Mech Time-Depend Mater (2019) 23:497–507
https://doi.org/10.1007/s11043-018-09402-z

# Stress relaxation effect on fatigue life of biaxial prestressed woven E-glass/polyester composites

**Nawras H. Mostafa**[1]

Received: 5 August 2018 / Accepted: 29 November 2018 / Published online: 2 January 2019
© Springer Nature B.V. 2019

**Abstract** In this study, the stress relaxation effect on the fatigue cycles-to-failure of the biaxial elastic fibre prestressed woven composite (E-glass/polyester) was investigated. The fibre pretension load was applied prior and during matrix cure, and then it has been released to induce compressive residual stresses within the matrix. The longevity of these stresses is questionable, and it needs investigation. The time of residual stress redistribution or relaxation was estimated experimentally for the E-glass fibre prestressing level be equal to 50 MPa. Residual stresses within the polyester matrix have declined by (27%) throughout 110 days leading to reduce the improved fatigue life by about 14% due to the stress relaxation process within the polyester matrix material. The study showed that even though the stress relaxation in the matrix reduced the improved fatigue cycles of the biaxial elastic prestressed E-glass fabric/polyester resin system, some improvement still is possible for long-term performance.

**Keywords** Stress relaxation · Elastic fibre prestressed composite · Residual stress · Fatigue life

## 1 Introduction

Fibre-reinforced (FR) composite materials are now of great concern due to their high strength and stiffness to weight ratios in comparison with the most common metals. The mechanical properties of these materials and their behaviour were widely studied during the last few years. Generally, the composite constituent materials and their fabrication processes share the total expenses of the composite structure production. For example, the cost of the fibre glass-reinforced polymer is approximately 60% for materials and 40% for the fabrication process (Ashby and Jones 2012). Consequently, the focus on developing the fabrication techniques is still important if they can improve the mechanical properties

---

✉ N.H. Mostafa
nawras1980@gmail.com

[1] Department of Mechanical Engineering, Faculty of Engineering, University of Babylon, Babylon Province, Al-Hillah City, Iraq

and performance of the composite products. Unfortunately, tensile residual stresses have been induced within the composites during the manufacturing process (Farrahi et al. 2002; Safarabadi and Shokrieh 2014). These stresses might considerably reduce the mechanical properties of the FR composites (Mostafa et al. 2016b; Parlevliet et al. 2007). Residual stresses induced in composite materials result from the chemical shrinkage of the polymer matrix, the difference in the thermo-mechanical properties of the constitutions, moisture absorption, and fibre pretension (Krishnamurthy 2006). Tensile residual stresses are induced within the matrix of FR composites due to thermal and chemical shrinkage; however, compressive residual stresses are generated when the FR composite is exposed to humidity or its fibre is pretensioned during the matrix solidification. Several methods have been used to minimise the detrimental effects of the tensile residual stresses within the FR composite. Optimising of the dwell cure cycle (White and Hahn 1993), curing the composite at low temperatures (Gopal et al. 2000), using electron beam curing (gamma irradiation) (Korenev 2001), using expanding monomers (Fu et al. 2014), inserting shape memory alloy wires (Naghashian et al. 2014), and using the fibre pretension (prestress) method (Mostafa et al. 2017), are the most common methods that have been used to reduce the tensile residual stresses within the composite structure. The fibre pretension is considered as an effective and very low-cost method used to reduce the fibre waviness and the tensile residual stresses within the FR composites (Krishnamurthy 2006; Mostafa et al. 2016c).

In general, two methods have been used for obtaining fibre prestressed composites, namely viscoelastic (invented by Fancey 2281299B, 1997) and elastic prestressed fibres (first use was by Zhigun 1968). The former is basically depending on the viscoelastic strain that some materials such as nylon 6,6 and ultra-high-molecular-weight polyethylene, after removing the applied creep stress, tend to recover it progressively over the time (Fazal and Fancey 2014; Pang and Fancey 2006). However, the latter is related to the immediate elastic strain recovery imparted to the matrix from the perfectly restrained (bonded) pretensioned fibre with the surrounded cured matrix just right after removing the load. The deformations of several common fibre materials such as glass, Kevlar and carbon are dominant by elastic behaviour rather than being viscoelastic.

Previous studies showed that reducing the tensile residual stresses within the matrix leads to enhance the mechanical properties of the composite by increasing the matrix ability to withstand the microcrack development (Mostafa et al. 2016c). As the compressive residual stresses could improve the fatigue life of metallic structures (Gangaraj and Farrahi 2011), the magnitude of the imparted compressive strain and the associated stress from the released fibre into the matrix could show the same improvement (Mostafa et al. 2018a).

Polymers are characterised by the fact that their behaviour under constant load or deformation is time-dependent even at room temperature (Papanicolaou and Zaoutsos 2011). This behaviour can be expressed by either creep or stress relaxation. Creep is a progressive change in deformation under a constant load; however, the stress relaxation is a gradual change in stress under constant deformation. The induced residual stresses that provided by releasing the elastic prestressed fibres into the cured matrix might relax with time elapsing accordingly. Therefore, the durability of the elastic fibre prestressed composites is questionable (Fancey 2016). The decline in the induced compressive residual stresses within the matrix and any acquired improvement in the mechanical properties of the fibre prestressed composite with time are usually expressed by the longevity aspect. The longevity of the material can be expressed by the time that the improved mechanical properties of the material could withstand. The improvement in the fatigue behaviour of the elastic fibre prestressed composite was significant as indicated in previous studies (Krishnamurthy 2006; Mostafa

**Table 1** Thermomechanical properties of the E-glass woven fabric (EWR600) (Mostafa et al. 2018b, 2016a)

| Properties | Value |
|---|---|
| Tensile strength (GPa) | 2.2 |
| Elastic Modulus (GPa) | 70 |
| Poisson’s ratio | 0.23 |
| Density (g/m$^2$) | 600 |
| Warp density (ends/m) | 285 |
| Weft density (ends/m) | 245 |
| Thermal expansion coefficient ($10^{-6}$ m/m °C) | 5.4 |

**Table 2** Thermomechanical properties of the unsaturated polyester resin (Reversol P9509) (Mostafa et al. 2018b, 2016a)

| Properties | Value |
|---|---|
| Tensile strength (MPa) | 61 |
| Elastic Modulus (GPa) | 2.77 |
| Poisson’s ratio | 0.25 |
| Thermal expansion coefficient ($10^{-6}$ m/m °C) | 120 |

et al. 2018b, 2016c), but how long this improvement can last has not been investigated yet. Up to now, it appears that there is no published study of possible stress alterations in the relatively intermediate and long-term performance of elastically fibre prestressed composites. Only Zhigun (1968) indicated that the plain-weave glass/phenol-formaldehyde composite sheets were kept at room temperature for 3 months before it had been cut and tested for eliminating the stress relaxation effect.

The objective of this work is to investigate the effect of stress relaxation process within the polymeric matrix on the fatigue cycles-to-failure of the elastically fibre prestressed composite. This study has used the same elastic biaxial fabric prestressed composite methodology that was indicated by Mostafa et al. (2016c). A tension–tension fatigue test is performed for different time scales in order to indicate the stress relaxation effect on the fatigue cycles-to-failure of the elastically fibre prestressed composite.

## 2 Materials and method

In this work, the plain-weave E-glass woven roving (EWR600) fabric was used as the reinforcement phase. The polymeric matrix was orthophthalic Reversol P9509 unsaturated polyester resin mixed with Butanox M-50 catalyst. The mechanical properties of the EWR600 fabric and the polyester matrix are listed in Tables 1 and 2, respectively.

The E-glass/polyester composite samples were fabricated with a fibre weight ratio equal to 16 at ambient conditions with temperature of 28 °C and relative humidity equal to 52%. The INSTRON 3382 machine was used to perform the tensile test according to ASTM D3039 standard. Fatigue tests were performed on the fabricated samples according to the ASTM D3479 standard using an INSTRON 8874 machine. The average mechanical properties of non-prestressed (uncontrolled) and the elastic fibre prestressed (controlled) are listed in Table 3. Five samples were tested for each case and the average values have been calculated.

The pretension load was applied to the fibre prior to and during the matrix cure using the biaxial prestressing frame shown in Fig. 1. Once the matrix was well cured, the applied

**Table 3** Average mechanical properties of the E-glass fabric/polyester resin composite

| Properties | Non-prestressed composite | Prestressed composite with 50 MPa |
|---|---|---|
| Tensile strength (MPa) | 66.02 ± 3.41* | 76.62 ± 2.38 |
| Elastic modulus (GPa) | 3.77 ± 0.23 | 4.42 ± 0.15 |

* Standard deviation

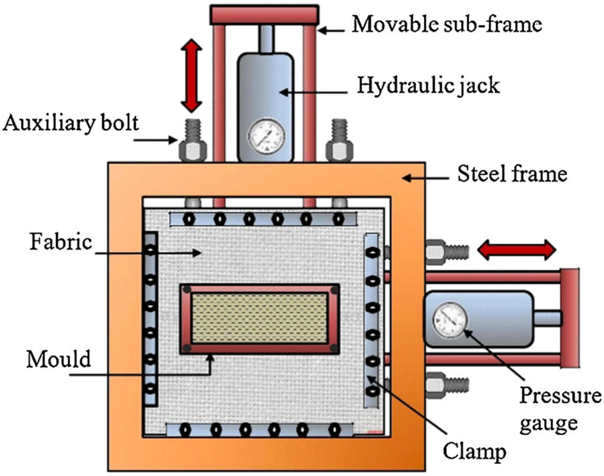


**Fig. 1** The biaxial fabric prestressing rig

fibre pretension has been released to recover some of the tensile elastic strain induced in the pretensioned fibre.

In order to evaluate the decline in the matrix residual stresses during relaxation process, the magnitude of these stresses should be well known. The initial values of residual stresses in the fibre ($\sigma_f^{\mathrm{res}}$) and the matrix ($\sigma_m^{\mathrm{res}}$) at a ply level just after releasing the fibre pretension stress are calculated according to (Mostafa et al. 2017):

$$\sigma_f^{\mathrm{res}} = E_f\left(\varepsilon_{1,2}^{\mathrm{pre}} - \varepsilon_{1,2}^{\mathrm{ther}}\right)^{\mathrm{res}} + \sigma^{\mathrm{pre}} \tag{1}$$

$$\sigma_m^{\mathrm{res}} = E_m\left(\varepsilon_{1,2}^{\mathrm{pre}} - \varepsilon_{1,2}^{\mathrm{ther}}\right)^{\mathrm{res}} \tag{2}$$

The fibre and matrix are denoted by the subscriptions $f$ and $m$, respectively. The symbols $\sigma$, $E$ and $\varepsilon$ represent axial stress, elastic modulus and axial strain, respectively. The subscripts 1 and 2 represent the direction of the warp and fill yarn directions within the composite, respectively. Thermal strains ($\varepsilon_{1,2}^{\mathrm{ther}}$) and prestressing strains ($\varepsilon_{1,2}^{\mathrm{pre}}$) in the principal directions of the woven composite are calculated as:

$$\left(\varepsilon_{1,2}^{\mathrm{ther}}\right)^{\mathrm{res}} = \alpha_{1,2}\Delta T \tag{3}$$

For the case of a plain-weave fabric pretensioned in the biaxial directions (i.e. the warp and the fill yarns), the induced strain $\varepsilon_1$ and $\varepsilon_2$ due to releasing the fibre pretension load after the matrix has cured well are equal to (Mostafa et al. 2017)

$$\left(\varepsilon_{1,2}^{\mathrm{pre}}\right)^{\mathrm{res}} = \frac{(\sigma^{\mathrm{pre}} V_f)_{1,2}}{\overline{E}_{1,2}} - \frac{\overline{\nu}_{12,21}(\sigma^{\mathrm{pre}} V_f)_{2,1}}{\overline{E}_{1,2}} \tag{4}$$

where $\alpha$ and $\Delta T$ are the thermal expansion coefficient of the composite and temperature difference between ambient and curing conditions, respectively. $\sigma^{\mathrm{pre}}$ denotes the fibre prestress level and $V_f$ represents the fibre volume fraction within the composite. Other material properties of the woven composite, such as the effective Poisson ratio ($\overline{\nu}_{12}$ and $\overline{\nu}_{12}$) and effective elastic modulus ($\overline{E}_1$ and $\overline{E}_2$), are calculated in this study by following the same approach as used by (Naik and Ganesh 1995) and recently used by (Mostafa et al. 2017).

The initial compressive residual stresses within the polymeric matrix that intended to improve the composite mechanical properties by obstructing the development of microcracks are undergoing a degradation over the time due to stress relaxation phenomenon. Therefore, the stress relaxation test is performed for the polyester bulk material in order to investigate the residual stress history within the prestressed polymeric matrix. The test was performed according to ASTM D2990 standard. Two samples were tested using the Kappa Multistation machine under a constant deformation at an ambient temperature be equal to 28 °C. Due to time limitation, the polyester samples were under testing for only 21 days. The stress relaxation data over time for the polyester samples were fitted according to Fancey's equation (Fancey 2005) in order to estimate the stress relaxation history for time more than 21 day. According to Fancey (2005), the stress relaxation ($\sigma_{\mathrm{rel}}$) could be expressed by

$$\sigma_{\mathrm{rel}}(t) = ae^{-(\frac{t}{b})^c} + d \tag{5}$$

where $a$, $b$, $c$ and $d$ are constants obtained by fitting the experimental data and $t$ is the time.

The creep test of the E-glass yarn under constant load was also performed using the same machine. This test is important because it can indicate whether the glass fibre behaves like any viscoelastic strain or not. In order to investigate the change in the strain with time under constant load, the creep compliance of the fibre is usually used, which is equal to the ratio of total strain $\varepsilon(t)$ to the applied constant stress $\sigma_o$, i.e.,

$$D(t) = \frac{\varepsilon(t)}{\sigma_o} \tag{6}$$

The stress relaxation effect on the mechanical behaviour of the biaxial fabric prestressed composites was investigated by testing the prestressed composite samples at different timescales, starting from the time of their manufacturing. The timescales used in this work were taken be equal to 2, 30, 90 and 180 days, respectively.

## 3 Results and discussion

Table 4 lists the initial values of theoretical induced residual stresses in the composite's constituents due to applying different levels of biaxial fabric prestressing. These results were obtained from Eqs. (1) and (2) for the fibre and matrix phases, respectively. It is very clear that increasing the prestress level increases both the tensile residual stress in the fibre and the compressive residual stress within the matrix. The induced residual stresses within the matrix at warp and fill directions of the fabric were not equal due to the use of unequal yarn number per meter along the principal directions of the used E-glass fabric as indicated in Table 1.

Creep and stress relaxation tests were conducted individually to the composite's constituents that used in this work to check if there was any change or redistribution in the strain and stress states with time. The creep test was performed in a single E-glass yarn at a temperature be equal to 28 °C. The testing time was six days at a constant stress be equal

**Table 4** Tensile residual stresses in the fibre after matrix cure due to applying different biaxial fabric prestressing levels (all stresses are in MPa)

| $\sigma^{\mathrm{pre}}$ | $\sigma_f^{\mathrm{res}}$ | $\sigma_m^{\mathrm{res}}$ Warp-direction | $\sigma_m^{\mathrm{res}}$ Fill direction |
|---|---|---|---|
| 25 | 5.841 | −0.99 | −1.20 |
| 50 | 11.68 | −1.98 | −2.35 |
| 75 | 17.52 | −2.94 | −3.53 |
| 100 | 23.30 | −3.91 | −4.62 |

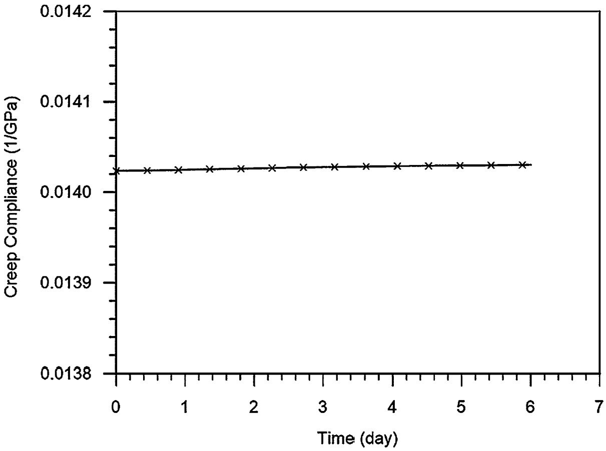


**Fig. 2** Creep compliance versus time history of the E-glass fibre at a constant applied stress of 100 MPa

to 100 MPa (maximum prestressed level used in this work). Figure 2 shows the creep compliance of the E-glass yarn. It is clear that the E-glass fibre does not exhibit a significant viscoelastic behaviour when it subjected to a constant stress. This behaviour is in agreement with previous study by Batra (2009). The creep compliance increases by only 0.0487% over six days, which can be considered as very small variation. Therefore, the E-glass fibre could be considered as an elastic material.

To find the stress history of matrix residual stresses induced by the elastic fibre prestressing, the initial stress should be specified from Table 4. In this work, only the composite with a fibre prestress level of 50 MPa is considered as it was approved previously as the optimal level. Therefore, the initial value of induced residual stress within the composite's matrix that associated with this fibre prestressing level is 1.98 MPa. This initial value of stress could be obtained by applying an axial strain to the bulk polyester sample using Kappa Multistation machine till reaching the required stress level. After this stage, no change in the applied strain was allowed while measuring the history of stress within the restrained polyester sample. The relaxation of stress over the time of the bulk polyester resin is shown in Fig. 3.

As the variation of stress in the bulk polyester sample seemed not reached to its full redistribution time during the testing period (i.e. 21 days), the Fancey equation of stress relaxation was used to fit the experimental data and to predict the stress relaxation for the time more than 21 days. The IBM SPSS Statistics was used to fit the experimental data according to Eq. (5). The predicted equation could have the form

Fig. 3 Stress versus time history of the bulk polyester at a constant applied strain that equal to 0.078%

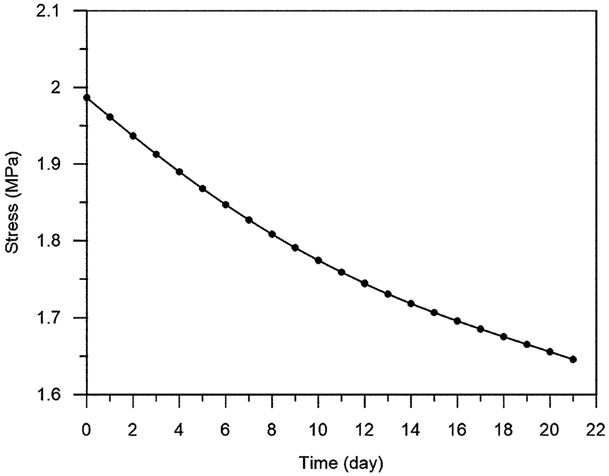
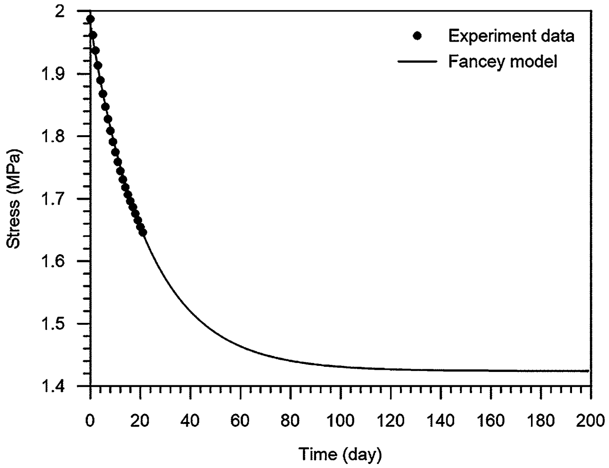


Fig. 4 Prediction of the stress redistribution of bulk polyester samples using Fancey's model



$$\sigma_{\mathrm{rel}}(t) = 0.5547\mathrm{e}^{-(\frac{t}{47.705})^{2.1}} + 1.424 \tag{7}$$

where $t$ is the time in a day and $\sigma_{\mathrm{rel}}$ is the stress in MPa.

The bivariate Pearson correlation coefficient $(r)$ between the experimental data and the predicted equation results is $+0.997$ (very strong correlation).

Figure 4 shows the results obtained from using the predicted equation versus the experimental data of the stress redistribution (relaxation) of bulk polyester material. The stress-time curve starts to level off (become almost time-independent) beyond about 110–120 days. The stress has declined from 1.98 MPa to about 1.43 MPa, i.e. about 27% of declination in stress has taken place. As the improvement in the mechanical properties of fibre prestressed composite is mainly depended on the value of compressive residual stresses that induced in the polymeric matrix, any improvement in these properties should be correspondingly assessed over the time.

Figure 5 shows the stress relaxation effect on the composite's tensile critical stress (the onset of matrix fracture). The fibre prestressing level of the adopted samples is equal to 50 MPa. The storing temperature of the samples was kept approximately constant at

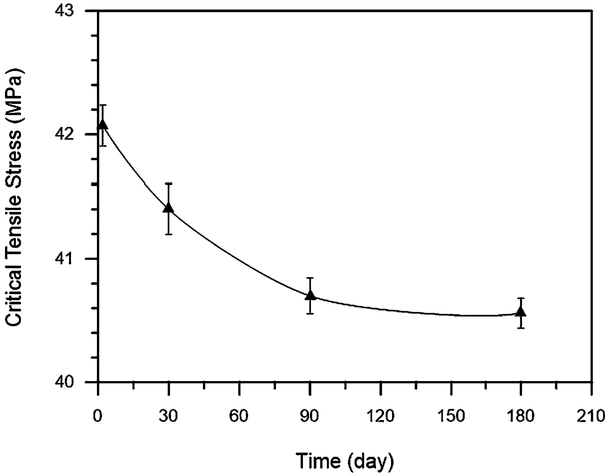


**Fig. 5** Effect of time on the critical stress of 50 MPa prestressed samples

28 ± 1.3 °C. Stress redistribution at and close to the matrix–fibre interface, which are the most stressed regions within the matrix due to fibre prestressing (Metehri et al. 2009; Mostafa et al. 2017), is expected to take place over time. Indeed, about 3.6% declination in the initially improved tensile critical stress of the elastic fibre prestressed composite is indicated after 6 months from when the prestressed composite samples have been fabricated. Clearly, the percentage decline in the improved mechanical properties of the prestressed composite is lower than bulk matrix material counterparts (i.e. 27%). This is due to the fact that the initial residual strain level provided from the prestressed fibre into the matrix had been decreasing over the time, which is not the same condition used in the standard stress relaxation test of the bulk matrix material. The relatively high local slippage in the matrix material close to the fibre-matrix interface region means that there is a relative movement between the prestressed fibre and the cured matrix material as time passed. This relative movement leads to a reduction of the initial fibre prestressing level within the cured composite as the restraining prestressed fibre with the surrounded cured matrix is not perfect any more. On the other hand, the reinforcement fibre within the composite plays a critical role of creep resistance (Kang et al. 2009; Miravalles 2007). These two important effects are the main reasons that led to decrease the effect of residual stress relaxation in matrix of the elastic prestressed FR composites.

Matrix cracking can be considered as an early stage of composite failure subjected to cyclic loading and it usually leads to a significant degradation in composite stiffness (Talreja and Singh 2012). Therefore, any improvement in the matrix strength that has been obtained from using an elastic fibre prestressing method can increase the cycles-to-failure of the composite. Consequently, the fatigue life of the fibre prestressed composite samples is also expected to decline over the time. Fatigue tests were performed at a normalised peak stress ($S$) equal to 0.55 (ratio of maximum applied fatigue stress to the ultimate tensile strength of the composite). The effect of the stress relaxation within the matrix material on the fatigue life of the fibre prestressed composite is very clear as shown in Fig. 6. The fatigue life ($N$) of the prestressed composite samples decreased by about 14% (from 28594 to 24432 cycles) after 6 months from the time when they were fabricated with 50 MPa biaxial fabric prestress. The curves in Figs. 5 and 6 start to level off (become almost time-independent) beyond about 110–130 days. Thus, the experimental data from these figures provide support for the predictive trend in Fig. 4.

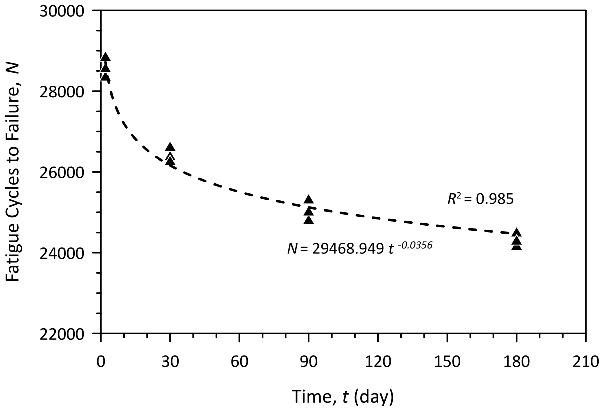


**Fig. 6** Effect of longevity on the fatigue life of 50 MPa prestressed samples at $S = 0.55$

The power fitting gives the best correlation coefficient of $+0.993$ for the fatigue cycle data degradation with time. The fitting equation could have the form:

$$N = 29468.949t^{-0.0356} \tag{8}$$

or it can be correlated to the initial fatigue cycles-to-failure before stress relaxation has taken its effect such as:

$$N = \left[1.0306t^{-0.0356}\right]N_i \tag{9}$$

where $t$ is the time in a day and $N_i$ represents the initial fatigue life of the fibre prestressed composite (i.e. $N_i = 28594$). Accordingly, the general form of Basquin's law of the $S$–$N$ curve could be modified in order to include the stress relaxation effect in the life of the biaxial fibre prestressed composites system used in this work. The modified equation could have the form

$$S = N^{\left(\frac{1}{0.0595\ln(t) - 17.2147}\right)} \tag{10}$$

where $t$ is the time in days.

## 4 Conclusions

This study showed that the stress relaxation process within the polymeric matrix of the fibre prestressed composite (E-glass/polyester system) could reduce its improved critical tensile stress and fatigue life to some extent. The decline in the prestressed characteristics is mostly taken place within the first 3 months after the prestressed samples have been prepared and then decreased slightly up to the time within 6 months. The study showed that most of the stress relaxation time occurred within the polyester matrix after 3 months of applying the fibre prestress and then decreased slightly up to the time of 6 months. The residual stresses within the polyester matrix that induced by fibre prestressing did not fully diminish due to the stress redistribution effect, but they only declined to about 27% from its original value. This led to decrease the improved fatigue life of the biaxial prestressed composite by 14% in comparison to the newly fabricated prestressed samples.

## References

Ashby, M.F., Jones, D.R.H.: Engineering Materials 1: An Introduction to Properties, Applications, and Design. Elsevier, The Boulevard, Langford Lane, Kidlington, Oxford (2012)

Batra, S.: Creep Rupture and Life Prediction of Polymer Composites (2009)

Fancey, K.S.: Composite fibre-containing materials, UK, Patent Number: 2281299B, 1997

Fancey, K.S.: A mechanical model for creep, recovery and stress relaxation in polymeric materials. J. Mater. Sci. **40**, 4827–4831 (2005)

Fancey, K.S.: Viscoelastically prestressed polymeric matrix composites: an overview. J. Reinf. Plast. Compos. **35**, 1290–1301 (2016)

Farrahi, G.H., Smith, D.J., Zhu, W.X., McMahon, C.A.: Influence of residual stress on fatigue life of hot forged and shot blasted steel components. Int. J. Eng. Trans. A Basics, Trans. B Appl. **15**, 79–86 (2002)

Fazal, A., Fancey, K.S.: UHMWPE fibre-based composites: prestress-induced enhancement of impact properties. Composites, Part B, Eng. **66**, 1–6 (2014)

Fu, J., Liu, W., Liu, X., Tuladhar, S.L., Wan, Q., Wang, H.: Properties of a new dental photocurable resin based on the expanding monomer and three-component photoinitiator system. J. Wuhan Univ. Technol. Sci. Ed. **29**, 384–390 (2014)

Gangaraj, S.M.H., Farrahi, G.H.: Side effects of shot peening on fatigue crack initiation life. Int. J. Eng., Trans. A: Basics **24**, 275–280 (2011)

Gopal, A.K., Adali, S., Verijenko, V.E.: Optimal temperature profiles for minimum residual stress in the cure process of polymer composites. Compos. Struct. **48**, 99–106 (2000)

Kang, G., Liu, Y., Wang, Y., Chen, Z., Xu, W.: Uniaxial ratchetting of polymer and polymer matrix composites: time-dependent experimental observations. Mater. Sci. Eng. A **523**, 13–20 (2009)

Korenev, S.: Electron beam curing of composites. Vacuum **62**, 233–236 (2001)

Krishnamurthy, S.: Prestressed Advanced Fibre Reinforced Composites: Fabrication and Mechanical Performance (2006)

Metehri, A., Serier, B., Bachir bouiadjra, B., Belhouari, M., Mecirdi, M.A.: Numerical analysis of the residual stresses in polymer matrix composites. Mater. Des. **30**, 2332–2338 (2009)

Miravalles, M.: The Creep Behaviour of Adhesives: A Numerical and Experimental Investigation (2007)

Mostafa, N.H., Ismarrubie, Z., Sapuan, S., Sultan, M.: Effect of equi-biaxially fabric prestressing on the tensile performance of woven E-glass/polyester reinforced composites. J. Reinf. Plast. Compos. **35**, 1093–1103 (2016a)

Mostafa, N.H., Ismarrubie, Z.N., Sapuan, S.M., Sultan, M.T.H.: Effect of equi-biaxially fabric prestressing on the tensile performance of woven E-glass/polyester reinforced composites. J. Reinf. Plast. Compos. **35** (2016b)

Mostafa, N.H., Ismarrubie, Z.N., Sapuan, S.M., Sultan, M.T.H.: Effect of fabric biaxial prestress on the fatigue of woven E-glass/polyester composites. Mater. Des. **92** (2016c)

Mostafa, N.H., Ismarrubie, Z.N., Sapuan, S.M., Sultan, M.T.H.: Fibre prestressed composites: theoretical and numerical modelling of unidirectional and plain-weave fibre reinforcement forms. Compos. Struct. **159**, 410–423 (2017)

Mostafa, N.H., Ismarrubie, Z.N., Sapuan, S.M., Sultan, M.T.H.: Theoretical development of biaxial fabric prestressed composites under tensile or flexural loading. In: IOP Conference Series: Materials Science and Engineering (2018a)

Mostafa, N.H., Ismarrubie, Z.N., Sapuan, S.M., Sultan, M.T.H.: Theoretical development of biaxial fabric prestressed composites under tension-tension fatigue loading. Pertanika J. Sci. Technol. **26**, 1253–1264 (2018b)

Naghashian, S., Fox, B.L., Barnett, M.R.: Actuation curvature limits for a composite beam with embedded shape memory alloy wires. Smart Mater. Struct. **23**, 1–10 (2014)

Naik, N.K., Ganesh, V.K.: An analytical method for plain weave fabric composites. Composites **26**, 281–289 (1995)

Pang, J.W.C., Fancey, K.S.: An investigation into the long-term viscoelastic recovery of Nylon 6, 6 fibres through accelerated ageing. Mater. Sci. Eng. A **431**, 100–105 (2006)

Papanicolaou, G.C., Zaoutsos, S.P.: Viscoelastic constitutive modeling of creep and stress relaxation in polymers and polymer matrix composites. In: Guedes, R.M. (ed.) Creep and Fatigue in Polymer Matrix Composites, pp. 3–47. Woodhead Publishing Limited, Cambridge (2011)

Parlevliet, P.P., Bersee, H.E.N., Beukers, A.: Residual stresses in thermoplastic composites—a study of the literature. Part III: Effects of thermal residual stresses. Composites, Part A, Appl. Sci. Manuf. **38**, 1581–1596 (2007)

Safarabadi, M., Shokrieh, M.M.: Residual stresses in composite materials. In: Shokrieh, M.M. (ed.) Residual Stresses in Composite Materials, pp. 197–232. Woodhead Publishing Limited, Cambridge (2014)

Talreja, R., Singh, C.V.: Damage and Failure of Composite Materials. Cambridge University Press, University Press, Cambridge (2012)

White, S.R., Hahn, H.T.: Cure cycle optimization for the reduction of processing-induced residual stresses in composite materials. J. Compos. Mater. **27**, 1352–1378 (1993)

Zhigun, I.G.: Experimental evaluation of the effect of prestressing the fibers in two directions on certain elastic characteristic of woven-glass reinforced plastics. Polym. Mech. **4**, 691–695 (1968)