



























Fig. 9. Plot showing relationship between applied creep stress  $\sigma$  and  $t_n$ .

Although the current work has demonstrated that VPPMC performance from fibres subjected to 37 minutes of creep at 590 MPa is equivalent to 24 h at 330 MPa, it is clear from Fig. 4 that these fibres can sustain 24 h at 590 MPa without creep-induced fracture. Thus a longer exposure to 590 MPa may provide increased prestress generation, thereby offering possibilities for further improvements to VPPMC performance. This aspect will be investigated in a future study.

## 5. Conclusions

This study has taken the first steps towards process optimisation by investigating the feasibility of reducing the creep loading period for VPPMC production. By using nylon 6,6 fibres, our main findings are:

- (i) The previously adopted viscoelastic creep strain, which requires a tensile stress of 330 MPa for 24 h, can be achieved over a shorter duration,  $t_n$ , using increased creep stress. Thus  $t_n$  was 92 min at 460 MPa and 37 min at 590 MPa. Subject to avoiding fibre damage however, it may be possible to reduce  $t_n$  further.
- (ii) Although there was some offset between viscoelastic recovery strain–time curves from the three creep settings, elapsed recovery strain values were similar. The latter concurred with Charpy impact test data from VPPMC samples corresponding to the three creep settings, as there were no significant differences in impact energy absorption, these being ~56% greater than their control (unstressed) counterparts.

Future work will focus on producing a generalised relationship between  $t_n$ , creep stress and fibre viscoelastic recovery characteristics (strain and force output).

## Acknowledgements

Support from the Hull-China Scholarship Council scheme for one of the authors (BW) is gratefully acknowledged. The authors also wish to thank Garry Robinson from the School of Engineering for technical support.

## References

- [1] Fancey KS. Investigation into the feasibility of viscoelastically generated pre-stress in polymeric matrix composites. *Mater Sci Eng A* 2000; 279(1-2):36-41.
- [2] Fancey KS. Prestressed polymeric composites produced by viscoelastically strained nylon 6,6 fibre reinforcement. *J Reinf Plast Compos* 2000; 19(15):1251-1266.
- [3] Fancey KS. Fibre-reinforced polymeric composites with viscoelastically induced prestress. *J Adv Mater* 2005; 37(2):21-29.
- [4] Pang JWC, Fancey KS. An investigation into the long-term viscoelastic recovery of Nylon 6,6 fibres through accelerated ageing. *Mater Sci Eng A* 2006; 431(1-2):100-105.
- [5] Fancey KS. Viscoelastically prestressed polymeric matrix composites – Potential for useful life and impact protection. *Compos Part B* 2010; 41(6):454-461.
- [6] Fazal A, Fancey KS. Viscoelastically prestressed polymeric matrix composites – Effects of test span and fibre volume fraction on Charpy impact characteristics. *Compos Part B* 2013; 44(1):472-479.
- [7] Fazal A, Fancey KS. UHMWPE fibre-based composites: Prestress-induced enhancement of impact properties. *Compos Part B* 2014; 66:1-6.
- [8] Fazal A, Fancey KS. Performance enhancement of nylon/Kevlar fiber composites through viscoelastically generated pre-stress. *Polym Compos* 2014; 35:931-938.
- [9] Pang JWC, Fancey KS. The flexural stiffness characteristics of viscoelastically prestressed polymeric matrix composites. *Compos Part A* 2009; 40(6-7):784-790.
- [10] Fazal A, Fancey KS. Viscoelastically generated prestress from ultra-high molecular weight polyethylene fibres. *J Mater Sci* 2013; 48:5559-5570.
- [11] Pang JWC, Fancey KS. Analysis of the tensile behaviour of viscoelastically prestressed polymeric matrix composites. *Compos Sci Tech* 2008; 68(7-8):1903-1910.
- [12] Zhigun IG. Experimental evaluation of the effect of prestressing the fibers in two directions on certain elastic characteristic of woven-glass reinforced plastics. *Mech Compos Mater* 1968; 4(4-6):691-695.
- [13] Tuttle M.E. A Mechanical/Thermal Analysis of Prestressed Composite Laminates. *J Compos Mater* 1988; 22(8):780-792.
- [14] Tuttle ME, Koehler RT, Keren D. Controlling thermal stresses in composites by means of fiber prestress. *J Compos Mater* 1996; 30(4):486-502.
- [15] Hadi AS, Ashton JN. On the influence of pre-stress on the mechanical properties of a unidirectional GRE composite. *Compos Struct* 1998; 40(3-4):305-311.
- [16] Motahhari S, Cameron J. Impact strength of fiber pre-stressed composites. *J Reinf Plast Compos* 1998; 17(2):123-130.
- [17] Motahhari S, Cameron J. Fibre prestressed composites: improvement of flexural properties through fibre prestressing. *J Reinf Plast Compos* 1999; 18(3):279-288.

- [18] Schlichting LH, de Andrada MAC, Vieira LCC, Barra GMD, Magne P. Composite resin reinforced with pre-tensioned glass fibers. Influence of prestressing on flexural properties. *Dent Mater* 2010; 26(2):118-125.
- [19] Nishi Y, Okada T, Okada S, Hirano M, Matsuda M, Matsuo A, Faudree MC. Effects of tensile prestress level on impact value of 50 vol% continuous unidirectional 0 degree oriented carbon fiber reinforced epoxy polymer (CFRP). *Mater Trans* 2014; 55:318-322.
- [20] Cui H, Guan M, Zhu Y, Zhang Z. The flexural characteristics of prestressed bamboo slivers reinforced parallel strand lumber (PSL). *Key Eng Mater* 2012; 517:96-100.
- [21] Fancey KS. A latch-based Weibull model for polymeric creep and recovery. *J. Polym. Eng* 2001; 21(6):489-509.
- [22] Howard WH, Williams ML. The viscoelastic properties of oriented nylon 66 fibers: part I: creep at low loads and anhydrous conditions. *Textile Res J* 1963; 33(9):689-696.
- [23] Fancey KS. A mechanical model for creep, recovery and stress relaxation in polymeric materials. *J Mater Sci* 2005; 40(18):4827-4831.
- [24] Pang JWC, Lamin BM, Fancey KS. Force measurement from viscoelastically recovering Nylon 6,6 fibres. *Mat Lett* 2008; 62(10-11):1693-1696.