01	0.01
α_{1f} (μm/°C)				-0.6	-16.0
α_{2f} (μm/°C)				77.2	121.6

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Property Anisotropy of Natural Fibres

	Jute	*Flax	*Sisal
E_{1f} (GPa)	39.4	48.0	21.6
E_{2f} (GPa)	5.5	7.9	9.7
E_{2f}/E_{1f}	**0.14**	**0.16**	**0.45**
G_{12f} (GPa)	3.5	7.3	5.1
ν_{12f}	0.11	0.18	0.12
ν_{21f}	0.01	0.07	0.06
α_{1f} (µm/°C)	-0.6		
α_{2f} (µm/°C)	77.2		

* Characterisation of the Thermoelastic Properties of Natural Fibres used in Composites, John Anderson, 2007/2008, Department of Mechanical Engineering, University of Strathclyde

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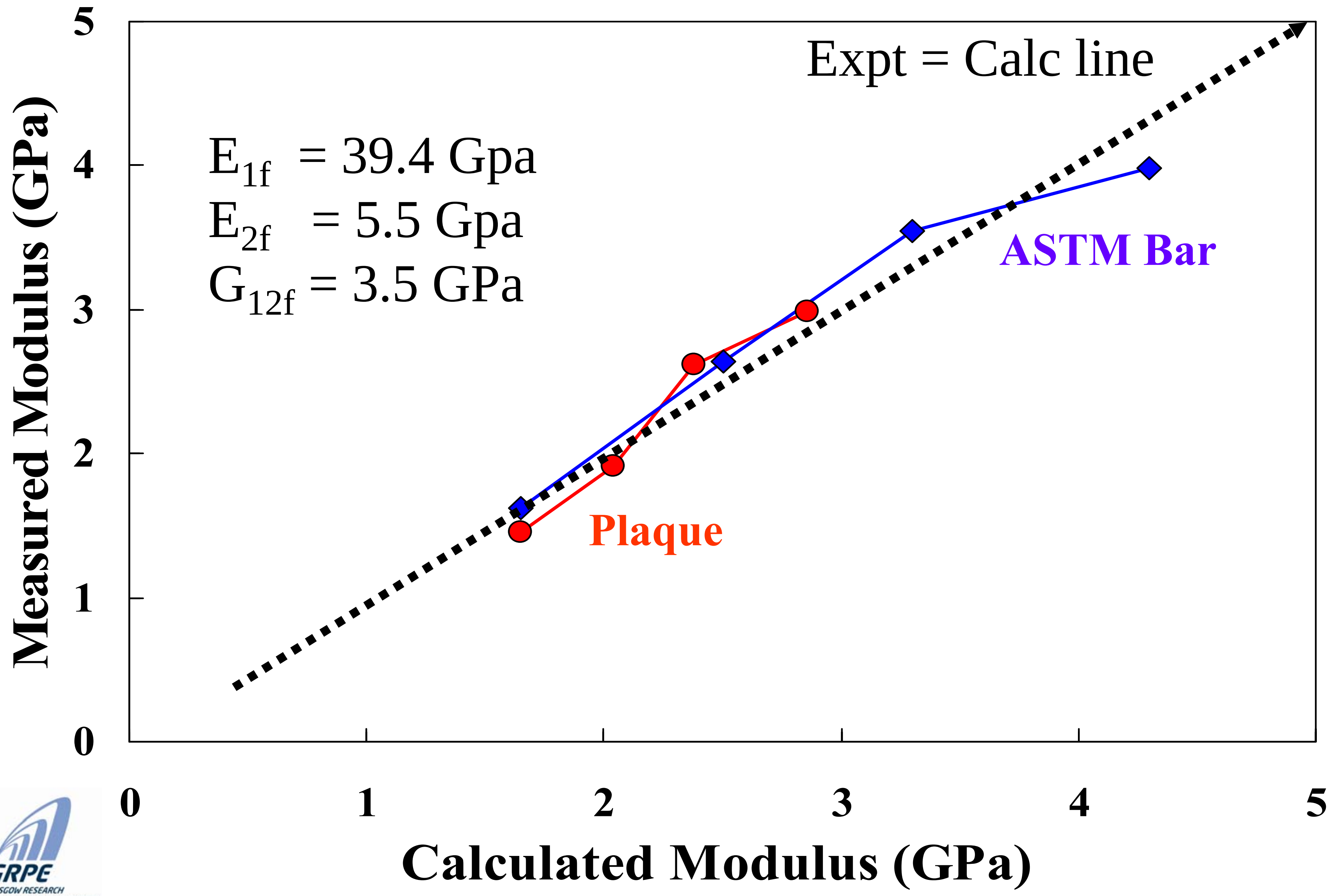
Jute-PP Modulus Experiment vs Calculated



Natural Fibre Anisotropy

- Modulus prediction improved (lowered) by consideration of fibre transverse properties.

- What about composite strength ?

Residual Thermal Stresses at the Interface

- **Thermoplastic composites formed in melt at high temperature and cooled**

- **Thermal expansion coefficient of polymer >> fibre**

- **Result - compressive radial stresses at interface σ_r**

- **If static friction $\mu_s > 0$ there will be a contribution from these stresses to apparent IFSS, $\tau = \mu_s . \sigma_r$**

Residual Thermal Stresses at the Interface

- **σ_r model** *–Wagner HD. and Nairn JA. Residual thermal stresses in three concentric transversely isotropic cylinders. Compos.Sci.Tech. 1997:57: 1289-1302.*

- **μ_s=0.65 for GF-PP** *Schoolenberg GE. Some wetting and adhesion phenomena in polypropylene composites, in Polypropylene: Structure, blends and composites. (Chapmann Hall, London 1995).*

- **μ_s=0.40 GF-PP, =0.7 GF-MaPP** *Thomason JL. 'Interfaces and Interfacial effects in glass reinforced thermoplastics', 28th Risø International Symposium on Materials Science' (Denmark, 2007)*

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Input Values for Thermal Stress Calculation

	Glass	Carbon	Aramid	Jute	PP
Longitudinal Modulus (GPa)	72	220	130	39.4	1.5
Transverse Modulus (GPa)	72	14	10	5.5	1.5
Longitudinal Poisson Ratio	0.22	0.08	0.3	0.11	0.35
Transverse Poisson Ratio	0.22	0.01	0.1	0.01	0.35
Longitudinal LCTE (μm/m.ºC)	5	-0.36	-3.6	-0.6	120
Transverse LCTE (μm/m.ºC)	**5**	**18**	**50**	**77**	**120**

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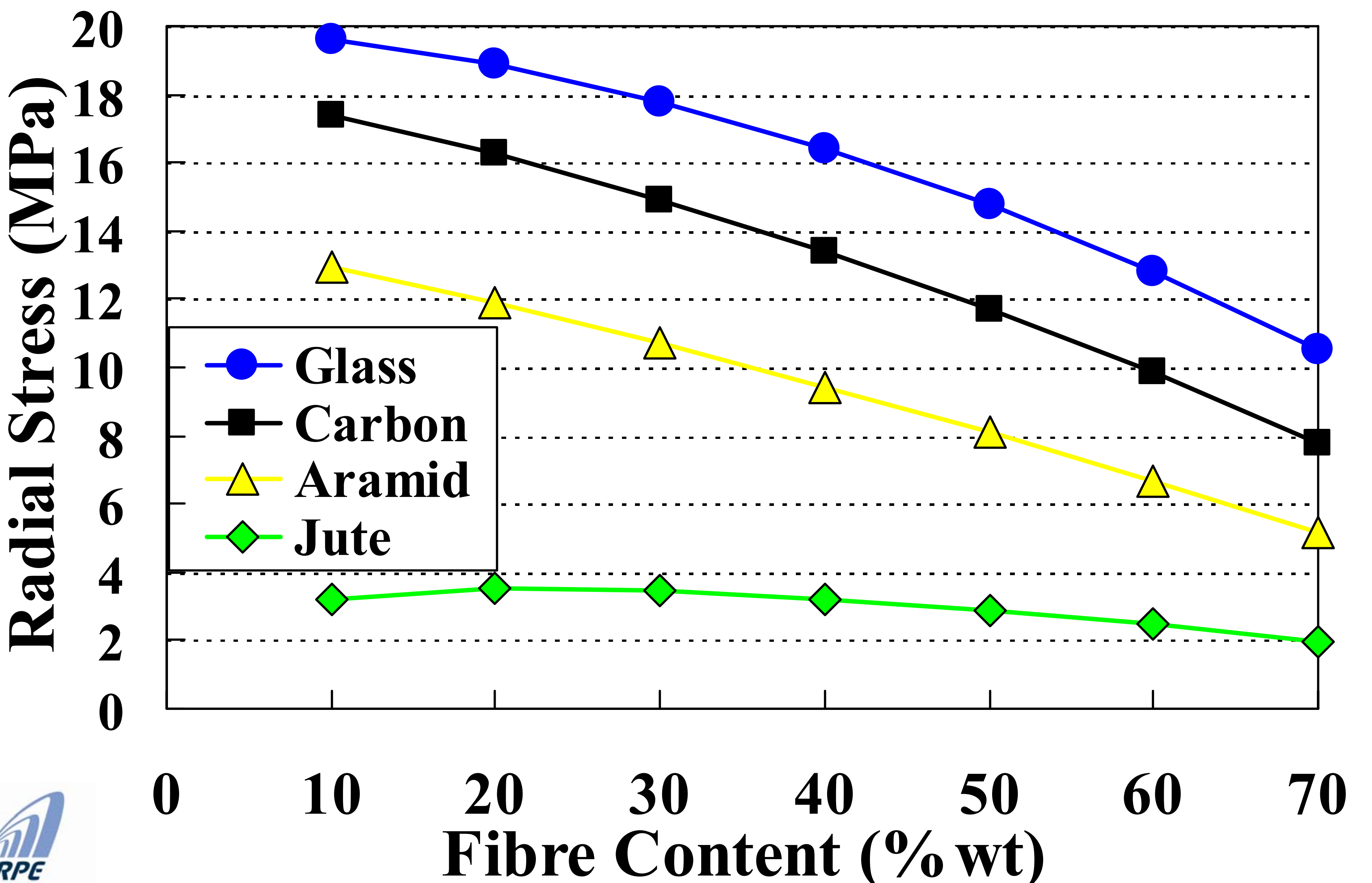
Model Thermal Stress at Fibre-PP Interface



Modelling IFSS of NF-PP

- NF $\sigma_r \approx 3$ MPa - gives $\tau \approx$ 1-2 MPa for μ_s=0.4-0.7
- Use Kelly Tyson model to calculate composite strength of long fibre Jute-PP
- L_f = 3-4mm, d_f = 40 μm, σ_f = 400 MPa

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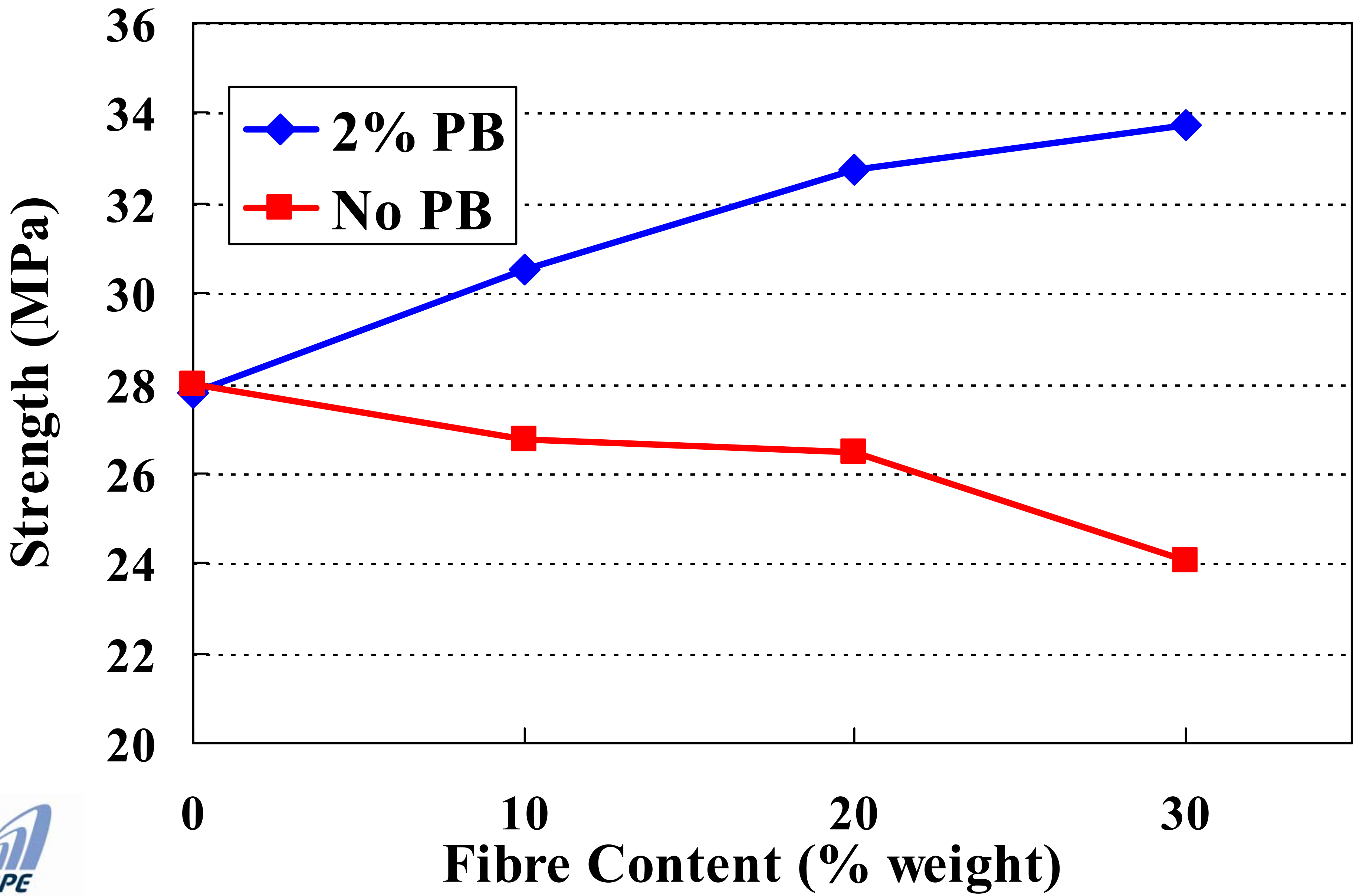
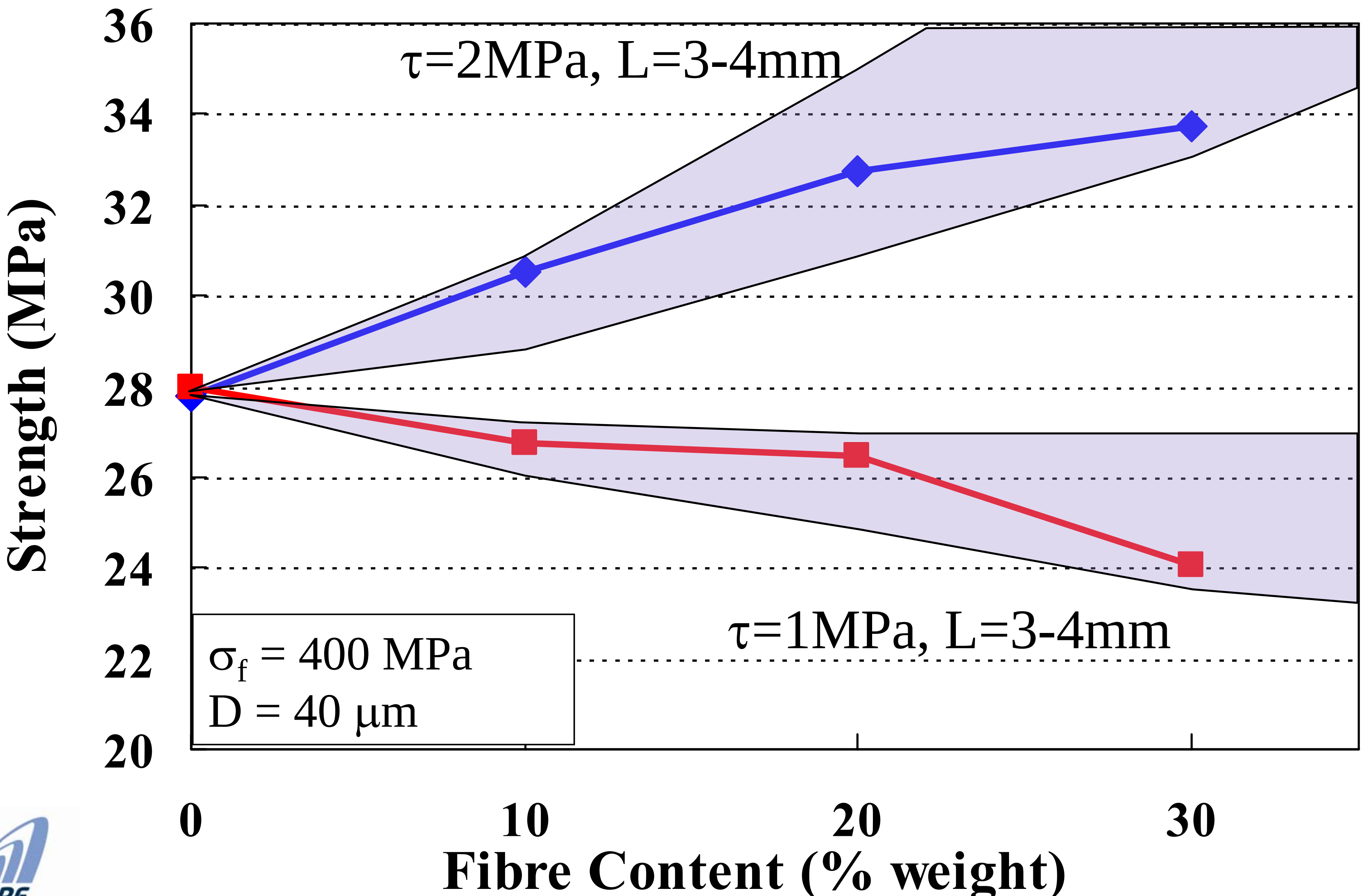
Jute-PP Tensile Strength



Jute-PP Tensile Strength



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Conclusions

- Residual compressive stresses at the interface may contribute significantly to the apparent IFSS in thermoplastic composites
- Magnitude of stresses strongly influenced by fibre structure
- Natural fibres are not delivering the generally overhyped performance in composite materials due to disregard of their highly anisotropic structure – which results in
  - Transverse performance similar to matrix polymers
  - Poor offaxis reinforcement efficiency
  - Low radial interfacial stress and consequently very low IFSS
- It is probable that major advances in the reinforcement efficiency of natural fibres will require significant attention to their internal structure

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