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Temperature Effect on the Creep Behavior on Carbon Fibre Reinforced Polymer Cable in A Suspen Dome

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Abstract
Introduction: A suspen dome model with carbon fibre reinforced polymer cable as its tengerity system was incorporated with creep theory is presented.
Objectives: Creep deformation of carbon fibre reinforced cable in as tensegrity system in a suspen dome with imposed load at a high temperature was considered numerically to justify its exception properties.
Methods: To predict the creep effect on carbon fibre reinforced polymer cable numerical simulation was carried out using an FEM package namely ANSYS.
Results: The analysis showed that for the proposed prototype at an elevated temperature based on atmospheric condition illustrated that the failure time for carbon fibre reinforced polymer cables due to creep raptures is negligible.
Conclusions: From the analysis of the model, it can be concluded that partially reinforcing a suspen dome with carbon fibre reinforced polymer cable as the tensegrity system is an excellent alternative with little or no creep effect on the cable.

Keywords: Suspen dome, Tensegrity system, Carbon fibre reinforced polymer cable, Numerical analysis, Creep , Temperature.

1. Introduction

With the application of carbon fibre reinforced polymer cable in cable roof structure such as suspen dome [1]in replacing the conventional steel cables with versatile properties such as corrosion resistance and high strength to mention a few. it is essential to understand it behavioral pattern due to temperature in respect to creep. Polymeric materials are sensitive to temperature which consequently affects their mechanical properties with variation in temperature [2].

Little or no information on the creep behavior of carbon fibre reinforced polymer cable has been investigated. However, researchers have investigated on creep behavior in shell structures such as rupture, deformation and damage in respect to cyclic loading[3][4][5].

This paper discusses preliminary findings based on simulation. It will help to predict the extent of creep at a specified temperature theoretically. It is necessary to compare creep pattern of carbon fibre reinforced polymer cable in a suspen dome with other numerical model predictions existing in literature as well as experimental data. However, the research on application of carbon fibre reinforced polyme cable in a suspen dome is new and its ongoing. Also, creep test are time consuming and expensive, numerical and analytical studies are preferred to experimentation. The data obtained from the analyses will be of immense use in defining the temperature range which carbon fibre reinforced polyme cable is exposed under operational condition of the structure.

2. Theoretical Overview

Creep might become an issue when the application involves heavy loads over a longer time at an elevated temperature. The combination of three factors, load, time and temperature determine whether creep is relevant for the application of carbon fibre reinforced polymer cables in a suspen dome. Material exhibits long term static strength which is remarkably lower than short term. The long term static strength is perceived by exposing the material to sustain stress for an extended period of time in an environment exposure like in the air at an ambient temperature[6].Effect of temperature over time as illustrated in fig.1. The failure due to degradation of material properties with time is referred to as creep rupture. Elevated temperature decreases strength and stiffness of composite and increases creep strains at such temperature and an inelastic response occurs when loaded thereby having an important effect on deformation phenomena[7]. Creep is rate-dependent on the nonlinearity of material in which continues to deform material under load. It is categorized into 3 stages as illustrated in Figure 2. First stage is work hardening behaviour of the material, second stage is the steady stage and the third stage is creep acceleration due to accumulated damage which will result in rupture.

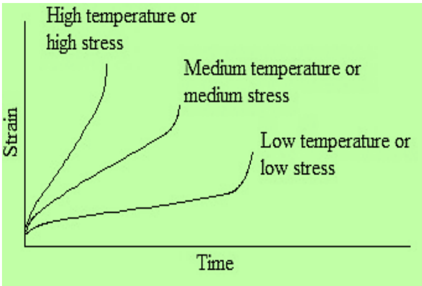

Figure 1 Effect of temperature over time

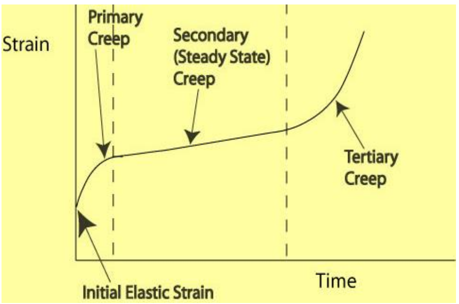

Figure 2 Creep stages

2.1 Creep theorem

Bailey-Norton Law states that [8]

$$\varepsilon^c = A\sigma^p t^q$$

(1)

Where *A,p* and *q* are constant that are functions of temperature. Value of *p* is greater than 1 and q is a fraction. The law models primary and secondary. Differentiating equation (1)

$$\dot{\varepsilon}^c = \frac{\partial \varepsilon^c}{\partial t} q A\sigma^p t^{q-1} \quad (2)$$

Which is the time hardening formulation of Equation (1) is solved for *t*

$$t = \left(\frac{\varepsilon^c}{A\sigma^p}\right)^{\frac{1}{q}} \quad (3)$$

Substituting Equation (3) into Equation (2)

$$\dot{\varepsilon}^c = qA^{1/q}\sigma^{p/q}(\varepsilon)^{(q-1/q)}$$

(4)

The time hardening formulation form in Equation (4) is used in ANSYS.

By means of joint force and joint load, the whole equilibrium equation can be obtained as[9]:

$$[K]\{\Delta\delta_n\} = \{\Delta P_n\}^L + \{\Delta P_n\}^C + \{\Delta P_n\}^T$$

(5)

where $[K]$ is integral stiffness, $\{\Delta P_n\}^L$ is node load increment due to load, $\{\Delta P_n\}^C$ is node load increment due to creep, and $\{\Delta P_n\}^T$ is node load increment due to temperature.

Since the nodes are collection of elements in a system, the load increment is given as:

$$\{\Delta P_n\}^C = \sum_e \{\Delta P_n\}_e^C, \{\Delta P_n\}^T = \sum_e \{\Delta P_n\}_e^T$$

(6)

The increment at each node displacement can be obtained by solving the increment of each unit stress increment given as:

$$\{\sigma_n\} = \{\Delta\sigma_1\} + \{\sigma_2\} + ... + \{\Delta\sigma_n\} = \sum\{\Delta\sigma_n\}$$

(7)

As stress increases, the rate of deformation increases. An equilibrium equation for nodal loads based on creep is described. The goal for creep design is to predict the behaviour over a long term.

3. Model Framework

A suspen-dome is a long span roof composite system of a single layer truss dome and a tensegric system (struts and cables)[10].Preliminary investigations and validation has been carried on the model frame work used in this study[11][12][13][14]. The model is presented in Fig 3 to predict temperature effect based on creep.

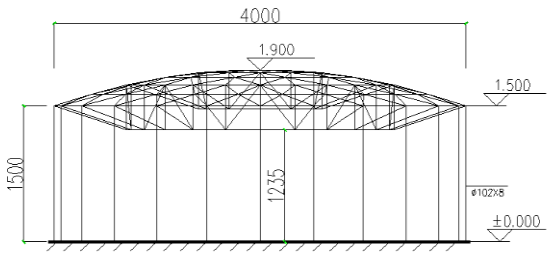

Figure 3 Model details

3.1 Material parameters

Table 1 illustrates details on the material properties implemented for the simulation. The single reticulated layer is made of Q235 steel. Assumptions were made for the constant which are functions of temperature.

Table 1 Mechanical properties of carbon fibre reinforced polymer cables

Material	Density(kg/m^3)	Tensile strength(GPa)	Elastic modulus(GPa)
Carbon fibre reinforced polymer	1600	2.55	147

4. Numerical Technique

Most material will certainly experience creep upon reaching its melting temperature because the minimum creep temperature is related to its melting point. Most polymer experience significant creep at temperature above -200°C[15]. The simulation algorithm for this analysis is illustrated in Figure 4

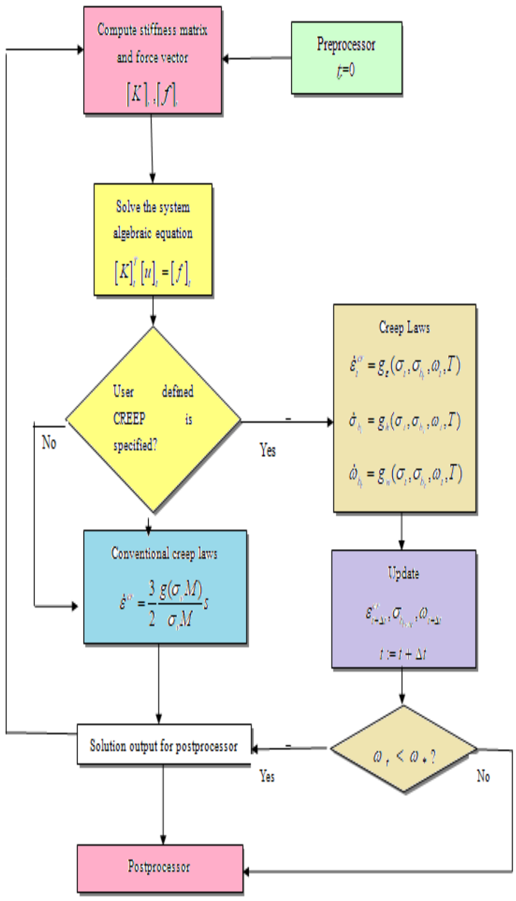

Figure 4 Creep analysis procedure on ANSYS

Considering the proposed prototype subjected to a load of 1000N over a year at 100°C with parameters and element description

4.1FEM model

The suspen dome was supported at the edge. The tensegrity system was discretized in LINK10 element and the single reticulated layer was in BEAM 188. The finite element model is shown in Figure 5.

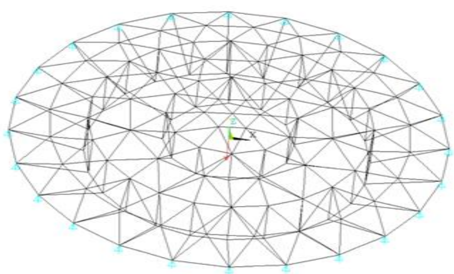

Figure 5 FE Model framework

5. Results and Discussion

Due to the symmetrical nature of the model any typical node can represent the behavioural pattern. The result of the model analysed at an elevated temperature based on atmospheric condition shows that the failure time for carbon fibre reinforced polymer cables due to creep raptures is negligible as illustrated in Figure 6 and 7.

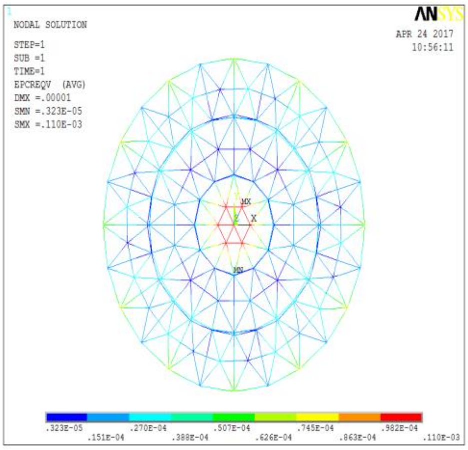

Figure 6 Creep contour

Carbon fibre reinforced composite are high temperature material par excellence. The strength of carbon fibre remains until 2000°C, the stiffness increases even with an increase of temperature of up to 2500°C [15].

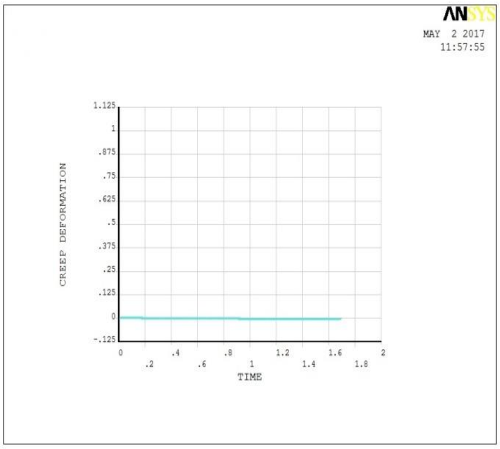

Figure 7 Creep mechanism of carbon fibre reinforced polymer cables at 100°C over a period of time.

Considering the maximum stress generated in the suspen dome over the specified period, the stresses generated in ccarbon fibre reinforced polymer cable was low as illustrated in Fig 8. Creep strain was small so it was assumed to be negligible.

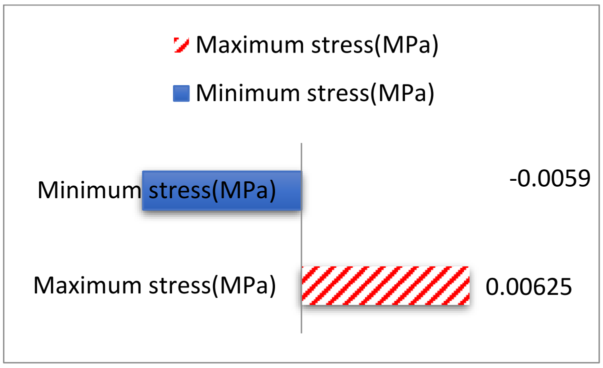

Figure 8 stress generated

Carbon fibre reinforced polymer cables can sustain 0.91 times their ultimate strength before encountering creep-rupture problem. Fig 6. shows that at the operating temperature, the yield strength applied was high which resisted creep for carbon fibre reinforced polymer cables in the structural system

6. Conclusion

Based on creep mechanism, carbon fibre reinforced polymer cables are least susceptible to rapture by creep and the compactness of the design is inspired using higher yield strength. Unlike steel, carbon fibre reinforced polymer cable strength is intact with rise in temperature. At high temperature it is in a large stress-free state, depending on the stress level, carbon fibre reinforced polymer succeeded in reducing creep rate. Hence, as far as temperature resistance is concerned, carbon fibre reinforced polymer cable is the ideal material for the tensegrity system in a suspen dome.

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