Effect of architecture on the mechanical properties of self-reinforced composites

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Outline

- Manufacturing of commingled yarn based woven and knitted self-reinforced Polymer(srP) composites
- Optical microscopic image of srP composites
- Tensile response of srP composites
- Flexural strength of srP composites
- Comparison of srP composites with prosthetic socket material.
- Summary

Introduction

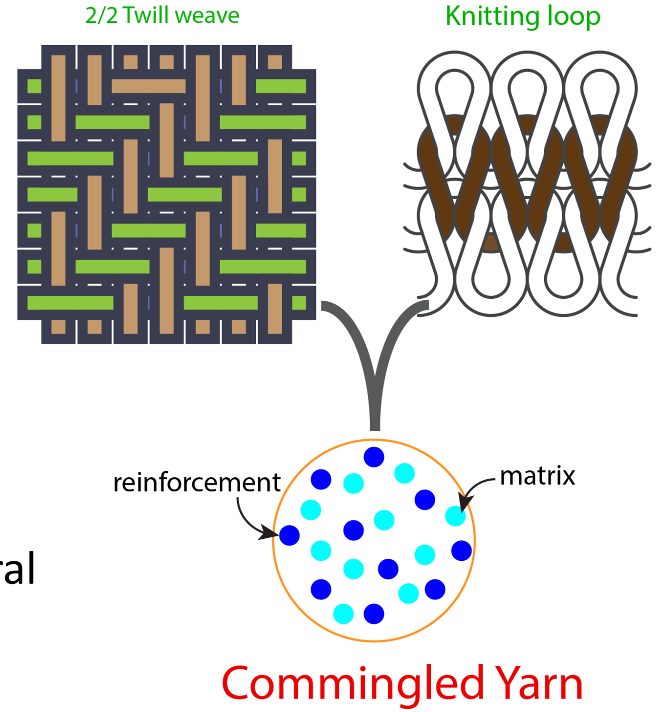
- The multitude of Self-reinforced polymers(srP) material's high mechanical properties and processibility embodies in different application like automotive, aerospace and construction industries.
- The commingled thermoplastic polymers enables manufacturing of composites at very short cycle times

- Prosthetic socket- An integral link which connects amputees residual limb to the rest of the prosthesis.

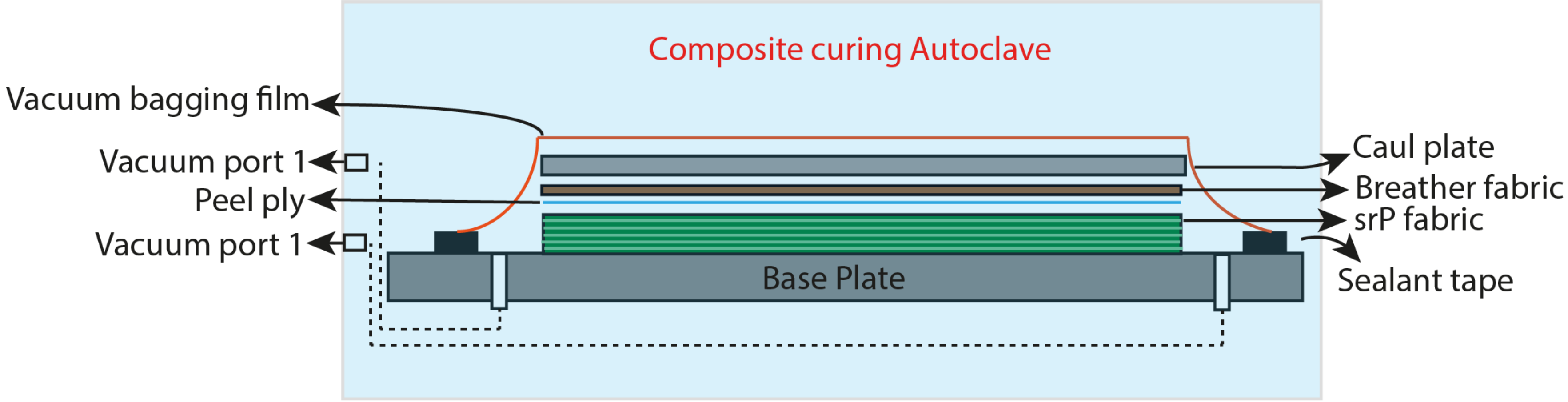
- Common materials: CFRP, GRRP, High-density polyethylene, polypropylene etc.

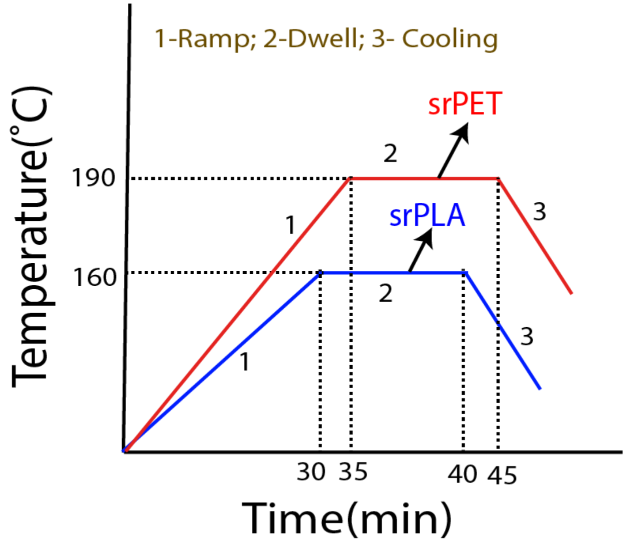
Objective:

- To perform mechanical characterization of the self-reinforced polyethylene terephthalate (srPET) and self-reinforced polylactic acid (srPLA) based thermoplastic composites.
- This commingled yarn based srPET and srPLA were examined in woven and architectural knitted preform to used as a candid material for socket manufacturing.



Manufacturing of srP Composite



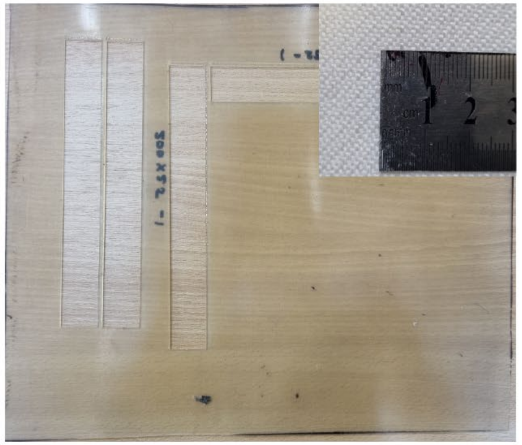


- The fibre volume fraction of srPET is 49% and srPLA is 50%.
- Six layers of woven Twill 2/2 srP fabric were used to fabricate the laminate using vacuum-assisted consolidation.
- The low-temperature matrix fibre made to melt to act as a binder for the reinforcing fibres.
- 85% vacuum were maintained whilst heating at the rate of $5°C/min$ until the consolidation temperature.

Laminate and optical Microscopy of srP woven composite

(a) The woven fabric and cured laminate of

srPLA

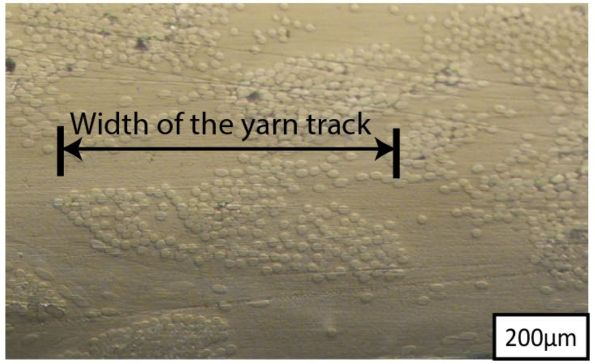


srPET

- The matrix is perfectly melted and encapsulated the reinforcing fibers in both srPET and srPLA laminates.
- No voids demonstrating the successful use of the thermal vacuum consolidation process of laminates

(b) The microscopic image of

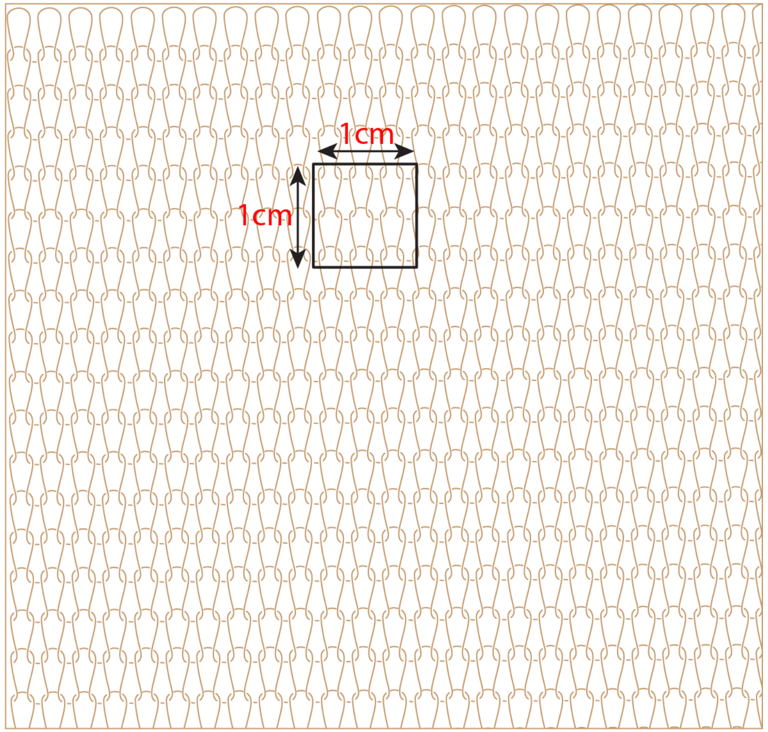
srPLA



srPET

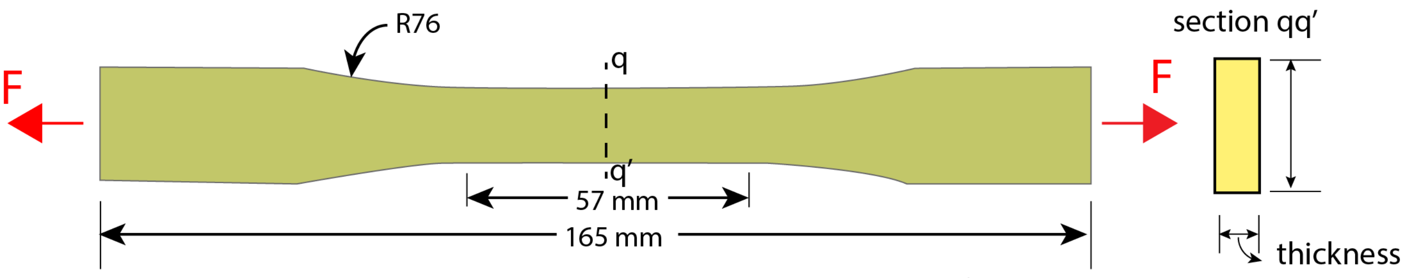
Architectural preforms of the srP composites

- The commingled thermoplastic yarn were weft-knitted with varying loop density.
- The architectural fabric of 400mm * 400mm were made using automated knitting machine.
- The similar vacuum-assisted consolidation were equipped for manufacturing PLA-K and PET-K laminate.

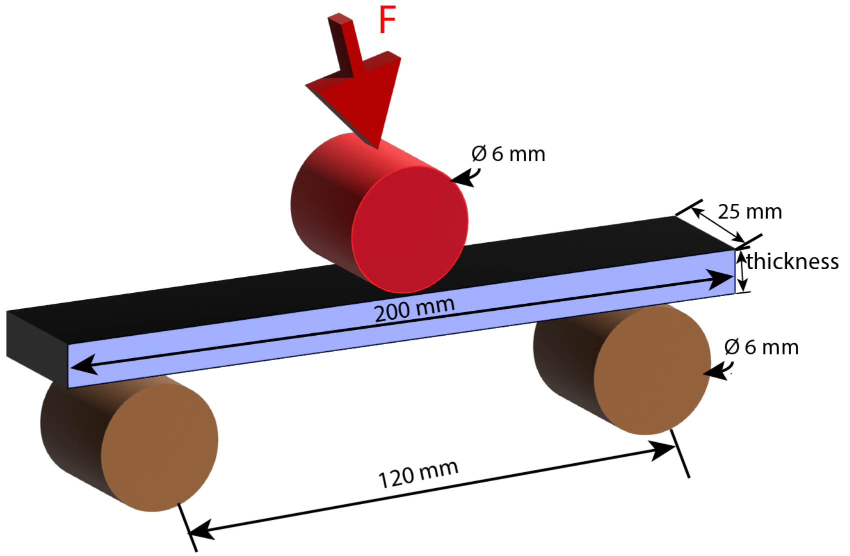


srPLA		srPET	
Case	Loop density($\frac{loops}{cm^2}$)	Case	Loop density(($\frac{loops}{cm^2}$))
A (high)	21 (tight)	D (high)	20 (tight)
B (medium)	17 (medium)	E (medium)	16 (medium)
C (low)	13 (loose)	F (low)	9 (loose)

Tensile and flexural tests of srP composites



(a) Dog bone specime as per ASTM D638



(b)Flexural three-pont bending as per ASTM 3039

- The fabricated woven and knitted laminates were examined in both the direction.
- Tensile and flexural tests were performed at the rate of 1mm/min.

Tensile response of srPLA laminate

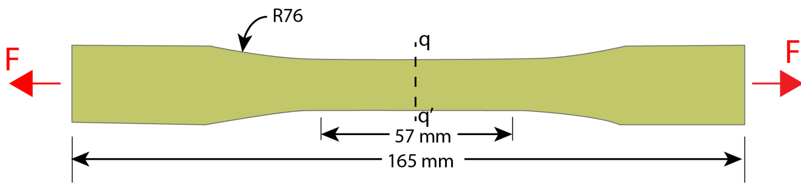
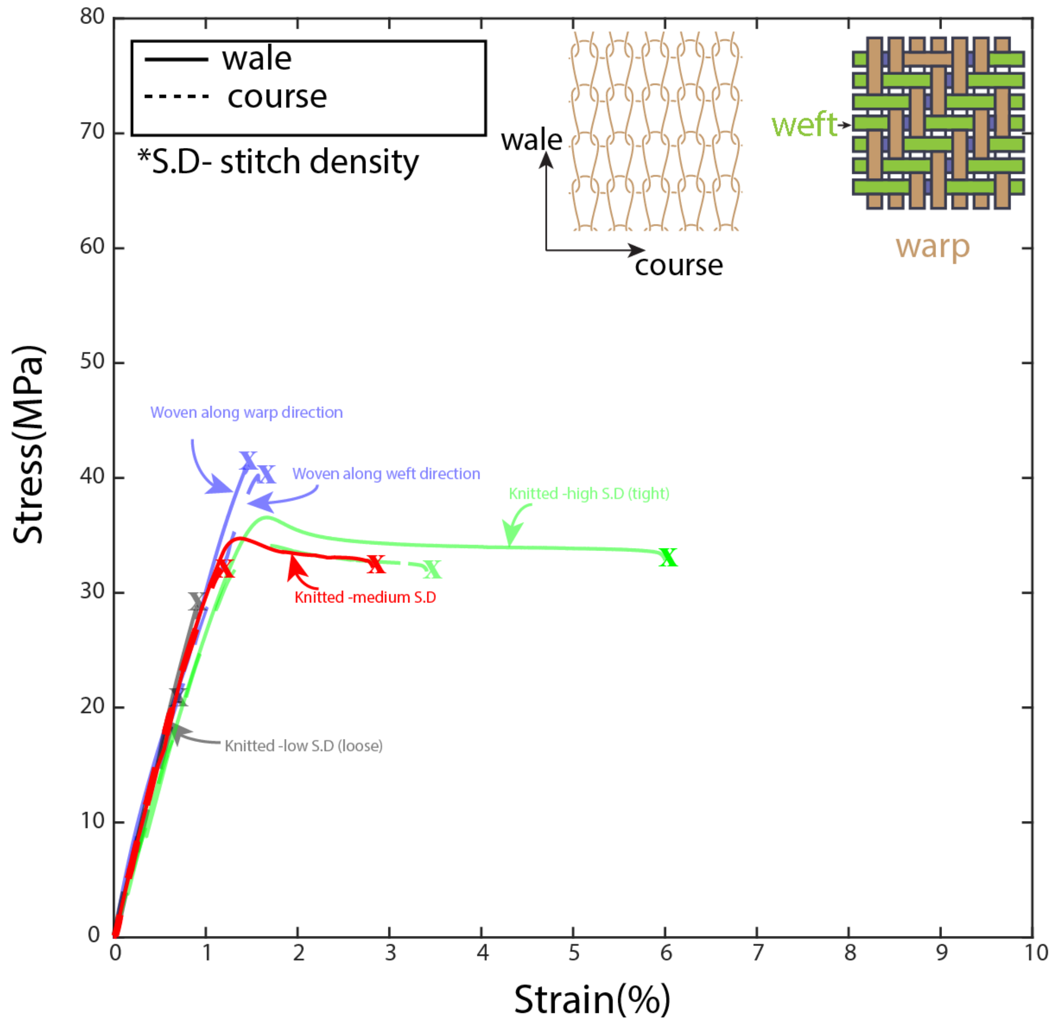


Table: The measured tensile properties of srPLA composite

Parameters	Ultimate strength (MPa)	Failure strain (%)	Elastic modulus (GPa)
PLAW-Warp	42±0.5	1.6	3.7±0.03
PLAW-Weft	41±2	1.8	3.85±0.25
PLA-high S.D(tight)*	**36.65±0.73**	**0.014±0.0005**	**2.88±0.008**
PLA-high S.D	33.94±1.95	0.014±0.0011	2.7±0.098
PLA-medium S.D*	**34.85±0.73**	**0.0134±0.0005**	**2.97±0.09**
PLA-medium S.D	31.82±1.06	0.0114±0.0005	2.96±0.12
PLA- low S.D(loose)*	26.44±1.38	0.007±0.0005	3.66±0.075
PLA-low S.D	**23.90±3.34**	**0.008±0.0016**	**3.2±0.042**

*- Wale direction; S.D- Stitch density



Tensile response of srPET laminate

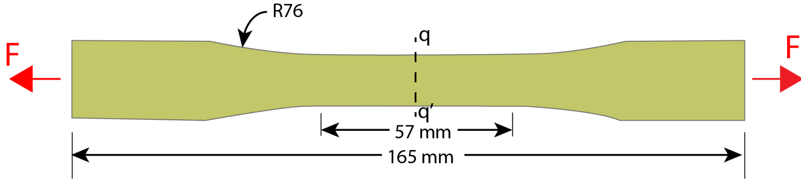
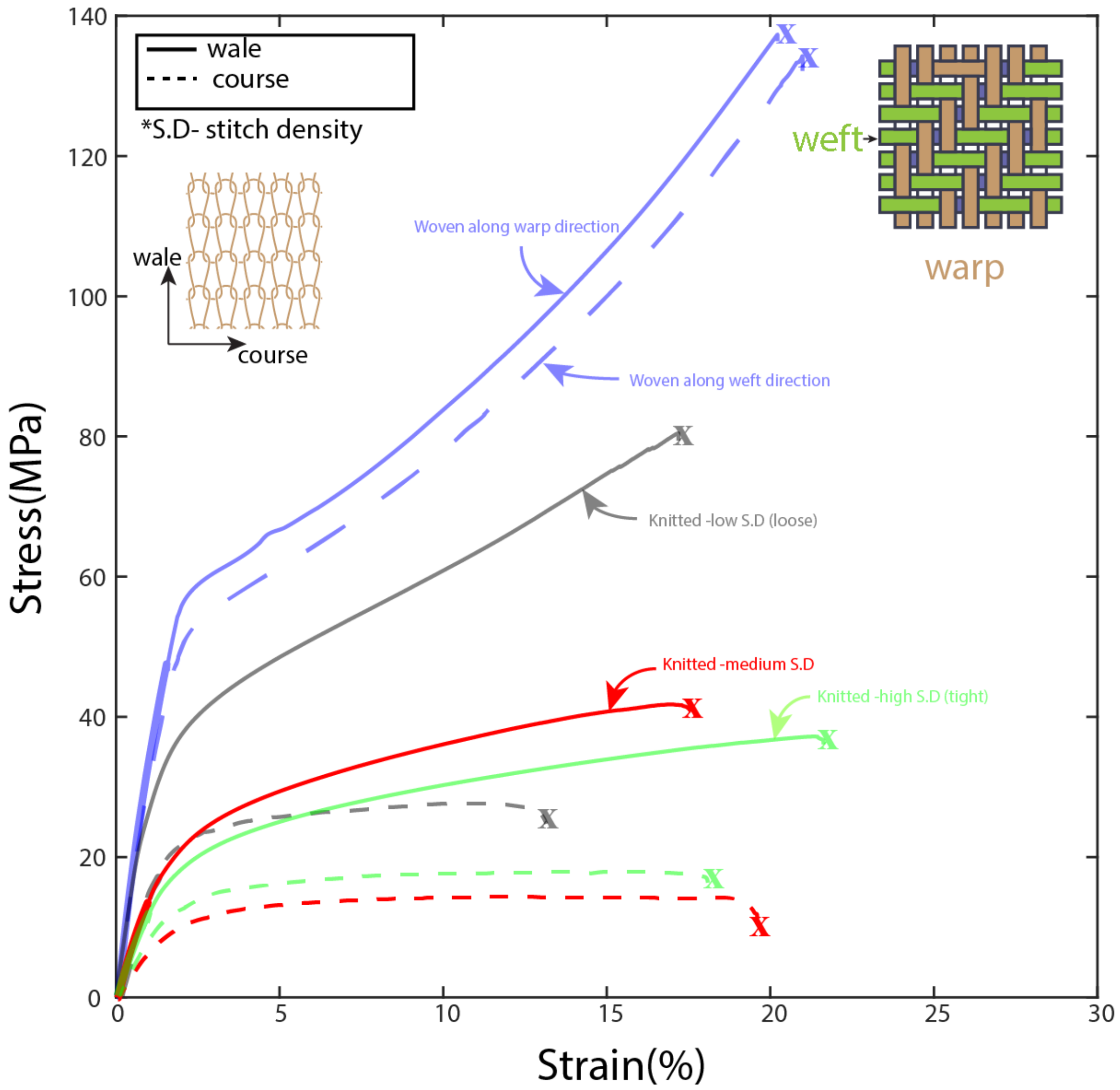


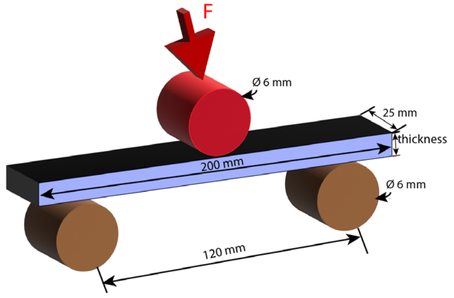
Table : The measured tensile properties of srPET composite

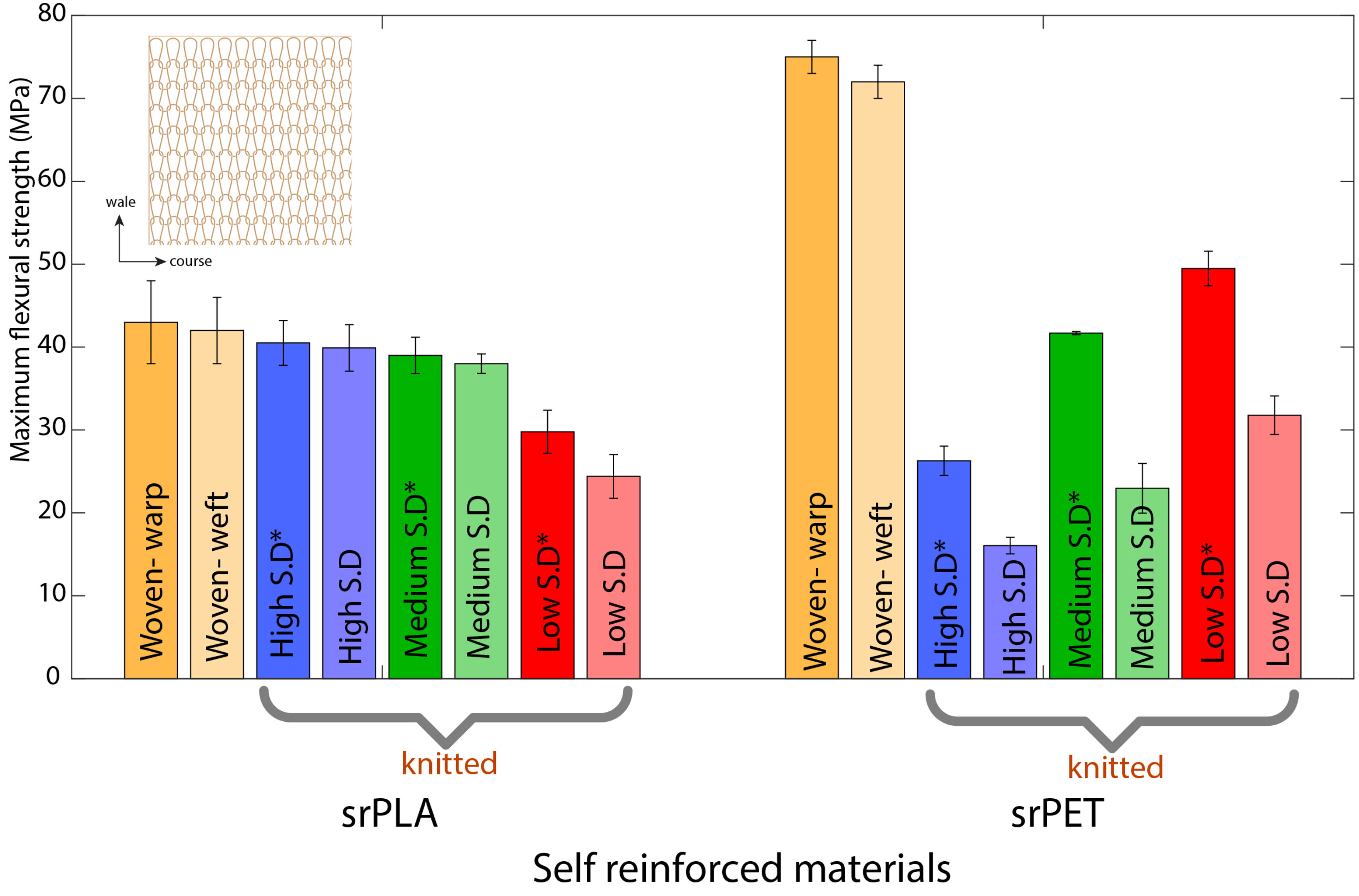
Parameters	Ultimate strength (MPa)	Failure strain (%)	Elastic modulus (GPa)
PETW-Warp	127±4	19	4.45±0.25
PETW-Weft	132±5	19	4.35±0.05
PET-high S.D(tight)*	**35.99±0.57**	**0.19±0.018**	**1.05±0.09**
PET-high S.D	17±0.54	0.17±0.03	0.62±0.04
PET- medium S.D*	**39.05±2.6**	**0.15±0.014**	**1.28±0.0.05**
PET-medium S.D	13.02±0.73	0.11±0.015	0.338±0.02
PET-low S.D(loose)*	**85.11±5.24**	**0.197±0.02**	**2.41±0.06**
PET-low S.D	26.61±0.53	0.103±0.011	1.307±0.135

*- Wale direction; S.D- Stitch density

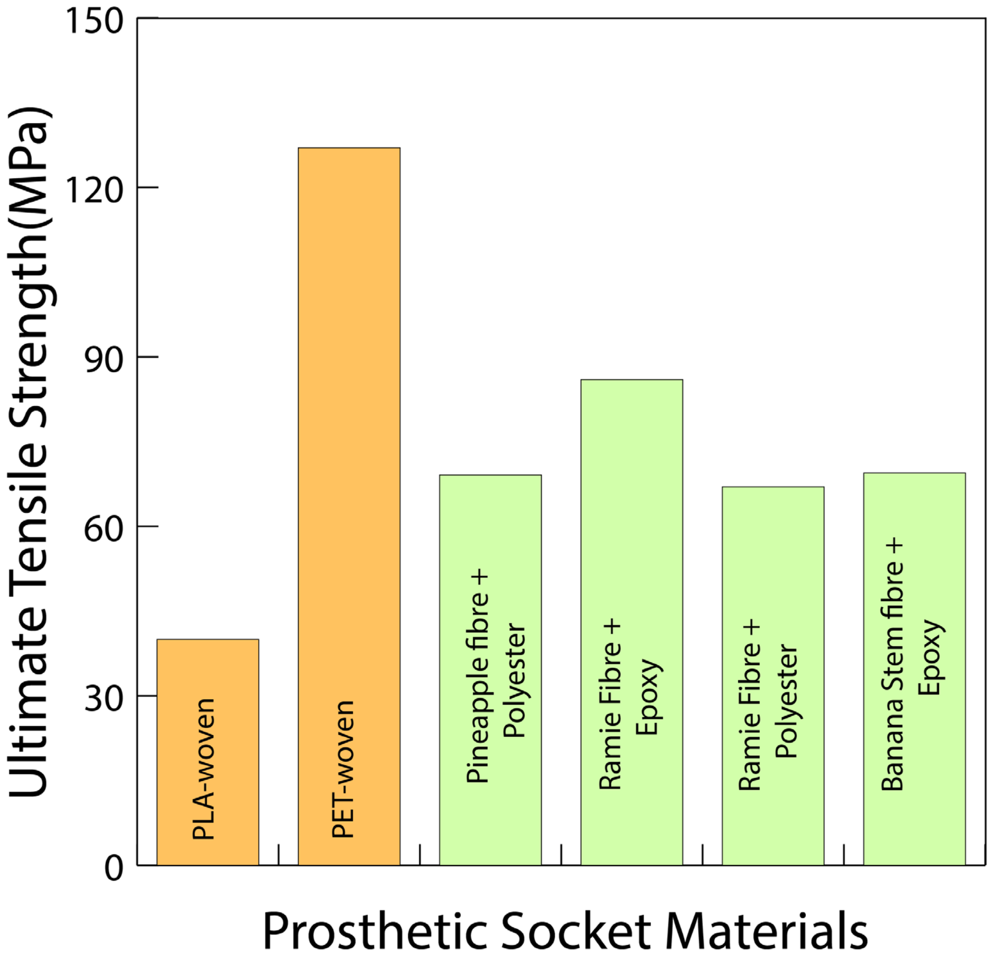


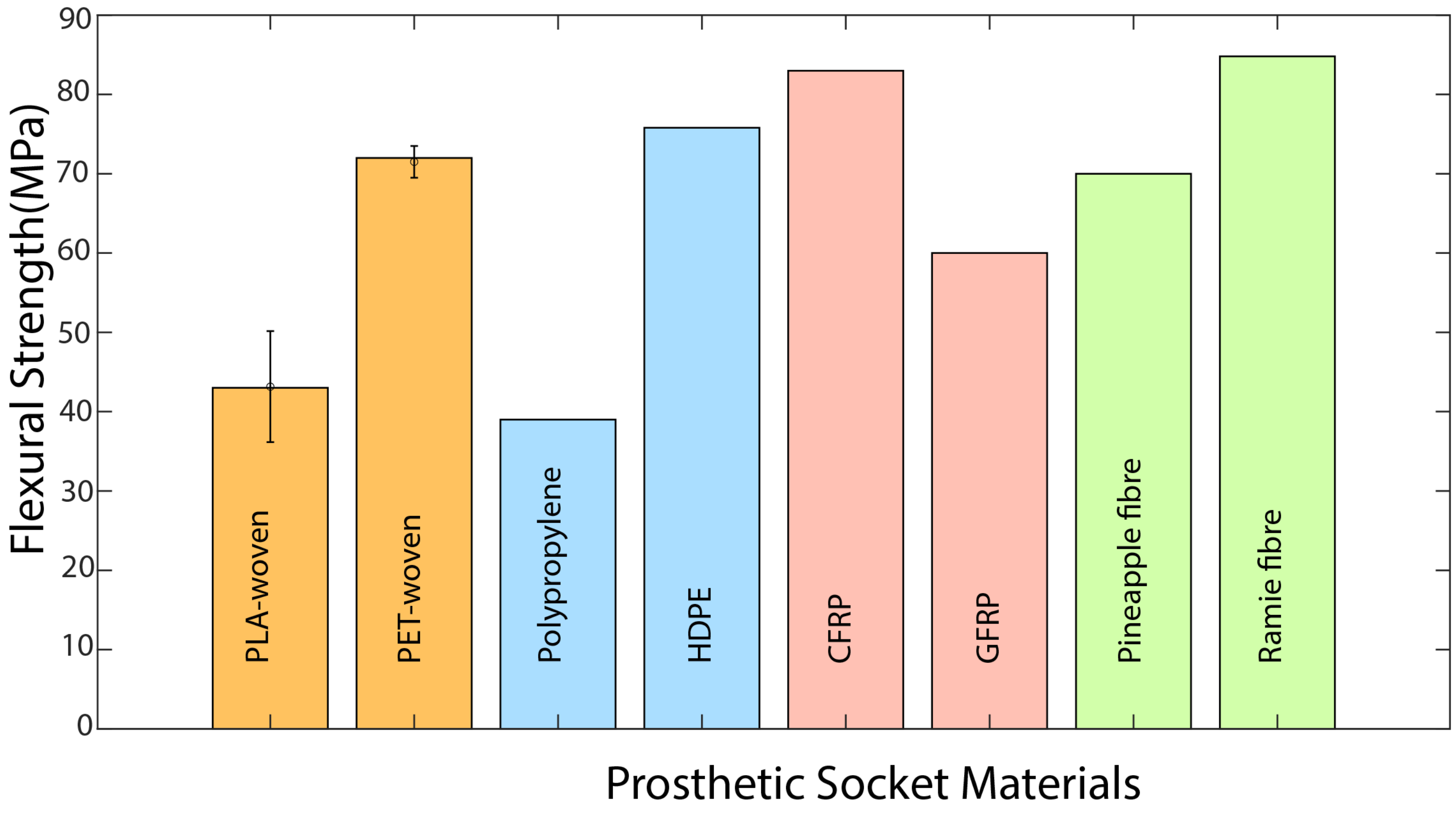
Flexural strength of woven and knitted srP composite





Comparison of tensile and flexural strength with the prosthetic socket materials





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3. Odusote JK, Oyewo AT, Adebisi JA, Akande KA. Mechanical properties of banana pseudo stem fibre reinforced epoxy composite as a replacement for transtibial prosthetic socket. Association of Professional Engineers of Trinidad and Tobago; 2016

Summary

- In woven laminates
  - The Vacuum- assisted thermal curing of commingled yarn shows the matrix are well encapsulated with the fibres with less voids.
  - Tensile and flexural response of both srPLA and srPET provides relatively consistent properties in both the weft and warp directions.

- In knitted laminates
  - The properties of the knitted composite laminates were greatly influenced by the stitch density.
  - The srPET shows the anisotropic behaviour in material properties in which the ultimate tensile and flexural strength predominantly increases by decreasing the stitch density and increasing the loop length.
  - In case of srPLA, the properties exhibits the inverse effect by demonstrating minimal difference between the wale and course direction.

- The mechanical response of these srPET and srPLA offers good strength and ease of manufacturing with minimal time compared to standard resin infusion composite fabrication protocol.

- Employing automated 3-dimensional knitting technique to create the near-shape of the amputee's residual limb could emphasize realistic potential for producing customized patient specific sockets.