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Compressive Creep of Reinforced Polymeric Piling

ABSTRACT: Reinforced polymeric piling (RPP) is a sustainable piling product that is gaining attention for use instead of timber piling in coastal and waterfront applications. However, unlike conventional construction materials that have well-documented creep behavior, there is virtually no reliable data on the compressive creep behavior of RPP. RPP is composed of a recycled plastic matrix made of high density polyethylene (HDPE) that is reinforced with steel or fiber reinforced polymer rods (FRP, E-glass, or fiberglass). In this study, an accelerated test method to predict the compressive creep of both recycled HDPE and FRP is employed. The method is based on the equivalence of strain energy density (SED) between conventional constant-stress creep tests and stress-strain tests, conducted at different strain rates. Test results indicate that the tested recycled HDPE exhibited a pronounced viscoelastic or viscoplastic response, at low strains, when loaded in compression. At room temperature, SED predicts that recycled HDPE will creep about 1.1 % in 100 years when loaded at an ultimate stress of 8.3 MPa (1200 psi). FRP exhibits a small viscoelastic tendency. SED predicts that the FRP loaded in compression will creep by less than 0.5 % in 100 years when loaded at an ultimate stress of 88 MPa (12 800 psi). The stress-strain behavior of RPP depends on strain compatibility of both HDPE and FRP. Creep of RPP will depend on the percentage of FRP reinforcement in the cross section. Creep of RPP is estimated to be on the order of 0.2 % to 1.8 % in 100 years under loading and reinforcement ratios employed for this research.

KEYWORDS: high density polyethylene, HDPE, fiber reinforced polymer, fiberglass, FRP, E-glass, polymer, pile, viscoelastic, viscoplastic, monotonic, modulus

Introduction

It is widely recognized that we use more polymers today than 50 years ago. In the United States, polymers in the municipal solid waste stream have increased from less than 1 % in 1960 to 12 % in 2008, according to the United States Environmental Protection Agency figures [1]. Although the overall recovery of plastics for recycling is only 7 % of plastics generation; HDPE milk and water jugs are recovered at a rate of 26 % of HDPE generation [2]. Therefore, use of recycled HDPE to produce structural members is important because it creates a sustainable solution for use of 11.3×10^6 tons of rigid plastic containers that annually ends in landfills in the United States alone [1].

Recycled polymeric piling (RPP) typically consists of a thermoplastic extruded recycled HDPE matrix reinforced with FRP or steel rods. Additives are used to improve mechanical properties, durability, and ultraviolet (UV) protection of the HDPE matrix. Foaming of the resin is used to make the product lighter. The HDPE matrix often contains a small percentage of glass fibers to enhance its mechanical properties. One linear meter of 275 mm (13 in.) diameter RPP typically uses 800 recycled milk jugs in its manufacture. RPP is intended to replace timber piling in marine structures for low to medium load ratings [3].

RPP offers a creative solution to a second longstanding problem of deterioration of timber piling in coastal and water front applications. For example, coastal communities recovering from hurricane disasters are now required to build above the *advisory base flood elevation,* which may result in structures being elevated by as much as 25 feet above ground level, requiring large amounts of exposed piling [4]. Use of RPP in these situations may be advantageous because it is unlikely to be attacked by termites, which feed on exposed timber piling.

Virgin polymers have been used successfully in geosynthetics and seismic retrofitting of structures, and methods to predict their tensile creep are available [5]. Nevertheless, there is little data on the

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compressive creep of recycled HDPE or FRP that can be used to calibrate predictive models of pile creep [6]. Therefore, this study was performed in order to characterize the long term compressive-creep behavior of RPP.

Creep of Polymers

Creep is an important design consideration for engineering structures, especially when a viscoelastic-viscoplastic element, such as FRP or HDPE, is involved. It is difficult to distinguish viscoelastic from viscoplastic creep. Therefore, HDPE is classified in literature as viscoelastic and viscoplastic by different researchers in low strain ranges. Creep of polymers is made complex in that they are often loaded in the plastic nonlinear range, and the stress-strain behavior of the material is highly rate dependant. Additionally, creep varies with the type of polymer and in-service temperature with respect to the glass transition temperature and melting temperature [7]. The manufacturing process varies with polymer type, and a wide range of creep behaviors are expected among different recycled polymeric products [8]. Therefore, the creep of each polymeric product should be evaluated so that the appropriate reduction factors can be applied in structural design.

Although constitutive models to predict the short-term creep behavior of polymers are available in the materials literature [9–11], few tests on creep of polymeric materials employed in construction are available to calibrate predictive models. For polymeric geosynthetics, tensile creep behavior is typically evaluated according to the ASTM standard D5262-07 [12], which requires a long testing time to obtain data at ambient temperature. Although ASTM D5262 allows for extrapolating creep data by one log cycle (e.g., from 10 000 to 100 000 h), this is not practical for predicting creep for the 50 to 100 year design life. The alternative is to use an accelerated test method [5,13]. For piling products, Pando et al. [14] carried out a long-term bending creep test on composite piling made of concrete filled FRP. Chen et al. [8] also employed accelerated methods in testing the compressive creep of recycled lumber polymers made of high and low density polyethylene along with varying amounts of sawdust, fly ash, and other waste materials. Chen et al. [8] found that the properties varied by manufacturer and by production season, depending on the constituents of the waste stream, which points to the importance of accelerated creep test methods for QA/QC of polymeric piling products.

The available accelerated creep projection methods can be grouped under two main approaches

- **Energy Methods**, such as the strain energy density method which take advantage of the equivalence of energy points in specimens tested using different strain rates. Thus creep is predicted by extrapolating the stress-strain behavior of specimens tested under different strain rates to obtain long term static creep [6,15,16].
- **Thermal Approaches**, such as time temperature superposition (TTS), and its derivative stepped isothermal method (SIM). These methods take advantage of the similarity between the effect of time and temperature on the creep behavior of polymers and typically employ an Arrhenius model to anticipate creep [8,13,17]. Thus time is accelerated by elevating temperature [18].

Bozorg-Haddad and Iskander [19] found that both energy and thermal approaches yield similar predicted creep rates for virgin HDPE under compressive loading at constant temperature that were consistent with conventional creep. Many polymers change their properties as a result of high temperature incubation, which limits the exposure temperature that can be employed in thermal creep acceleration approaches. Therefore, energy approaches have the advantage of being able to extrapolate creep over much longer durations than thermal methods.

There are three variables that affect the magnitude of creep: stress, temperature, and time. When temperature is constant, viscoelastic creep is typically simplified; as shown in Fig. 1; as preliminary, secondary, and tertiary creep, followed by rupture. In civil engineering applications, the tertiary stage of creep cannot be tolerated, because it signifies eminent failure.

The Equivalent Strain Energy Density Method (SED)

SED is a predictive model for compressive creep of polymers. The methodology is described and validated for virgin and recycled HDPE by Bozorg-Haddad et al. [6,20]. This paper extends the methodology to the case of RPP which consists of an HDPE matrix reinforced by FRP bars. Although the theoretical basis of SED is somewhat complex, the resulting computational scheme is simple to implement. Matsouka [21] introduced a scheme for generating a stress-strain curve at any strain rate, temperature, or pressure in

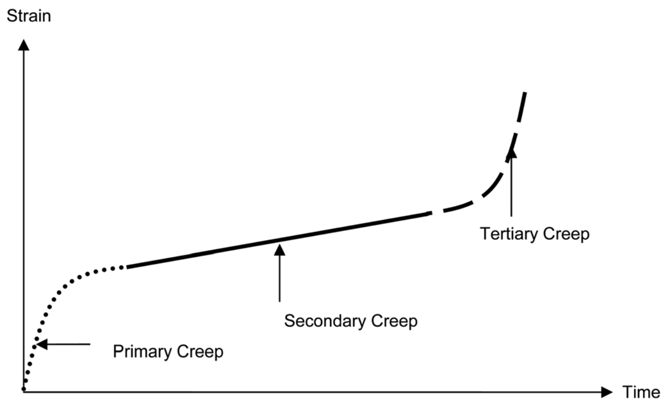

FIG. 1—*Typical stages of tensile creep.*

tension, shear, or compression from a set of stress-strain data performed on a viscoelastic material. The SED takes advantage of the equivalence of energy points in specimens tested using different strain rates. Thus creep is predicted by extrapolating the stress-strain behavior of specimens tested under different strain rates to obtain long term static creep. Lynch [22] and Van Ness et al. [23] have also used a similar concept.

The strain energy density is the area under the stress strain curve (Fig. 2). For any two *reference* stress strain curves performed at two different strain rates ($\dot{\varepsilon}_{r1}, \dot{\varepsilon}_{r2}$), it is assumed that a relationship between points having equal strain energy density (ε_{r1}, ε_{r2}) exists, such that

$$\left(\frac{\dot{\varepsilon}_{r1}}{\dot{\varepsilon}_{r2}}\right)^m = \frac{\varepsilon_{r2}}{\varepsilon_{r1}} \tag{1}$$

where the exponent m is a variable that changes as the strain energy density changes. According to Matsuoka [21], for viscoelastic materials, any point on a stress-strain curve has a corresponding point on a different stress-strain curve conducted at a different strain rate so that the two points have the same energy density and satisfy Eq 1.

If a material exhibits a linear viscoelastic relationship between stress and strain (having a constant modulus of elasticity), the strain energy density method can be reformulated to compute two reference stresses, σ_{r1}, σ_{r2}, corresponding to points having equal strain energy density, as follows:

$$\sigma_{r1} = E_{r1} \times \varepsilon_{r1} \Rightarrow \frac{\sigma_{r1}}{\varepsilon_{r1}} = E_{r1} \tag{2}$$

$$\sigma_{r2} = E_{r2} \times \varepsilon_{r2} \Rightarrow \frac{\sigma_{r2}}{\varepsilon_{r2}} = E_{r2} \tag{3}$$

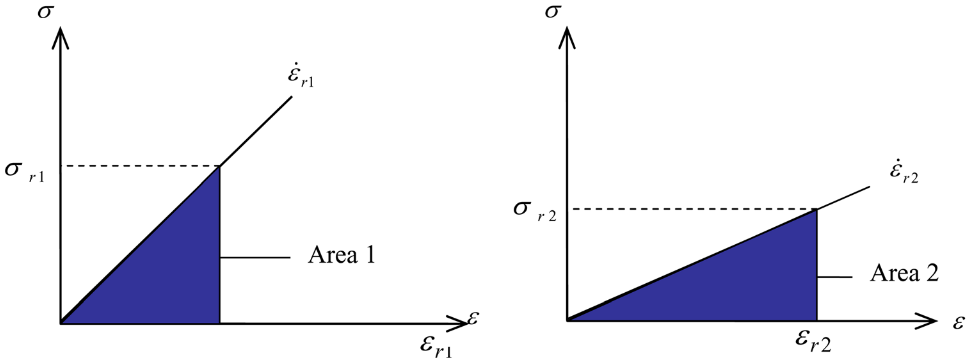

FIG. 2—*Stress-strain curves of viscoelastic material with equal strain energy density (area 1 = area 2 and* $\dot{\varepsilon}_{r1} > \dot{\varepsilon}_{r2}$*).*

At any point where area 1 = area 2 we can derive the following relationship between the strains:

$$\frac{E_{r1} \times \varepsilon_{r1}^2}{2} = \frac{E_{r2} \times \varepsilon_{r2}^2}{2} \Rightarrow \left(\frac{\varepsilon_{r2}}{\varepsilon_{r1}}\right)^2 = \frac{E_{r1}}{E_{r2}} \Rightarrow \frac{\varepsilon_{r2}}{\varepsilon_{r1}} = \sqrt{\frac{E_{r1}}{E_{r2}}} \tag{4}$$

Rearranging Eqs 1 and 4 we can obtain

$$\left(\frac{\dot{\varepsilon}_{r1}}{\dot{\varepsilon}_{r2}}\right)^m = \sqrt{\frac{E_{r1}}{E_{r2}}} \Rightarrow m = \frac{\log\,(E_{r1}/E_{r2})}{2\,\log\,(\dot{\varepsilon}_{r1}/\dot{\varepsilon}_{r2})} \tag{5}$$

Therefore, by performing two reference experiments with different strain rates the value of m can be calculated.

Assuming the modulus of elasticity E changes with the rate of loading, but remains a constant for any particular strain rate, the term m would also be a constant number that no longer depends on the strain energy density.

The fundamental assumption of SED is that the creep strain ε_c, (under constant load) can also be obtained from a stress-strain test where the imaginary creep strain ε_i corresponds to the creep stress σ_c (Fig. 3). The strain rate of the *imaginary equivalent-creep stress-strain* (*iECSS*) test $\dot{\varepsilon}_i$ corresponding to the creep time of interest (e.g., 100 years) t_i is unknown, but can be predicted as follows.

The iECSS is assumed to have a linear elastic behavior; therefore, the strain energy density, SED_{ci}, corresponding to the creep stress of interest $\sigma_{c,}$ and the creep time of interest t_i can be calculated as

$$SED_{ci} = \frac{\sigma_c \times \varepsilon_i}{2} \tag{6}$$

The only unknown in Eq 6 is the value of the creep strain ε_i. The value of m can be calculated, according to Eq 5 by performing two stress-strain experiments with different strain rates. Choosing one of the performed experiments as a reference experiment, and substituting in Eq 1 yields

$$\left(\frac{\dot{\varepsilon}_r}{\dot{\varepsilon}_i}\right)^m = \frac{\varepsilon_i}{\varepsilon_r} = \frac{\dot{\varepsilon}_i \times t_i}{\dot{\varepsilon}_r \times t_r} \tag{7}$$

where $\dot{\varepsilon}_r, \dot{\varepsilon}_i$ are the stress-strain rates of the reference test and the unknown strain rate of the iECSS test, respectively; ε_r and ε_i are the strains of points having equal strain energy density on the reference and iECSS test, respectively; t_i is the time the creep is to be predicted (e.g., 100 years); and t_r is the time on the reference stress-strain test to achieve equal strain energy density at the creep stress of interest σ_c. The unknowns in Eq 7 are $\dot{\varepsilon}_i$ and t_r.

The next step is to equate the strain energy density of the reference and iESCC tests. The strain energy density at any point in the reference experiment is

$$SED_{ci} = \frac{E_r \times \varepsilon_r^2}{2} \Rightarrow \frac{E_r \times \dot{\varepsilon}_r^2 \times t_r^2}{2} \tag{8}$$

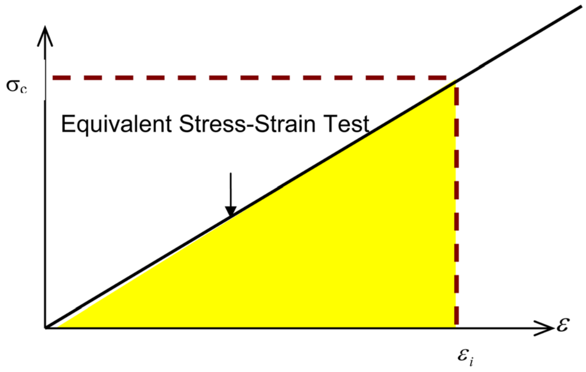

FIG. 3—*Imaginary equivalent stress strain creep (iESSC) test.*

The strain energy density for the iECSS is

$$SED_{ci} = \frac{\sigma_c \times \varepsilon_i}{2} = \frac{\sigma_c \times \dot{\varepsilon}_i \times t_i}{2} \tag{9}$$

From Eqs 8 and 9

$$\sigma_c \times \dot{\varepsilon}_i \times t_i = E_r \times \dot{\varepsilon}_r^2 \times t_r^2 \tag{10}$$

The unknowns in Eq 10 are $\dot{\varepsilon}_i$ and t_r. Equations 7 and 10 are two equations with two unknowns that can be used to determine the values of $\dot{\varepsilon}_i$, t_r as follows:

$$\dot{\varepsilon}_i = \sqrt[2m+1]{\frac{\sigma_c \times \dot{\varepsilon}_r^{2m}}{E_r \times t_i}} \tag{11}$$

$$t_r = \sqrt{\frac{\sigma_c \times \dot{\varepsilon}_i \times t_i}{E_r \times t_r}} \tag{12}$$

The strain on the iECSS corresponding to creep ε_i, can be calculated from the strain rate of the iECSS test simply as

TABLE 1—*Representative calculation of creep strain using SED method.*

Creep Stress			1900 psi	13.10 MPa	
Ref. 1	Reference strain rate		0.00003 (m/m)/min		$m = 0.027$ (Eq 5)
	Modulus of elasticity		701.95 MPa	101 810 psi	
Ref. 2	Reference strain rate		0.03 (m/m)/min		
	Modulus of elasticity		1023.04 MPa	148 380 psi	
t_i	t_i	ε_i (rate)	t_r	ε_i	ε_c
days	min	(m/m)/min	min	m/m	(%)
		Eq 11	Eq 12	Eq 13	Eq 14
0	0	0	0	0.0000	0.00%
0	5	2.91E–03	549	0.0145	0.73%
1	1440	1.35E–05	636	0.0195	0.97%
30	43 200	5.38E–07	694	0.0232	1.16%
60	86 400	2.79E–07	707	0.0241	1.20%
120	172 800	1.44E–07	720	0.0250	1.25%
365	525 600	5.03E–08	740	0.0264	1.32%
3650	5 256 000	5.67E–09	786	0.0298	1.49%
7300	10 512 000	2.94E–09	800	0.0309	1.54%
18 250	26 280 000	1.23E–09	819	0.0324	1.62%
36 500	52 560 000	6.38E–10	834	0.0336	1.68%
100 000	144 000 000	2.45E–10	856	0.0353	1.77%

$$\varepsilon_i = \dot{\varepsilon}_i \times t_i \tag{13}$$

During the real-time creep process the load is constant but varies in iECSS. In order to take the variation of the loads into account, the average of ε_i is used to as the creep strain (ε_c)

$$\varepsilon_c = \varepsilon_i / 2 \tag{14}$$

The uncorrected stress values are used for the creep projection. This is a conservative assumption since the corrected stress value decreases by time in compression. It is expected that the real compressive creep to be lower than the projections based on this assumption.

Application of SED Method to Predict the Compressive Creep of RPP

The SED method has been described and validated for the compressive creep of virgin and recycled HDPE [6,20]. This paper extends the methodology to the case of RPP which consists of an HDPE matrix reinforced by FRP bars. The methodology is as follows. First, two stress-strain tests are performed in order to compute the value of exponent m using Eq 5. Second, a creep stress σ_c is selected for computation. Third, a time is selected for computing the corresponding creep strain as shown in Table 1. Fourth, the stress-strain test having the slower of the two strain rate is selected as a reference for further calculations. Fifth, the strain rate of the iECSS test $\dot{\varepsilon}_i$ corresponding to the creep time of interest is computed using Eq 11. Sixth, the strain on the iECSS corresponding to creep $\varepsilon_{i,}$ can be calculated from the strain rate $\dot{\varepsilon}_i$ using Eq 13. Finally, the creep

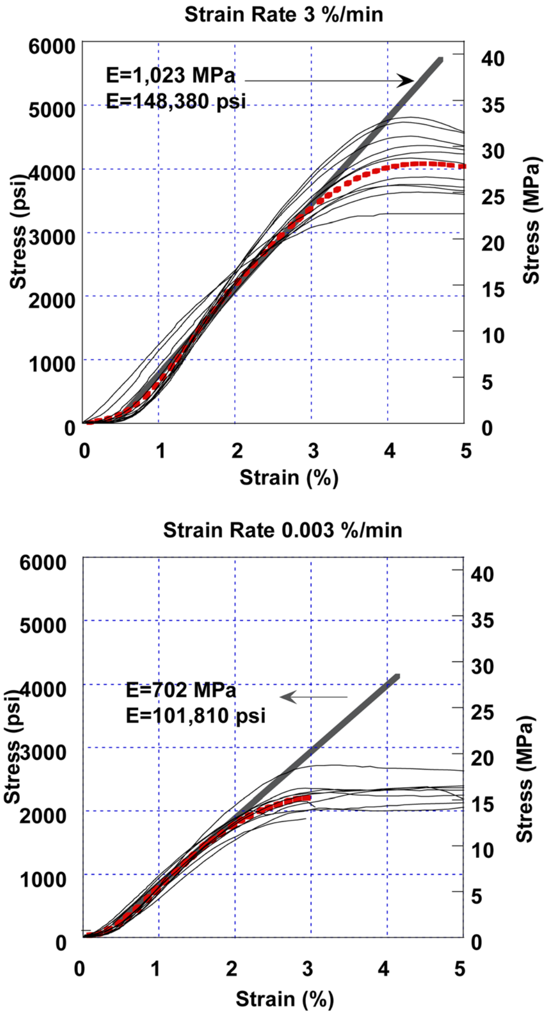

FIG. 4—*Stress-strain curves of recycled HDPE at shown strain rates and linear fit of the average stress strain curves. (Individual tests are shown as thin solid lines and average is shown as a thick dashed red line.)*

strain is taken as half of ε_I according to Eq 14. The assumptions that were employed are (1) linear elasticity; (2) the relationship between points having equal strain energy density on stress-strain curves performed using different strain rates is expressed by Eq 1; (3) creep strain ε_c (under constant stress) for a given time of interest t_i can be obtained from an iECSS at a point whose strain energy density is computed as [1/2] σ_c ε_i; and (4) temperature remains constant thought the prediction interval.

Testing Program on Recycled HDPE

Recycled HDPE rods were obtained from Trelleborg Marine Systems (TMS), which produces Seapile polymeric piling. In addition to HDPE obtained from the waste stream, the material also contains approximately 5 % glass fiber randomly mixed in the matrix for added strength, as well as carbon for UV protection, and proprietary additives. The material is designed to resemble the polymer used to produce commercially available polymeric piling, although commercially available polymeric piling contains a foaming agent to reduce the density of the piling product. Foaming significantly affects the strength of the polymer [24], so the authors opted to use solid specimens in order to obtain a baseline for determining the creep of the polymers used to manufacture polymeric piling. The rods were 28 mm (1.1 in.) in diameter and were saw cut and the edges machined such that the resulting specimens are 56 mm (2.2 in.) long.

Specimens have been tested with two different strain rates. The applied strain rates were 3 and 0.003 %/min. All tests were performed using Geotac computerized strain-controlled loading frame made by Trautwein Soil Testing Equipment Company. Each experiment was repeated 10 times and the results of those experiments have been averaged for each strain rate (Fig. 4). Recycled HDPE exhibits a pronounced viscoelastic behavior. The material is stronger as the strain rate increases. In our tests the strain rate varied by 3 orders of magnitude from 0.003 to 3 %/min. The strength of the specimens tested using the fastest

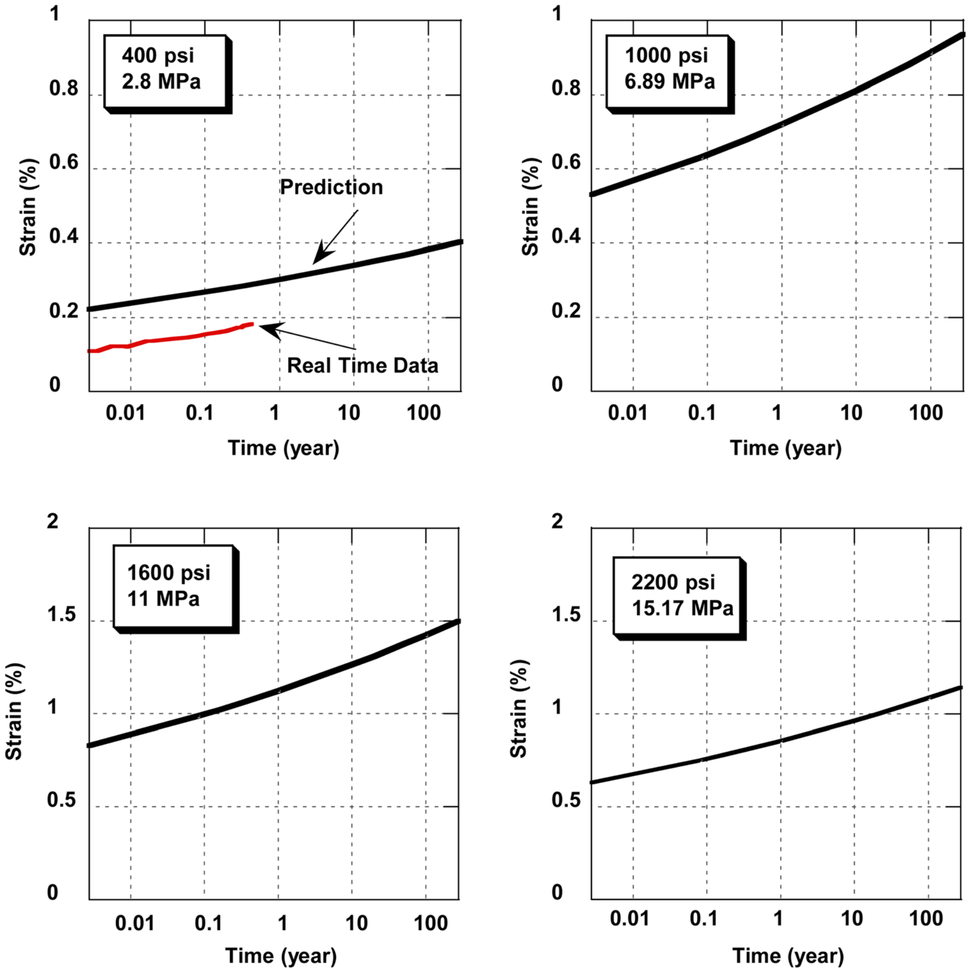

FIG. 5—*Recycled HDPE predicted creep calculated using a pairs of strain rates having a difference of 3 orders of magnitude for 2.8, 6.9, 11, and 15.2 MPa (400, 1000, 1600, and 2200 psi).*

strain rate (defined at a strain of 2.5 %) was 70 % larger than that of specimens tested using the slowest strain rate. A linear modulus of elasticity was fitted in the early segment of each of the average stress strain curves shown in Fig. 4. The first 2.5 % of the stress strain curve was selected for the linear fit because (1) it corresponds to the strain of practical interest in civil engineering applications, and (2) the material exhibited yielding after approximately 2.5 %. The modulus of elasticity was 45 % higher at the fastest rate of loading than the slowest rate of loading.

Predicted Creep of Recycled HDPE Using SED

Creep strains were computed using SED in Fig. 5 for four different creep stresses as follows: 2.8, 6.9, 11, and 15.2 MPa (400, 1000, 1600, and 2200 psi). Table 1 illustrates sample calculations for creep stress of 13.1 MPa (1900 psi).

One real-time creep test was performed on recycled HDPE with a creep stress of 2.8 MPa (400 psi) for 150 days. The test was performed using a mechanical Wykeham Farrance load frame that allows for loading the specimen via a fulcrum that provides a mechanical advantage of 10:1. Creep strain was measured using a dial gauge with a resolution of 0.00254 mm (0.0001 in.). The system was loaded gradually, and did not allow for capturing creep strain during loading; therefore, creep was lost during the first 10 to 20 s of loading. The results of the real-time creep test are superimposed over the computed creep curve using SED for 2.8 MPa (400 psi) in Fig. 5. The slope of the conventional creep matches the slope of the computed curves. The vertical shift between the curves is because the mechanism of initial creep is not modeled similarly in the two experiments. Nevertheless, since the slope of the constant creep stage (Fig. 5) controls the long term behavior of recycled HDPE in compression, then the slope of the average SED curve can be used.

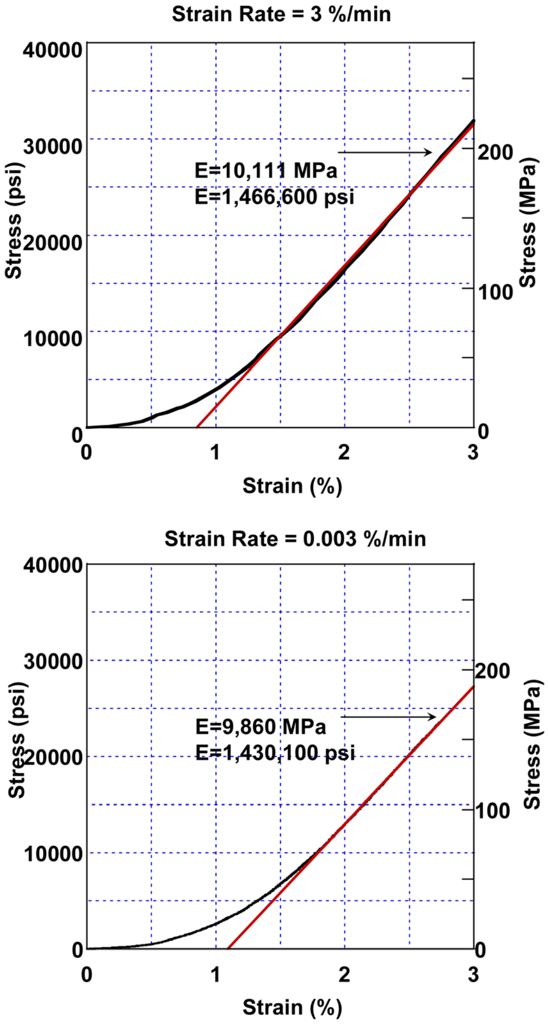

FIG. 6—*Average stress-strain curves of E-glass at shown strain rates and linear fit of the average stress strain curves.*

At ambient temperature, creep strains ranged between 0.4 and 1.5 % (Fig. 5) depending on the applied stress, for a duration of 100 years, assuming that the creep process remains within the primary or secondary mechanisms. If tertiary creep were to occur, the strain would exceed the values shown in Fig. 5.

Testing Program on FRP (E-Glass)

A similar testing program was performed on the E-glass rods. E-glass (fiberglass) rods having a nominal diameter of 14 mm (0.55 in.) were obtained from TMS. The E-glass material is a composite material consisting of two components, glass fiber and resin. The glass-fiber strings are arranged in a bundle, and are glued together using the resin. A spiral support stirrup is also wound around the longitudinal bundle and glued to it.

Coupon specimens of E-glass were formed by cutting the E-glass bar into pieces with a length to diameter ratio of 2. Each experiment was repeated at least three times and the results of these experiments have been averaged for each strain rate in Fig. 6. E-glass does not exhibit a pronounced viscoelastic behavior like recycled HDPE. The modulus increased by only 3 % when the strain rate was increased from 0.003 to 3 % at ambient temperature.

Predicted Creep of E-Glass (FRP) Using SED

The SED methodology for creep prediction is implemented to predict the creep of E-glass and the results are shown in Fig. 7. As expected creep strain is dependent on the creep stress, but unlike recycled HDPE, time has a small effect on creep because E-glass exhibits a small viscoelastic tendency. The creep strains ranged between 0.05 and 0.5 % in a duration of 100 years depending on the applied stress.

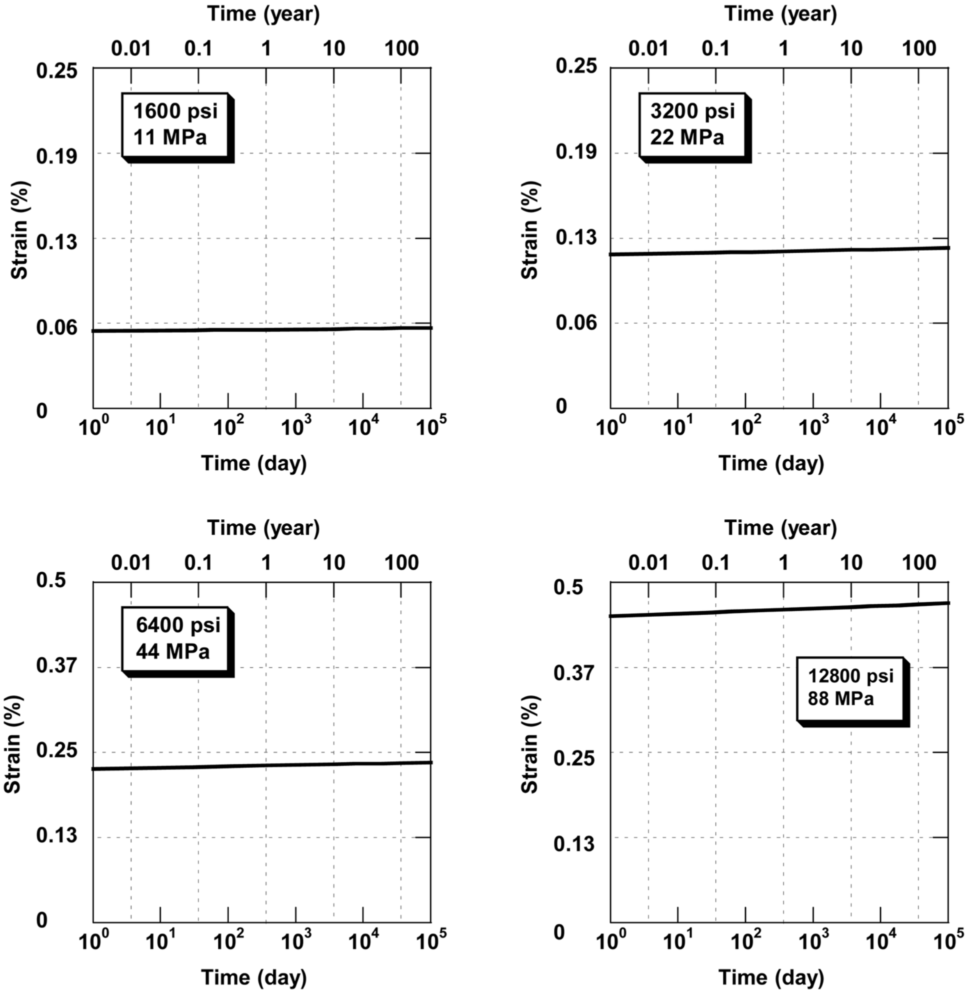

FIG. 7—*E-glass predicted creep calculated using a pair of strain rates having a difference of 3 orders of magnitude for 11, 22, 44, and 88 MPa (1600, 3200, 6400, and 12 800 psi).*

TABLE 2—*Calculation of the composite Young's modulus.*

		Modulus of Elasticity, MPa (psi) (3 %/min)	Modulus of Elasticity, MPa (psi) (0.003 %/min)
E-glass		10 111 (1 466 600)	9860 (1 430 100)
Recycled HDPE		1023 (148 380)	702 (101 810)
E-glass (%)	3 %	1296 (187 927)	977 (141 659)
Recycled HDPE (%)	97 %		
E-glass (%)	8 %	1750 (253 838)	1435 (208 073)
Recycled HDPE (%)	92 %		

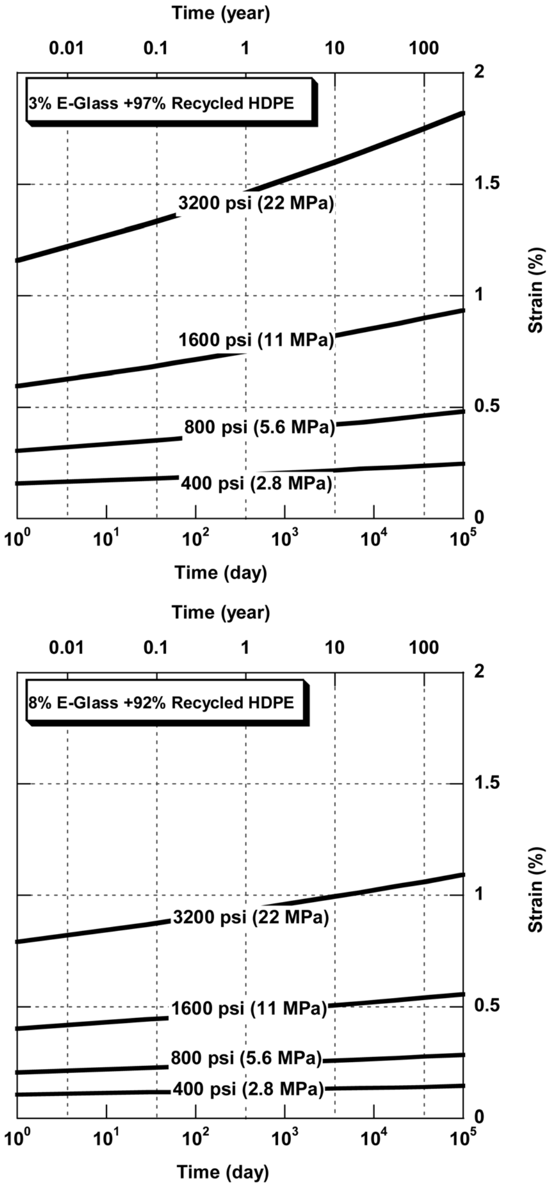

FIG. 8—*Effect of creep stress on computed creep strain of the composite piles.*

Creep of Composite Sections Made of HDPE and Reinforced With FRP (RPP)

Since the creep of the main constituents of RPP can be predicted using SED, the creep of the composite section can also be calculated. A composite modulus can be computed assuming strain compatibility between HDPE and E-glass. Young's modulus for 3 and 0.003 % strain rates for an RPP pile are estimated by using the weighted average of measured modulii (Figs. 4 and 6) as shown in Table 2.

SED calculations are performed using the composite modulli for two representative RPP having reinforcement ratios of 3 and 8 %. The composite modulli were calculated based on the assumption of strain compatibility. The results of the creep projection for the RPP for different stress levels and different percentage of reinforcement ratio are summarized in Fig. 8. Creep depends on the degree of reinforcement. The modulus of FRP is only 10–15 times larger than that of HDPE, so creep of RPP is strongly affected by the FRP reinforcement, but does not eliminate the need to consider the effect of HDPE on creep, at least theoretically. SED predicts creep magnitude ranging from 0.2 to 1.8 % in 100 years under loading and reinforcement ratios illustrated in Fig. 8.

Limitations of the SED Methodology

SED can be used with the following precautions. First, for the composite material, it is assumed that the strain compatibility of the constituents is valid both in the short and long terms. This is probably a valid assumption although the difference in the creep rates of FRP and HDPE may affect the composite modulus used for SED computations. Second, the methodology is limited to small strains. We believe this requirement has been met since all computed strains are less than 2 %. Third, the effect of foaming was neglected. Foaming is likely to reduce the computed modulii, with two effects, (a) increasing the predicted creep, and (b) over-emphasizing the role of FRP in resisting creep. These two effects may tend to negate each other, but more research is needed to quantify the effect of foaming. Fourth, the methodology assumes that the temperature is constant at room temperature. Although buried piles can reasonably be assumed to have a constant temperature, piles with long above ground stick-ups may be subject to wide temperature fluctuation. The creep behavior of an exposed polymeric pile will depend on the ambient temperature, and the thermal acceleration methodology must be revisited to account for the effect of a changing reference temperature. Finally, this methodology does not take into the account the possible chemical or physical material degradation that might occur within the prediction cycle.

Conclusions

The equivalent strain energy density method (SED) may provide a powerful approach for estimating creep for up to 100 years based on laboratory testing that can be concluded in one or two days. SED has been employed for predicting the creep of recycled HDPE. SED predicts that recycled HDPE and FRP (E-glass) will creep by approximately 1.1 and 0.5 %, respectively, in 100 years when loaded at an ultimate stress of 8.3 MPa (1200 psi) and 88 MPa (12 800 psi), respectively. Creep of RPP depends on the percentage of FRP reinforcement in the cross section. Creep of RPP is estimated to be on the order of 0.5–0.8 % in 100 years when typical RPP geometries and reinforcement ratios are considered. The methodology is ideal for (1) comparing the creep behavior of different polymeric products for purposes of preliminary design, (2) defining the appropriate loading loads for meeting serviceability requirements, or (3) quality control, since recycled products my undergo differences in their material properties depending on the constituents of the waste stream.

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