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Investigation of Fatigue Phenomenon in Short-Fiber Reinforced Composites

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ABSTRACT

Nowadays, the use of short fiber reinforced composites (SFRC) has become very widespread. In the meantime, the investigation of the fatigue behavior of this group of composites is a very demanding topic. In this research, the behaviour of SFRC is computationally studied under cyclic loading for both aligned and randomly-oriented SFRC. As a novel approach, a methodology developed for long-fiber composites is adopted for the purpose of fatigue analysis of SFRC through a micro-macromechanical approach. Namely, the aligned SFRC is firstly converted into a virtual long-fiber composite at the microscale, and then fatigue analysis is performed at the macroscale. For a randomly-oriented SFRC composite, the laminate analogy approach is employed to transform it into virtual long-fiber laminated composites, and then fatigue analysis is implemented. The estimated results through computational modelling are compared with available experimental observations in the literature. The discrepancy between predictions and experimental measurements for aligned SFRC falls below 10%, implying proper performance of the proposed method for aligned SFRC. However, some improvements are required for the specific purpose of randomly-oriented SFRC, since the discrepancy exceeds 25%.

1. Introduction

The initiation and growth of damage in laminated composites under static loading and, more importantly, under cyclic loading is a complicated process. Failure analysis of composite multilayers has been one of the important areas of theoretical and experimental research by researchers. The degradation process of mechanical properties in fiber-reinforced composites under fatigue gradually reduces the stiffness and strength of the structure. Unlike metals, where a single macroscopic factor accounts for fatigue failure, fatigue in polymeric composites initially appears in the form of microcracks at different points and grows to the limit of strength as a result of damage accumulation. The microstructural mechanisms of damage accumulation include fiber breakage, resin cracking, debonding of fiber and resin, transverse layer cracking, and delamination. These mechanisms sometimes occur independently and sometimes interactively, and the dominance of each is strongly influenced by material type and working conditions.

Despite the considerable efforts devoted to analyzing fatigue phenomena in long-fiber composites either experimentally or theoretically [1, 2], very little attention has been given to the fatigue analysis of short-fiber composites [2-5]. The fatigue behavior of SFRC is

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quite different from that of long-fiber composites. Thus, the demand for customized models for predicting fatigue in short-fiber composites is clearly recognized [2]. Beside conducted experimental studies for determining the fatigue life of short-fiber composites (e.g. [6-9]), limited computational studies have also been conducted in the form of numerical and/or semi-empirical methods.

Wang et al. [10, 11] studied the effect of fatigue experimentally and analytically in SFRC and derived equations for the reduction of elastic mechanical properties based on elliptical crack growth. They also concluded with the help of experimental data that there is an exponential relationship between the degree of fatigue damage and the degree of cyclic loading. Zago and Springer [12] obtained the stress distributions of two different geometries for SFRC using a commercial finite element package. Then, Miner's rule was employed to estimate fatigue lives under different cycling loadings. Kabir et al. [13] used a micromechanical fatigue damage model on the basis of a statistical microscopic law described by fiber failure and fiber-matrix debonding. Then, numerical methods were used to predict the failure. Jain et al. [14] used FEM to obtain fatigue properties of SFRC through a master SN curve approach. Taking into account various fiber orientations, local SN curves were obtained using a combination of micromechanics and tests, while damage in the micro-scale was linked to macro-scale fatigue properties. Aforementioned characteristics were characterized using experimental stress-life diagrams and manufacturing simulation. Jain has extended the master SN curve approach for multi-axial fatigue modeling in another study [15] on the basis of characteristic plane and critical plane approaches. Krairi et al. [16] presented two multi-scale methods for estimating the fatigue life of short fiber polymer composites with glass fibers. In this study, both viscoelastic and viscoplastic behavior are considered, and continuum damage mechanics is used. Laribi et al. [17] used a micromechanical model and proposed an equation of state where the local damage rate was related to the macroscopic residual stiffness rate relying on experimental data. They have generalized this approach to a multi-scale description of fatigue damage, leading to the fast determination of SN curves. Tamboura et al. [18] modelled fatigue life and residual stiffness of SFRC subjected to thermo-mechanical loadings. They have used a combination of micromechanical and phenomenological models to obtain the progress of the local damage rate. Then, the evolution of micro-crack density until failure. Zhang et al. [19] developed a novel micromechanical fatigue model for SFRC accounting for fiber–matrix debonding. They have shown that the progressive fatigue damage of each constituent can be quantitatively analyzed. Abdul Hamid et al. [20] analyzed the failure of SFRC under static and fatigue loads using continuum damage mechanics. They have constructed the model at the scale of macro, relying on an anisotropic linear elastic assumption inspired by experimental observations. The elastic model is coupled with a damage formulation assuming that damage is driven by the approach of a state point in strain space to a Tsai-Hill type failure envelope. The developed model was fed into a finite element formulation. Amjadi and Fatemi [21] studied the multiaxial fatigue behavior of short glass fiber reinforced thermoplastics using a critical plane-based damage approach. The effects of fiber orientation, stress state, mean stress, stress concentration, temperature, and frequency on multiaxial fatigue behavior are taken into account. Zhang et al. [22] proposed a multi-axial high-cycle fatigue model for SFRC considering the fiber microstructure. The core assumption of the model was that fatigue is triggered by fiber-matrix interface stress at the critical region. Shokrieh and his co-workers [23] have recently predicted the fatigue behavior of SFRC based on the damage-entropy and self-heating concepts. The developed model considers the material's viscoelastic energy, stored energy, and wasted energy.

As observed from the literature review, investigations into the fatigue phenomenon in SFRC have gradually shifted from purely experimental and semi-empirical studies in their early stages [4-13] to advanced numerical modeling techniques in the modern era [14-23].

Considerable efforts have been dedicated to developing accurate computational models for the fatigue analysis of long fiber composites. Thus, a robust framework exists for modeling fatigue in long-fiber composites, encompassing various approaches such as fatigue life models, phenomenological models for residual properties, physics-based methods, progressive damage modeling, and continuum damage mechanics. It is intended to predict the fatigue life of SFRC by adapting a procedure originally developed for long fiber composites. Leveraging the long fiber composite fatigue foundation, the main objective is to customize one of these models and implement it for SFRC.

2. Foundation of Fatigue Modeling

Categorized under the progressive damage modeling group, the Generalized Material Property Degradation (GMPD) technique is chosen in this study as the foundation of fatigue modeling. GMPD was originally developed by

Shokrieh and Lessard [24, 25] for the long-fiber composites as the most comprehensive form of progressive damage modeling for multi-axial loading. The GMPD model incorporates stiffness and strength degradation in all material directions, accompanied by a normalized fatigue life assessment. This model can be applied to any arbitrary lay-up configuration, as it only requires characterization of the behavior of constituent unidirectional plies. Therefore, full characterization of each configuration is not necessary. Since variations of strength are much less than stiffness variations during cycling loading, it is reasonable to use a single measure of stiffness reduction to reduce the runtime of the analysis significantly. Subsequently, Shokrieh and Zakeri [26] developed a Cumulative Fatigue Damage Modeling (CFDM) as a simplified version of GMPD, where just stiffness degradation is taken into account for estimating fatigue life. A more simplified version of CFDM has been developed by Rafiee and his coworkers based on employing Classical Lamination Theory (CLT), and its performance was validated experimentally [27, 28]. The simplified CFDM technique is chosen in this study as the core of the fatigue modeling, and it is briefly explained in this section.

CFDM consists of three main parts: stress analysis, damage estimation, and degradation of material properties. The flowchart of the CFDM technique is shown in Fig. 1.

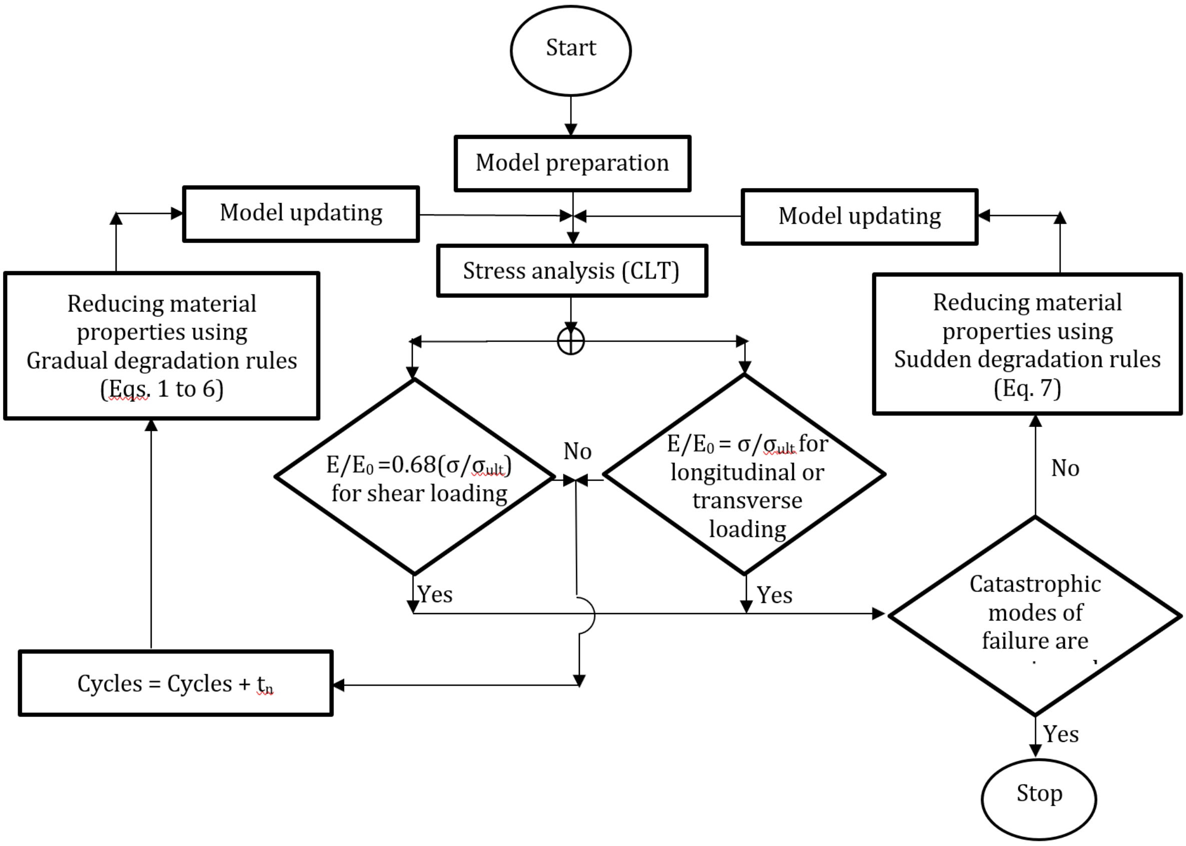

Fig. 1. Flowchart of simplified CFDM technique

Prior to fatigue modeling, initial material properties, maximum and minimum fatigue load, and the incremental number of cycles are defined. This is referred to as model preparation. The induced in-plane stress components in each layer are computed using CLT at the first stage at each loading cycle and are fed into the second stage for damage evaluation.

In the second stage, normalized damage estimation is utilized to assess the damage progression at each cycle of loading [26]. This model takes into account the role of stress ratio and stress level in damage accumulation and provides a rational trend of damage growth with respect to the number of cycles. The normalized damage parameter ($\widetilde{D}$) is defined as below [26]:

$$\widetilde{D} = f(\sigma,\sigma_{ult})D \qquad (1)$$

where D is a damage parameter and $f(\sigma,\sigma_{ult})$ is a function of stress state obtained through experimental data of U-D specimens [26]. σ and σ_{ult} are applied stress and ultimate strength, respectively. A complete series of relationships between the normalized damage parameter ($\widetilde{D}$) and normalized number of cycles ($\widetilde{N}$) has been extracted [25, 26]. Normalized number of cycles is defined using below equation [24]:

$$\tilde{N} = \frac{log(n) - log(0.25)}{log(N_f) - log(0.25)} \qquad (2)$$

where, n and N_f denotes the number of applied cycles and cycles to failure, respectively. N_f is computed using the following equation for a U-D ply subjected to uniaxial loading [29]:

$$u = \frac{ln(a/f)}{ln(1-q)\,(c+q)} = A + B\,log\,N_f \qquad (3)$$

where "u" and "f" are curve fitting parameters [29]. The parameter "f" can be taken constantly as 1.06 [24, 25]. "A" and "B" are also obtained by linear regression through the obtained data on the logarithmic scale. Other parameters reflected in Eq. (3) are introduced as follows:

$$\sigma_a = \frac{(\sigma_{max} - \sigma_{min})}{2}, \quad \sigma_m = \frac{(\sigma_{max} + \sigma_{min})}{2}$$
$$q = \sigma_m/\sigma_t\,,\ a = \sigma_a/\sigma_t \qquad (4)$$
$$C = \begin{cases} \sigma_c/\sigma_t & Longitudinal\ loading \\ \sigma_t/\sigma_c & Transverse\ loading \\ 1 & Shear\ Loading \end{cases}$$

where σ_{max} and σ_{min} are the maximum and minimum stresses created in the desired U-D layer. σ_t and σ_c stands for tensile and compressive strengths, respectively.

It has been shown that for the case of shear loading, Eq. (3) is modified to the following equation [25]:

$$log\left(\frac{ln(a/f)}{ln[(1-q)(C+q)]}\right) = A + B\,log\,N_f \qquad (5)$$

It should be pointed out that corresponding values of "A" and "B" coefficients for longitudinal, transverse, and shear loading directions have been fully characterized and reported for U-D plies of Carbon/Epoxy [25] and Glass/Polyester [27].

The third stage is devoted to the stiffness degradation in the damaged plies employing gradual or sudden degradation rules. Gradual degradation of stiffness is accomplished in CFDM as follows [26]:

$$E(n, \sigma, R) = \left(1 - \frac{\tilde{D}}{f(\sigma, \sigma_{ult})}\right) E_0 \qquad (6)$$

where E_0 and E represents initial stiffness before the start of fatigue loading and residual stiffness, respectively. Therefore, Eqs. (1-5) is used to calculate the normalized damage parameter, and then residual stiffness is computed at each cycle of loading through Eq. (6).

The stiffness of the U-D ply is gradually degraded cycle by cycle until they reach to a level that it cannot tolerate any more loading. This indicates the occurrence of failure, and the stiffness of failed plies should be reduced suddenly using proper sudden degradation rules in accordance with the experienced failure mode [26]. It is worth mentioning that conventional failure criteria cannot be used here, due to the fact that only stiffness is reduced, and the strength reduction is not considered, as explained before. Therefore, the failure is assumed to occur along the fiber or matrix direction when the ratio of instantaneous stiffness to initial stiffness ($S_E = \frac{E}{E_0}$) becomes equal to the ratio of the instantaneous applied stress to the ultimate static failure ($\frac{\sigma}{\sigma_{ult}}$). For the case of shear loading, the aforementioned ratio is taken as 0.68 based on experimental observations [25].

After the occurrence of the failure, the properties of the failed ply are suddenly degraded using one of the following rules based on the experienced failure mode in the context of the ply-discount method, as per Table 1.

Table 1. Sudden degradation rules [27, 28]

Failure mode	E_L	E_T	ν_{LT}	E_S
Fiber breakage	0	0	0	0
Fiber buckling	0	0	0	0
Matrix tension	E_L	0	ν_{LT}	E_S
Matrix compression	E_L	0	ν_{LT}	E_S
Shear failure	E_L	E_T	0	0

After reducing the stiffness of constitutive U-D plies either gradually or suddenly, the model is updated considering new mechanical properties, and the whole three-stage procedure repeats. As can be seen in Table 1, fiber breakage and fiber buckling failure modes are considered as catastrophic failure modes where the failed ply cannot accommodate any more loading at all. It should be noted that for those cases where mechanical properties are required to be reduced to zero, a very small value close to zero is chosen, avoiding numerical instability in the computational procedure.

3. Fatigue Modeling Methodology for Aligned SFRC

It is intended to use the introduced simplified CFDM technique in the previous section for analyzing the fatigue behavior of SFRC. For this purpose, the strategy of converting the Representative Volume Element (RVE) is employed. Thus, the RVE of an aligned SFRC is converted into a RVE of a virtual long fiber composite as depicted in Fig. 2.

In both RVEs shown in Fig. 2, the fiber length and the mechanical properties of both the fiber and resin are kept constant. In this conversion, the RVE of SFRC is transformed into an appropriate RVE for long-fiber composites by adjusting the fiber volume fraction while maintaining the fiber length and the properties of the fiber and resin.

Fig. 2. Converting the RVE of SFRC to the RVE of a virtual long-fiber composite

For the purpose of obtaining fiber volume fraction in the adopted virtual long-fiber RVE, the Young's modulus of the RVE of SFRC is firstly estimated using the following micromechanical rule [30]:

$$\frac{E_L}{E_m} = \frac{1+(\frac{2l}{d})\eta_L \mathrm{V}_f^{sh}}{1-\eta_L \mathrm{V}_f^{sh}},\ \eta_{\mathrm{L}} = \frac{\frac{E_f}{E_m}-1}{\frac{E_f}{E_m}+\frac{2l}{d}} \tag{7}$$

where V_f^{sh} stands for fiber volume fraction in the RVE of SFRC.

The Young's modulus of long-fiber RVE can be estimated using a simple rule-of-mixture as below [31]:

$$\mathrm{E}_L = \left(\mathrm{V}_f^{lg} E_f\right) + \left[\left(1-\mathrm{V}_f^{lg}\right)E_m\right] \tag{8}$$

where V_f^{lg} stands for fiber volume fraction in the RVE of a long-fiber composite.

Having in hand the mechanical properties of fiber and resin and also the fiber volume fraction of SFRC, the longitudinal modulus of SFRC is estimated using Eq. (7). Substituting the obtained longitudinal Young's modulus into Eq. (8) with the same mechanical properties for fiber and resin, the corresponding fiber volume fraction for the RVE of long-fiber composite is obtained accordingly. In other words, Eqs. (7) and (8) are set equal, because $\mathrm{E_L}$ should be the same for both RVEs depicted in Fig. 2. Then, the unknown value of V_f^{lg} is calculated. Therefore, the RVE of aligned SFRC is converted into the RVE of a virtual long-fiber composite.

After obtaining the fiber volume fraction of the long-fiber RVE, other mechanical properties and also initial strength properties of the adopted virtual long-fiber RVE are also required to be extracted as the requirements of the model preparation stage in Fig. 1. For this purpose, the following micromechanical rules are used [30, 31]:

$$\begin{gathered}
E_T = E_m \frac{\left(1+2\eta_T V_f^{lg}\right)}{\left(1-\eta_T V_f^{lg}\right)}, \eta_T = \frac{\left(\frac{E_f}{E_m}-1\right)}{\left(\frac{E_f}{E_m}+2\right)} \\
E_S = G_m \frac{\left(1+\eta_s V_f^{lg}\right)}{\left(1-\eta_s V_f^{lg}\right)}, \eta_s = \frac{\left(\frac{G_f}{G_m}-1\right)}{\left(\frac{G_f}{G_m}+1\right)} \\
\nu_{LT} = \nu_f V_f^{lg} + \nu_m V_m^{lg} \\
X_T = X_f[V_f^{lg} + V_m^{lg}\frac{E_f}{E_m}] \\
X_C = 0.5X_T,\ \ Y_T = V_m^{lg} X_m, \qquad Y_C = V_m^{lg} X'_m \\
S_S = [1-\left(\sqrt{V_f^{lg}}\right) - V_f^{lg})](1-\frac{G_f}{G_m})S_m
\end{gathered} \tag{9}$$

where $\mathrm{E_f}$, $\mathrm{E_m}$, $\mathrm{G_f}$, and $\mathrm{G_m}$ represent fiber modulus, matrix modulus, fiber shear modulus, and matrix shear modulus, respectively. ν_f and ν_m denote fiber and matrix Poisson's ratios. $\mathrm{E_L}$, $\mathrm{E_T}$, $\mathrm{E_S}$, and ν_LT represent longitudinal modulus, transverse modulus, shear modulus, and major Poisson's ratio of long-fiber RVE, respectively. $\mathrm{X_f}$, $\mathrm{X_m}$, $\mathrm{X'_m}$, and $\mathrm{S_m}$ imply the tensile strength of fiber, the tensile strength of resin, the compressive strength of resin, and the shear strength of resin, respectively. $\mathrm{X_T}$, $\mathrm{X_C}$, $\mathrm{Y_T}$, $\mathrm{Y_C}$, and $\mathrm{S_S}$ are the initial longitudinal tensile strength, longitudinal compressive strength, transverse tensile strength, transverse compressive strength, and in-plane shear strength of long-fiber RVE, respectively.

After model preparation, the remaining stages of the fatigue modeling are performed in complete accordance with the explained procedure under section (2) and the presented flowchart in Fig. 1.

4. Fatigue Modeling Methodology for Randomly-Oriented SFRC

For modeling fatigue in randomly oriented SFRC, the laminate analogy is utilized. In this process, a randomly-oriented SFRC ply is transformed into a long-fiber composite consisting of four layers containing continuous fiber with a lay-up configuration of [0/90/±45]. In other words, a randomly-oriented SFRC is replaced with a quasi-isotropic long-fiber composite, while the total thickness of the long-fiber composite is the same as the thickness of the SFRC ply. The conversion procedure accomplished through the laminate analogy approach is schematically shown in Fig. 3. The laminate analogy approach was originally developed by Halpin and Pagano [32] for the purpose of estimating the mechanical properties of randomly oriented SFRC. However, it was successfully applied by Rafiee and Ghamarzadeh to predict the creep response of SFRC [33]. Therefore, predicting the fatigue life of an SFRC is examined by relying on the laminate analogy approach.

After this conversion, the fatigue life of the aforementioned long-fiber laminated composites is predicted using simplified CFDM techniques outlined under section (2).

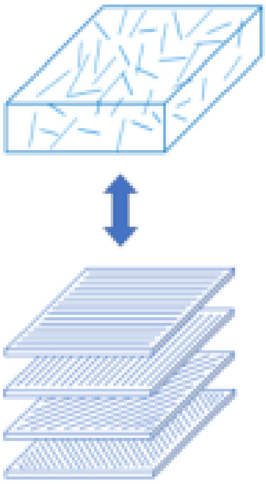

Fig. 3. Illustration of the laminate analogy approach

5. Results

The numerical example presented in this section for the validation purpose of the developed modeling for predicting fatigue life of aligned SFRC is motivated by the experimental investigations carried out by Mortazavian and Fatemi [34]. They measured the fatigue life of Glass/PBT.[1] composites subjected to cyclic loading along the longitudinal or transverse directions with different stress levels.

Following the explained procedure under section (3), the RVE of SFRC is converted into a RVE of virtual long-fiber composites with a fiber volume fraction of 19%. The mechanical properties, as the output of the model preparation stage, are reflected in Table 2.

Table 2. Mechanical properties of Glass/PBT

Property	Value
E_L [GPa]	8.8175
E_T [GPa]	3.262
E_S	1.2566
υ_{LT}	0.34
X_T [MPa]	110
X_C [MPa]	55
Y_T [MPa]	58.6
Y_C [MPa]	91.6
S_S [MPa]	37.3

Rafiee and Eslami [27] reported corresponding “A” and “B” coefficients reflected in Eqs. (3) and (5) for Glass/Polyester composites, and they are used here.

Implementing the proposed approach under section (3) in combination with the simplified CDFM technique outlined in section (2), the obtained results are compared with experimental observations in Table 3. In Table 3, the normalized stress level denotes the ratio of maximum stress to ultimate tensile strength. It indicates how close the cyclic peak stress is to the material’s ultimate strength. Fiber orientations of 0° and 90° in Table 3 imply applied loading along fiber and transverse directions, respectively.

Table 3. Results comparison for fatigue analysis of aligned SFRC

Fiber orientations	Loading	Normalized stress level	Estimated life cycle	Experimental life cycle [34]	Discrepancy
0°	Longitudinal	0.3272	2,296	2,488	7.7%
0°	Longitudinal	0.2772	17,659	19,611	9.9%
90°	Longitudinal	0.3295	923	943	2.2%
90°	Longitudinal	0.3839	3,317	3,444	3.7%

As can be seen from Table 3, A very good agreement is observed between predicted and experimentally measured fatigue lives. This implies the efficiency of the proposed model for fatigue modeling in aligned SFRC. Considered as one of its advantages, the model underestimates the life cycle in all cases, categorizing the proposed approach as a conservative method.

Since normalized life curves for Glass/PBT were not available, a generic behavior was estimated based on the pattern of decreasing mechanical properties observed in Glass/Polyester. It can be seen that this generic behavior is appropriate. However, it is important to note that, even though the generic method functions adequately, a more complete treatment

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[1] Parabean Book Tension

would involve extracting the normalized life curve and other necessary parameters specifically for the type of Glass/PBT used in this study.

Motivated by the experimental program conducted by Laribi and his colleagues [17, 18], the modeling procedure is executed for the same investigated randomly oriented SFRC. They have fabricated randomly oriented Glass/Polyester composites through the sheet molding compound process and measured the fatigue life cycles of three specimens [17, 18]. The thickness of the investigated ply was 3 mm, so it is converted into a four-layer long-fiber composite where the thickness of each ply is assumed to be 0.75 mm in accordance with the laminate analogy. The simplified CFDM model is executed on the equivalent quasi-isotropic laminate, and the results are presented in Table 4.

Table 4. Fatigue results for randomly-oriented SFRC

Specimen	Normalized stress level	Experimental	Estimated	Discrepancy
1	0.48	36,860	37,607	2%↑
2		52,015		27.7%↓
3		47,055		20.1%↓
		Average: 45,310		17%↓

As can be seen from Table 4, the proposed technique for randomly oriented SFRC is not reliable enough, and the level of discrepancy between the estimated and measured live is high. This can originate from the generic behavior considered for normalized life curves for Glass/Polyester [27]. Moreover, the proposed approach is suffering from a fundamental limitation where it fails to capture associated fatigue damage mechanisms with randomly-oriented SFRC, like fiber pull-out and fiber-end stress concentration. As another shortcoming, the simplified CFDM technique considers a homogenous material, which is not pertinent to the case of randomly oriented SFRC, due to the random distribution of discontinuous fibers. It is expected that the performance of the simplified CFDM technique and the laminate analogy approach can be improved by taking into account the length of the fiber as a random variable. This necessitates stochastic modeling. For this purpose, the material region of randomly oriented SFRC is required to be partitioned into different blocks with different fiber volume fractions, and then the laminate analogy is implemented on each block. This is the subject of ongoing research by the same authors to overcome the aforementioned shortcomings.

6. Conclusions

In this study, the behavior of SFRC is analyzed computationally under cyclic loading conditions for both aligned and randomly-oriented fibers.

Due to the strong background of available models for fatigue analysis of long-fiber composites, one of the sophisticated progressive damage modeling techniques is tailored for SFRC. Originally developed for long-fiber composites, the CFDM technique is first simplified to reduce the runtime of analysis. Then, a novel two-scale model is proposed where SFRC is transformed into a virtual long-fiber composite at the microscale, and then simplified CFDM is utilized for estimating the fatigue life at the macro scale. Consequently, a simple yet efficient approach is proposed for fatigue analysis of SFRC.

Two separate strategies are suggested for converting SFRC into long-fiber composites. For aligned short fibers, the microscale RVE of SFRC is converted into an equivalent virtual long-fiber RVE based on adjusting fiber volume fractions. For randomly-oriented short fibers, a randomly-oriented SFRC is mapped into a quasi-isotropic long-fiber laminated composite relying on laminate analogy techniques.

The performance of the proposed techniques is examined by comparing their outputs with available experimental data in the open literature. The results reveal that while the proposed approach for aligned SFRC performs at a very acceptable level of accuracy, the accuracy of the suggested strategy for randomly oriented SFRC requires further enhancement and improvement in the modeling procedure to achieve higher precision. In other words, the proposed approach for modeling fatigue of randomly-oriented SFRC based on a combination of a laminate analogy and the CFDM technique fails to predict fatigue lives of this type of composite.

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

References

[1] Harris, B., 2003. Fatigue in composites. Woodhead Publishing.

[2] Bernasconi, A., Quaresimin, M., 2025. Fatigue of short fiber-reinforced thermoplastic composites, in Fatigue in Composites (2nd edition), Science, Damage Mechanics, and Design Applications, Edited by: Quaresimin, M., Woodhead publishing, pp. 257-295.

[3] Degrieck, J. and Paepegem, W.V., 2001. Fatigue damage modeling of fiber-reinforced composite materials, Review. *Appl Mech Rev*, 54(4), pp.279–299.

[4] Mortazavian, S. and Fatemi, A., 2017. Fatigue of short fiber thermoplastic composites: A review of recent experimental results and analysis, *International Journal of Fatigue*, 102, pp. 171–183.

[5] Mortazavian, S. and Fatemi, A., 2015. Fatigue behavior and modeling of short fiber reinforced polymer composites: A literature review, *International Journal of Fatigue,* 70, pp. 297-321.

[6] Capela, C., Oliveira, S.E., and Ferreira, J.A., 2019. Fatigue behavior of short carbon fiber reinforced epoxy composites. *Composites Part B: Engineering*. 164, pp. 191-197.

[7] Solfitia, E., Solberga, K., Gagania, A., Landib, L., and Bertoa, F., 2021. Static and fatigue behavior of injection molded short-fiber reinforced PPS composites: Fiber content and high temperature effects. *Engineering Failure Analysis.* 126, p. 105429

[8] Mortazavian, S. and Fatemi, A., 2015. Fatigue behavior and modeling of short fiber reinforced polymer composites including anisotropy and temperature effects, *International Journal of Fatigue,* 77, pp. 12–27.

[9] Rolland, H., Saintier, N., Raphael, I., Lenoir, N., King, A., and Robert, G., 2018. Fatigue damage mechanisms of short fiber reinforced PA66 as observed by in-situ synchrotron X-ray microtomography. *Composites Part B: Engineering*. 143, pp. 217-229.

[10] Wang, S.S., Chim, E.M., and Suemasu, H., 1986. Mechanics of fatigue damage and degradation in random short-fiber composites, Part I—damage evolution and accumulation. *Journal of applied mechanics.* 53, pp. 339-346.

[11] Wang, S.S., Chim, E.M., and Suemasu, H., 1986. Mechanics of fatigue damage and degradation in random short-fiber composites, Part II—Analysis of anisotropic property degradation. *Journal of applied mechanics*. 53, pp. 347-353.

[12] Zago, A., and Springer, G.S., 2001. Fatigue lives of short fiber reinforced thermoplastics parts. *Journal of Reinforced Plastics and Composites*. 20(7), pp. 606-620.

[13] Kabir, M.R., Lutz, W., Zhu, K., and Schmauder, S., 2006. Fatigue modeling of short fiber reinforced composites with ductile matrix under cyclic loading. *Computational materials science*. 36(4), pp 361-366.

[14] Jain, A., Veas, J.M., Straesser, S., Van Paepegem, W., Verpoest, I., and Lomov, S.V., 2016. The Master SN curve approach–A hybrid multi-scale fatigue simulation of short fiber reinforced composites. *Composites Part A: Applied Science and Manufacturing*. 91, pp. 510-518.

[15] Jain, A., 2021. On the multi-axial fatigue modelling of short fibre reinforced composites: Extensions to the Master SN curve approach, *International Journal of Fatigue*. 145, p. 106106.

[16] Krairi, A., Doghri, I., and Robert, G., 2016. Multiscale high cycle fatigue models for neat and short fiber reinforced thermoplastic polymers. *International Journal of Fatigue*. 92, pp. 179-192.

[17] Laribi, M.A., Tamboura, S., Fitoussi, J., Bi, R.T., Tcharkhtchi, A., and Dali, H.B., 2018. Fast fatigue life prediction of short fiber reinforced composites using a new hybrid damage approach: Application to SMC. *Composites Part B: Engineering.* 139, pp. 155-162.

[18] Tamboura, S., Laribi, M.A., Fitoussi, J., Shirinbayan, M., Tie Bi, R., Tcharkhtchi, A., and Ben Dali, H., 2020. Damage and fatigue life prediction of short fiber reinforced composites submitted to variable temperature loading: Application to Sheet Molding Compound composites, *International Journal of Fatigue*. 138, p. 105676.

[19] Zhang, L., Li, Z., Zhang, H., Liu, Z., and Zhu, P., 2022. Fatigue failure mechanism analysis and life prediction of short fiber reinforced polymer composites under tension-tension loading, *International Journal of Fatigue*. 160, p. 106880.

[20] Abdul Hamid, Z.M., Findeisen, C ., Laveuve, D.M., Rohrmüller, B., Richter, H., De Monte, M., Spancken, D., and Hohe, J., 2024. A continuum damage mechanics model for fatigue degradation and failure of short fiber reinforced composites, *Composites Science and Technology.* 254, p. 110679.

[21] Amjadi, M., and Fatemi, A., 2024. A critical plane approach for multiaxial fatigue life prediction of short fiber reinforced thermoplastic composites, *Composites: Part A*. 180, p. 108050.

[22] Zhang, L., Xu, W., Qiu, R., and Xu, D., 2024. Multiscale-based multiaxial fatigue model of short fiber reinforced polymer composites under high-cycle proportional loading, *Composites Part B.* 275, p. 111308.

[23] Fatemi, E., Shokrieh, M.M., and Mirzaei, A.H., 2025. Fatigue Life Simulation of Short Glass Fiber/Rubber Composites Using the Damage-Entropy and Self-Heating Concepts, *Fatigue and fracture of engineering materials and structures*. 48(4), pp. 1833-1846.

[24] Shokrieh, M.M., and Lessard, L.B., 2000. Progressive fatigue damage modeling of composite materials, Part I: modeling. *Journal of Composite Materials*. 34, pp. 1056–1080.

[25] Shokrieh, M.M., and Lessard, L.B., 2000. Progressive fatigue damage modeling of composite materials, Part II: material charactgerization and model verification. *Journal of Composite Materials*. 34, pp. 1081–1116.

[26] Shokrieh, M.M., and Zakeri, M., 2007. Generalized technique for cumulative damage modeling of composite laminated. *Journal of Composite Materials*. 41(22), pp. 2643–2656.

[27] Rafiee, R., and Elasmi, F., 2017. Theoretical modeling of fatigue phenomenon in a composite pipes, *Composite Structures.* 161, pp. 256-263.

[28] Rafiee, R., Abbasi, F., and Maleki, S., 2020. Fatigue analysis of a composite ring: Experimental and theoretical investigations, *Journal of Composite Materials*. 54(26), pp. 4011-4026.

[29] Adam, T., Fernando, G., Dickson, C.J., Reiter, H., and Harris, B. 1989. Fatigue life prediction for hybrid composites. I *International Journal of Fatigue*. 11(4), pp. 233–237.

[30] Halpin, J., and Tsai S., 1969. Effects of Environmental Factors on Composite Materials. Air Force Tech Rep AFML-TR 1969:67–4

[31] Hull, D., 1981. *An Introduction to Composite Materials.* Press Syndicate of the University of Cambridge.

[32] Halpin, J.C., and Pagano, N.J., 1969. The Laminate Approximation for Randomly Oriented Fibrous Composites. *Journal of Composite Materials.* 3(4),720-724.

[33] Rafiee, R., and Ghamarzadeh, A., 2023. A micro-macromechanical approach for analyzing creep in randomly oriented short fiber composites, *Polymer Composites.* 44, pp. 2187-2195.

[34] Mortazavian, S., 2015. *Fatigue Behavior and Modeling of Short Fiber Reinforced Polymer Composites*. Doctoral dissertation, The University of Toledo).