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Property Modelling

Experiments for the long-term prediction of creep strain of expanded polystyrene under compressive stress

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ABSTRACT

Expanded polystyrene (EPS) slabs were tested to determine their strength and the effects of creep strain under compressive stress. The results were statistically analysed based on long-term experiments between 65 and 2034 days. The analysis shows that it is possible to predict creep strain development for a lead time of 50 years on the basis of the data obtained in experiments shorter than 608 days, as specified in Standard EN 13163. Sufficiently accurate point-wise prediction of creep strain of EPS slabs under a compressive stress σ_c of (0.25 and 0.35)$\sigma_{10\%}$ for a lead time of 50 years is possible by extrapolating the creep described via a power equation (Findley W.N.) and using data from the 65-day direct experiment.

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1. Introduction

Expanded polystyrene (EPS) is an abundant material, and it possesses performance characteristics that make it widely used as a construction material (e.g. underground structures), where it is subjected to various mechanical actions [1–3]. Usually, the performance of expanded polystyrene is measured under short-term compression [1,3–6], tension [7] or bending [8], which are all easily measurable. However, to determine its performance under long-term compressive stress, labour and time intensive experiments should be conducted [1,9,10]. These types of experiments can be shortened if an extrapolation method is used, which allows the EPS deformability to be predicted under long-term compression for virtually any lead time [11,12]. However, an appropriate calculation model must be selected [11,13,14]. Some researchers still believe that this method is unreliable, although the careful use of experimentally grounded extrapolation data usually yields reliable results. These data are required for the effective use of expanded polystyrene products such as those used in building insulation, railways and highways [15,16].

According to Ref. [17], the total strain of expanded polystyrene slabs under compressive stress can be approximated by Fiendly's equation which can be converted into a power law relationship for the creep strain:

$$\bar{\epsilon}_c(t) = b_0 t^{b_1} \tag{1}$$

where

$\bar{\epsilon}_c(t)$ is the mean creep strain value at time t, %;
b_0,b_1 are constants, depending on the material properties;
t is time, days.

After taking logarithms, the power equation (1) can be expressed as

$$\log\bar{\epsilon}_c(t) = \log b_0 + b_1 \log t \tag{2}$$

and extrapolation by about 30 times the experimental timeframe is valid, as long as the determination coefficient $R^2_{\log\epsilon_c \cdot \log t} \geq 0.9$.

In Europe, the extent of allowable creep strain of EPS slabs to be used in building and railway construction as

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a geofoam, as determined by long-term tests, is specified for lead times of 10, 25 and 50 years [15,16]. This means that the duration of direct experiments should be 122, 304 and 608 days for each of these lead times, respectively.

It should be noted that there is a methodological error in Ref. [17] on interpreting the correlation and determination coefficients of the time series $log\epsilon_c(y_t)$ and time indicator $\log t(t)$, assuming the integer values $t = 1, 5, 24, \ldots, n$. It is well known that the correlation coefficient (for a linear relationship, the square of the correlation coefficient serves as the determination coefficient) is calculated somewhere between the random x and y values based on the random sample $x_1, x_2, \ldots x_n$; $y_1, y_2, \ldots y_n$, taken from the x and y statistical populations, respectively. Thus, any y_i has the same expectation and variance as those of x_i. In this case, the closer the determination coefficient is to unity, the more "functional" the statistical dependence is between y and $x_1, \ldots x_n$. Therefore, $R^2_{y \cdot x}$ is an indicator of the adequacy of the regression of the initial system of random values y and $x_1, \ldots x_n$. It is clearly incorrect to consider a series 1, 5, and 24,…n (with the time moments expressed in hours, as recommended in Ref. [17]) to be a random sample of a given statistical population. The determination coefficient in regressions with determinate independent variables should be treated as an indicator, which demonstrates the level of improvement of the regression model over the model using the mean value. This interpretation of $R^2_{y \cdot x}$ explains why the above coefficient has large values for increasing time series [18]. The model of the mean value for these series does not fit adequately in this case, implying that $R^2_{y \cdot x}$ should be close to unity. The statistical interpretation of $R^2_{\log\epsilon_c \cdot \log t}$ presented in Ref. [17] is of limited practical value, often yielding a rough, sometimes trivial, estimate.

The above considerations do not imply that it is not possible to use other standard statistical regression characteristics in determining the trends, e.g. standard errors and confidence intervals for parameters and predictions [13,19].

The analysis of experimental data of EPS slabs under compression stress $\sigma_c = 0.35\sigma_{10\%}$, which were obtained from direct experiments with durations between 65 and 608 days [20], has shown that their creep strain can be predicted, described by a power model (1), and extrapolated by about 95 times the test duration (1).

This paper aims to determine the appropriate timeframe for direct experiments that allows the creep strain of EPS to be predicted for a lead time of 50 years. The analysis is based on data obtained from a long-term 5-year experiment. We also compare our results to a corresponding power equation regression based on the digital parameters determined in experiments, which have durations of 608, 295, 122 and 65 days.

2. Investigation methods

Mass-produced EPS slabs that are commonly used in construction were tested. A variety of slabs were examined, types EPS 60–EPS 250 [15,16] with densities between 14 and 35 kg/m^3. They were made by various manufacturers using a non-compaction method, which is based on frothing raw material in bead form (granules of 0.8–2.5 mm in diameter, manufactured by the leading European companies 'Styrochem' and 'BASF').

The deformation of cubic test specimens having a side $a = 50$ mm was used to determine expanded polystyrene slab deformability. The deformation of specimens was measured using special test stands [17,21], by maintaining a constant compressive stress for a long time (up to 2034 days). Each of fifteen tests was made on three specimens, which all had the same density. The compressive force was assumed to act perpendicular to the surface of the slab from which the specimens were cut. The creep strain was determined by methods described in Ref. [17] for static stresses σ_c equal to $(0.25$ and $0.35)\sigma_{10\%}$. The stress $\sigma_{10\%}$ was determined according to Ref. [22]. The error for stabilizing long-term compressive stress was $\leq 1\%$, while the error for creep strain measurement was 0.005 mm. Specimens were loaded and measurements were taken in compliance with the requirements given in Ref. [17].

Long-term testing was carried out at ambient temperature (23 ± 2) °C and relative humidity of (50 ± 5) %.

3. Experimental data processing methods

The values of relative creep strain $\epsilon_c(t)$, %, were calculated by the formula:

$$\epsilon_c(t) = \frac{X(t) - X_0(t = 60s)}{d_s} \cdot 100 = \frac{X_c(t)}{d_s} \cdot 100 \quad (3)$$

where

$X_0(t = 60\ s)$ is the decrease in specimen thickness at time t $t = 60\ s$ after application of the compressive load, mm;
$X(t)$ is the decrease in specimen thickness at the fixed time t, mm;
d_s is the initial specimen thickness under the specific load of 250 Pa, mm.

According to Ref. [17], the creep strain of EPS specimens under compressive stress can be approximated by equation (1).

The experimental data were processed for direct experiments lasting 65, 122, 295 and 608 days and for the 5-year experiment. The regression equation for the long-term experiment $t_n = 5$ years (sample 1 as a general population) was compared with the regression equations based on the experimental data for the shorter experiments $t_n = 608, 295, 122, 65$ days (samples 2, 3, 4 and 5, respectively). Efforts were made to determine if the differences between the regression equations (2) are by chance, i.e. the samples compared demonstrate the same linear dependence of $log\epsilon_c(t)$ on $\log t$, or if their differences were more fundamental [23,24].

The comparative analysis was performed in three steps.

3.1. Testing of hypothesis $H_0^{(1)}$ around the residual variances (i.e. variances with respect to the regression line)

Sample variances were assumed to be equivalent and describable by the expression:

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