

Natural fibre-reinforced geopolymer composites

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Introduction:

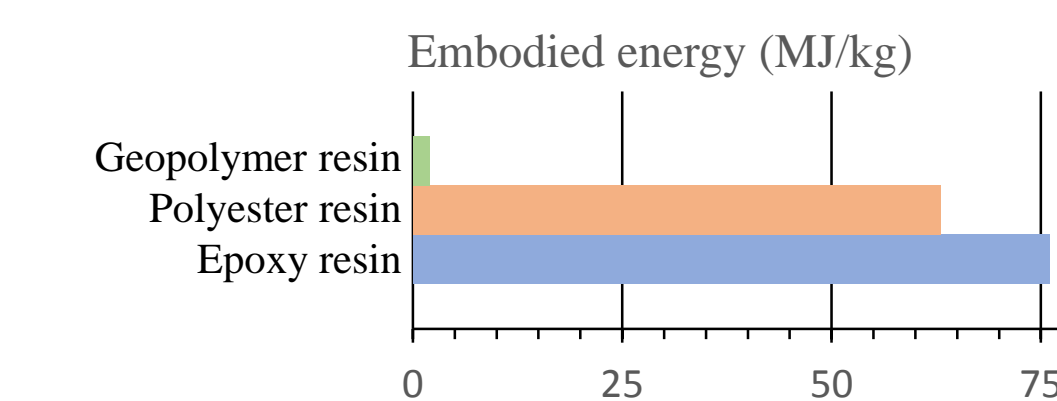
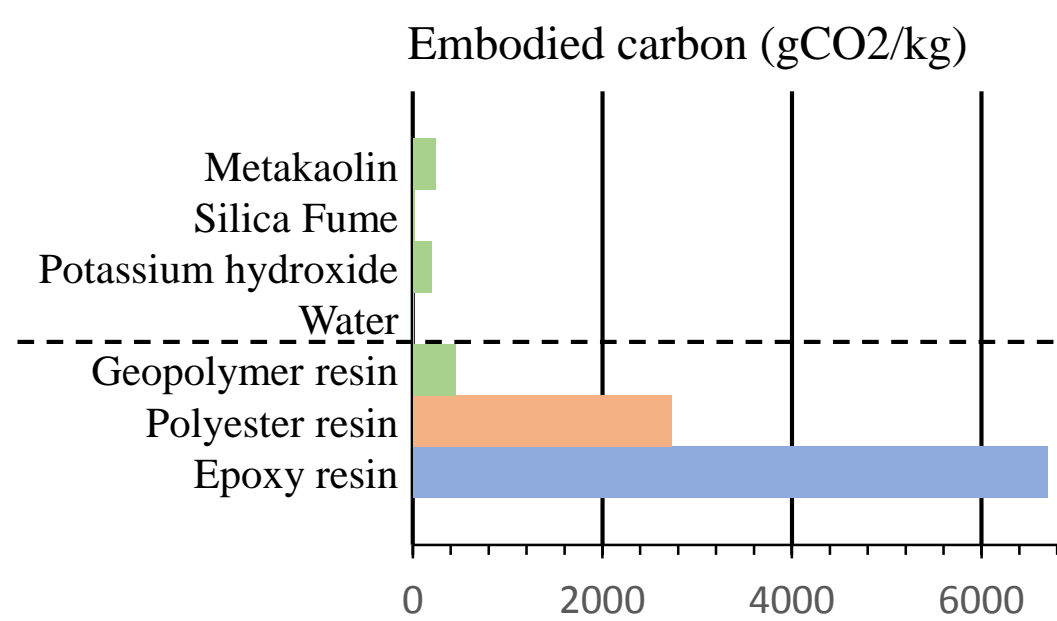
This PhD project aims to develop natural fibre-reinforced geopolymer composites in order to provide a structurally viable, sustainable alternative to ordinary fibre-reinforced polymers (FRP) – such as those reinforced with glass fibres (GFRP). More specifically, the aim is to successfully demonstrate that geopolymeric matrices, when reinforced with sustainably sourced natural fibres, can provide comparable mechanical performance to polymeric composites such as GFRP at potentially 10% of their cost, carbon emissions and embodied energy. In addition, the risks posed by fire such as structural deformation and emission of toxic gases are eliminated due to the ceramic, incombustible nature of geopolymers.

Objectives:

- Elucidate the influence of chemical composition on the fluid, chemical, and mechanical properties of geopolymers.
- Select suitable compositions with high workability and strength to be manufactured with fibre-reinforcement.

Geopolymer raw materials	Chemical composition (%)			
	SiO ₂	Al ₂ O ₃	K ₂ O	H ₂ O
Metakaolin	56	38	-	-
Silica fume	93	-	-	-
Potassium hydroxide	-	-	83.96	16.04
Water	-	-	-	100

Raw materials combined in varying quantities to form compositions of the following molar ratios.



SiO ₂ /Al ₂ O ₃	Molar ratios		Water/Solids	
	H ₂ O/K ₂ O	Water/Solids		
4	11	2	2	
		2.25	2.25	
		2.5	2.5	
		2.75	2.75	
		14	2	2
			2.25	2.25
	2.5		2.5	
	2.75		2.75	
	17		2	2
			2.25	2.25
		2.5	2.5	
		2.75	2.75	
6		11	1.85	1.85
			1.9	1.9
	1.95		1.95	
	2		2	
	14		1.85	1.85
			1.9	1.9
		1.95	1.95	
		2	2	
		17	1.85	1.85
			1.9	1.9
	1.95		1.95	
	2		2	
10	5		1.45	1.45
			1.5	1.5
		1.55	1.55	
		1.6	1.6	
		6	1.45	1.45
			1.5	1.5
	1.55		1.55	
	1.6		1.6	
	7		1.45	1.45
			1.5	1.5
		1.55	1.55	
		1.6	1.6	

Results:

To ensure high material quality and optimal mechanical performance, composite manufacture must facilitate impregnation of resin and fibre, ergo requiring sufficient resin flow.

Figure (1)[Right] details the dependency of resin flow on the ongoing geopolymer synthesis – described using reaction heat. It can be seen that peak reaction heat, due to dissolution, coincides with the onset of reduced viscosity. Figures 2, 3, and 4 [Below] detail the progression of Viscosity (Pa.s) Vs. Time (s) for respective compositions, with key points provided below said figures.

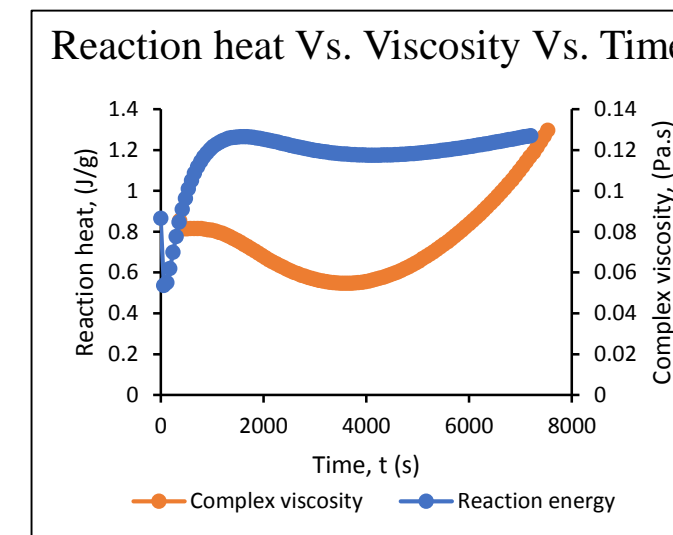


Figure 1: Reaction heat and Viscosity

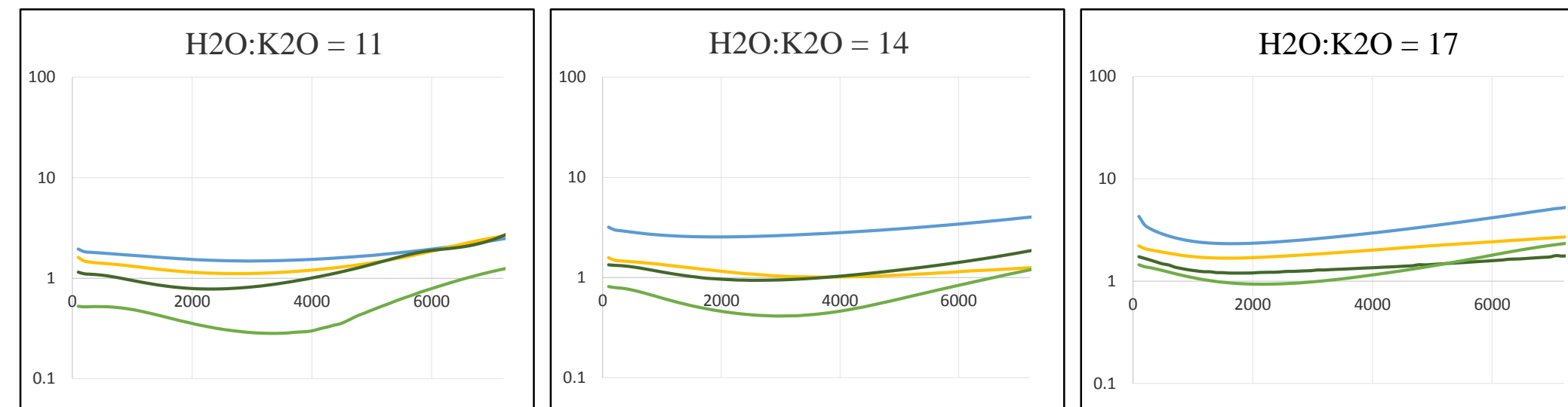


Figure 2: Complex viscosity Vs. Time for SiO₂:Al₂O₃ = 4 at H₂O:K₂O = 11, 14 and 17.

- Diminishing alkalinity (increasing H₂O:K₂O) increases resistance to flow.
- Rising Water:Solids reduces viscosity; both observations are applicable to all compositions.

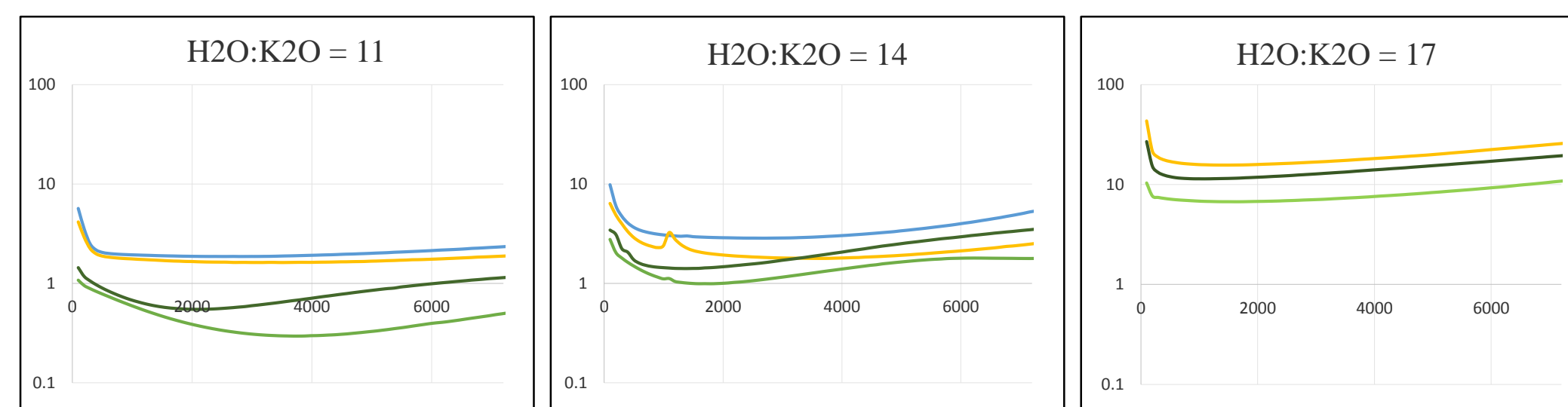


Figure 3: Complex viscosity Vs. Time for SiO₂:Al₂O₃ = 6 at H₂O:K₂O = 11, 14 and 17.

- All show viscosity minima, occurring later in samples of higher Water:Solids.
 - Viscosity increases when compared to equivalent SiO₂:Al₂O₃ = 4 samples.
- Note: Water:Solids ratios are relative to specified SiO₂:Al₂O₃ ratios only.

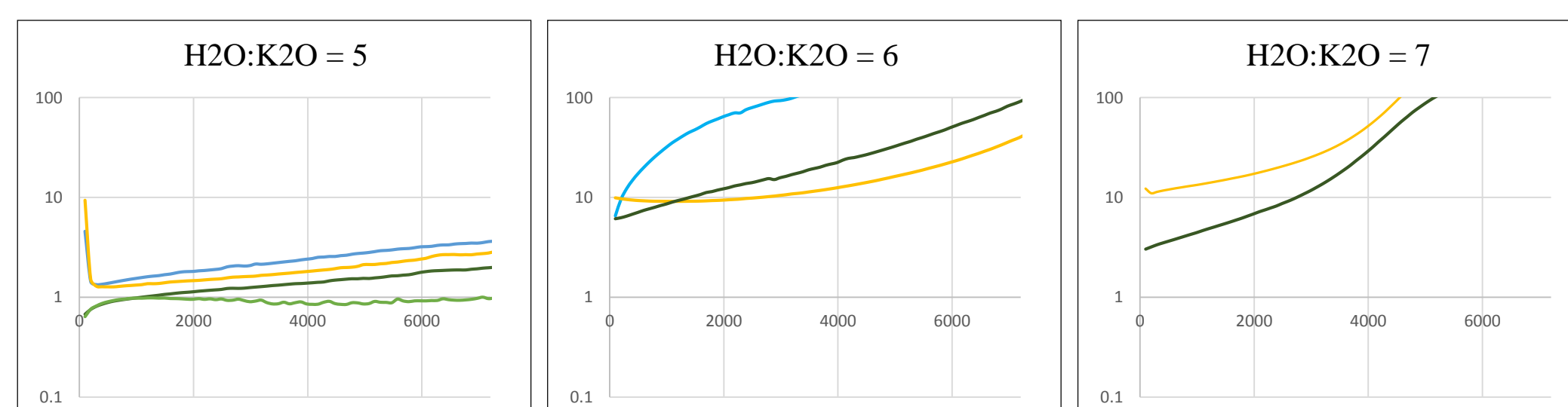


Figure 4: Complex viscosity Vs. Time for SiO₂:Al₂O₃ = 10 at H₂O:K₂O = 5, 6 and 7.

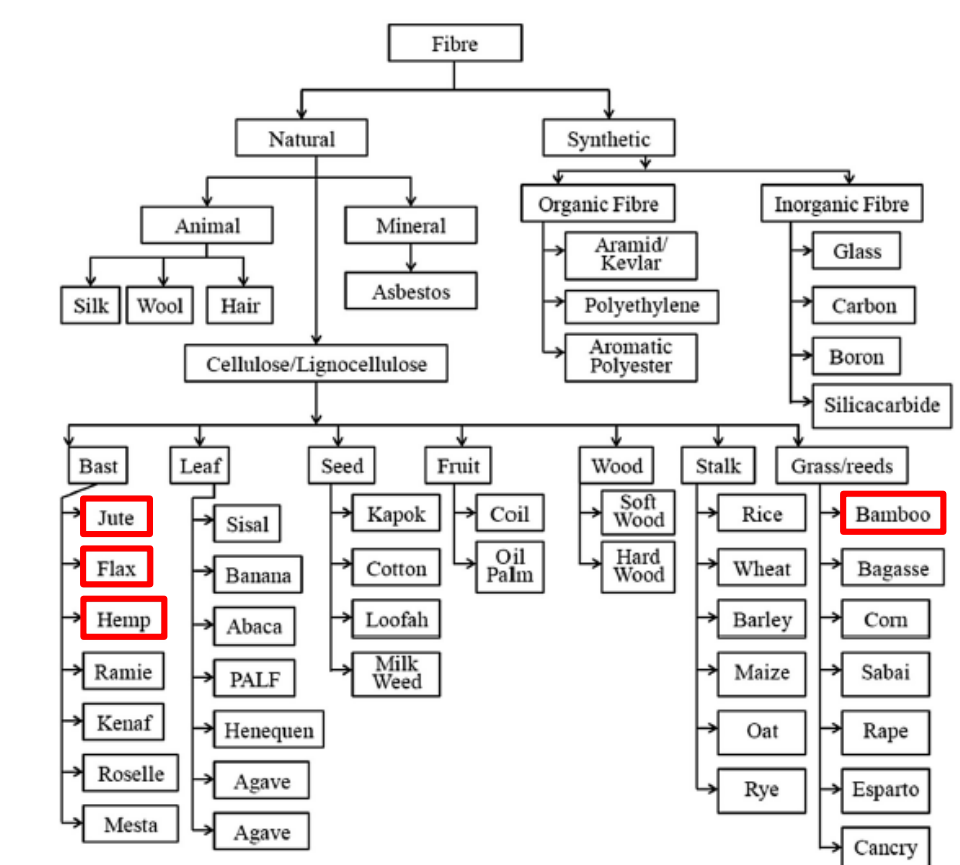
- At H₂O:K₂O > 5 sample viscosity is excessive and therefore disregarded.
- The two lower Water:Solids ratios experience a sudden, sharp viscosity reduction, whereas the two higher ratios display minimum viscosity from the beginning, all of which exhibit a progressive rise thereafter.

Conclusions:

- Higher alkalinity dissolves solids more rapidly, therefore high-alkaline, fresh-mixed resins possess lower viscosity
- Viscosity minima occur due to dissolution reducing intermolecular interaction; therefore samples with larger solid content proportion display changes due to dissolution earlier.
- All formulations of SiO₂:Al₂O₃ = 4, excluding Water:Solids of 2 at H₂O:K₂O 14 and 17, are adequate for manufacture.
- The increase in solid content from SiO₂:Al₂O₃ = 4 to 6 meant that alkalinities used prior were inadequate, exacerbating the effect of diminishing flow with decreased alkalinity.
- At SiO₂:Al₂O₃ = 6, only resins of Water:Solids = 1.95 and 2 at H₂O:K₂O = 11 and 14 are suitable.
- The substantially greater solid content of formulations at SiO₂:Al₂O₃ = 10 require time to wet and dissolve, with higher Water:Solids proving more effective.
- Here, only resins containing H₂O:K₂O = 5 are manufacturable.

Future work:

- How do the chosen natural fibres, seen below, interact with the alkaline geopolymer matrices? i.e. Understand the response and interactions between different combinations of fibres and geopolymer matrices, determining their compatibility.
- This will include investigations into degradation to the fibres' chemical and physical structure, and the effect this has on tensile strength and fibre-matrix bonding.



- How well do selected fibre-matrix combinations perform mechanically and how can the chosen configurations be developed? i.e. Characterise the composites physically and mechanically, and develop their properties.
- The exact area of development is yet to be determined due to the dependency upon future data. Potential areas for improvement may be the materials durability, fire performance, or fibre-matrix bonding and failure mode.