SECONDARY CREEP RESPONSE OF HAND LAY-UP GRP COMPOSITES

A.N. Enetanya
Dept. of Mechanical Engineering
University of Nigeria, Nsukka

ABSTRACT
Glass Reinforced Plastics (GRP) composite load bearing components are now in common use, quite often at temperatures above the ambient, where creep behaviour may be significant, as in pressurized industrial containers. This is especially true of those composites produced by the Hand Lay-Up Contact Moulding Technique, which may possess some production defects. Creep in an engineering material depends on the temperature as well as the stress level within the material. This paper examines the Secondary Creep Strain and Strain Rate of Hand Lay-Up GRP composites subjects to uniaxial stress at an elevated temperature. Empirical expressions are sought to relate Creep Strain Rate and Stress Level with time at the Secondary Creep stage. The Secondary Creep Strain Rate at a given stress level is found to be approximately constant and increases with the stress.

(**KEYWORDS**: *Secondary Creep, Rate, Temperature Stress Dependence).*

INTRODUCTION
Creep involves a continuous deformation of an engineering material subjected to a constant load. This is especially significant above certain temperatures, which depend on the nature of the material. For Fibre Reinforced Plastics (FRP), creep becomes significant at temperatures approximately close to half the softening temperature (T_g) of the composite matrix. Creep occurs as a result of thermal activities involving dislocations, grain boundary shearing and diffusion of vacancies within the engineering material.

A creep test is carried out at a constant stress and a specified temperature, to obtain a Strain - Time curve. One of the earliest creep investigations was done by Andrade [I] on metals. His results led to an empirical equation for Creep Strain:

$$\varepsilon = \left(1 + At^{1/3}\right)e^{Bt} - 1 \qquad (1.1)$$

where A and B are constants and ε is the strain at time *t*. Over a typically long period of creep behaviour, equation (1.1) can be shown to represent two creep stages: a Primary and a Secondary Creep. The Primary Creep is relatively brief, with an initially high creep rate, which decreases very rapidly. The Secondary stage is of the longest duration at a fairly steady rate. In a typical creep test, there is a Tertiary Creep stage with a comparatively rapidly increasing creep rate, which ends with necking and a final fracture of the test material.

Although equation (1.1) approximately describes the creep response of a metal, other homogeneous and some composite engineering materials have been Shown to exhibit similar creep behaviours in general Chen and Cheng [2] showed a similar Secondary Creep response for Silicone - Rubber composites. For many engineering materials, the Secondary Creep Stage is of the longest duration, it is more or less steady, with a fairly constant creep rate. The secondary creep stage in the GRP composite is of major interest in the present

investigation.
At low and ambient temperatures creep deformation is insignificant for GRP composite materials such as are used in automobile and other motor vehicle components, However at higher temperatures, approximately half the softening temperatures (T_g) of GRP composite matrices, creep becomes significant as dislocations within the material gain greater freedom while the molecules vibrate at a higher energy level, with greater tendency to promote dislocations. These are the operational temperatures of many GRP industrial pressurized fluid containers and other composite engineering components. Creep behaviour of these composites also depends on the stress level of operation and usage of these materials. Additionally the creep - stress dependence is related to the elastic and yield strengths of the particular composite and becomes significant at stress levels approximately equal to or higher than a third of the elastic limit of the composite.
The strength of GRP depends on several factors, which include the nature of the materials, the method of production and related production defects, the volume fraction (V_f) of the reinforcing fibres, the properties of the resin (or matrix), and the adhesion of the matrix to the fibre reinforcement. Other factors affecting the composite strength, creep response and fracture and delamination resistance revolve around the above factors. Thus studies are frequently focused on methods (and benefits) of improving these properties of composites, such as Linsenmann's work on Hybridization of composites [3] several years age and Luo and Wang's more recent investigation of Intermingled Hybrid Composite [4]. Modeling of the Creep behaviour of composites was also investigated by Laws and Mclaughlin[5]· Earlier studies by popovics [6] tried to extend composite materials theory to predict their creep response. Zhu et al [7] studied the creep behaviour of a hydride Glass/Carbon composite over a range of stress levels and recommended a parameter for creep damage, which they related with adjustments in the modulus of the composite.
A number of empirical, and theoretical equations were suggested for creep behaviour of engineering materials. More recent theories now show that the actual mechanics of creep are quite complicated on account of the many types of dislocations and the interrelationship between them, especially in the presence of production defects. Production defects in GRP composites are especially responsible for differences in creep characteristics of identical materials produced by different methods, as shown by Morii et al [8] who demonstrated heavy water absorption at 60°C with subsequent degradation in mechanical properties of GRP composites although the actual production method was not indicated. The different effects of production defects are especially evident in those composites moulded by the Hand Lay-Up Method, a common technique in developing countries. This method requires inexpensive tooling, and well supervised semi-skilled labour. Such defects as embedded Cracks [9, 10] have significant effects on creep behaviour. Fracture propagation, however, is often the major failure mechanism at micro scale for FRP composites with embedded cracks. In general correlation of empirical formulas with experiments may be most reliable for prediction of creep response of these composites

2. EMPIRICAL CREEP RELATIONS

In spite of more detailed creep response theories on composites, based on fibre orientation, composite stress level, and

volume fraction dependence, Andrade's approximate empirical equation may be modified to obtain sufficiently useful expressions for design and production of hand lay-up GRP composites so as to avoid further extensive time consuming creep experiments.
Thus for the Primary and Secondary Creep stages, the creep curve could be represented by:

$$\mathcal{E} = \mathcal{E}_1 + \mathcal{E}_2 \qquad (2.1)$$

Where

$$\mathcal{E}_1 = C(\sigma)t^n \qquad (2.2)$$

And

$$\varepsilon_2 = \varepsilon_0(\sigma) + K(\sigma)t^n \qquad (2.3)$$

Here ε_1 and ε_2 represent the Primary and Secondary Creep Strains respectively; C (σ), K (σ),$\varepsilon_0(\sigma)$ and n are constants which depend on the stress at a given material temperature. The Secondary Creep Strain Rate is therefore given by

$$\frac{d\varepsilon_2}{dt} = K(\sigma) \qquad (2.4)$$

Frequently the E-Glass Chopped Strand Mats and Woven Roving laminates are the reinforcing fibres in the GRP. The fibres are moulded with preaccelerated catalyzed polyester resins. The fibre arrangements of these laminates are such as to make them quasi-isotropic so that uniaxial creep tests on sample specimens are possible. Equations (2.3) and (2.4) can then be fitted on the experimental curves for the secondary creep.

3. EXPERIMENTAL CREEP INVESTIGATIONS

Preliminary experiments were performed to select the relevant temperature and stresses for the creep tests. Since creep studies typically involve several hundred hours, only a single temperature and a few stress levels could be considered for this investigation.

3.1 Test Temperature and Stress Levels

Preliminary tests showed that the Softening Temperature (T_g) of the composite matrix was very close to 140°C so that (1/2) T_g of 70°C was used for the creep investigation at all stress levels, starting at below one third of the elastic limit. The following stresses were selected for the Strain - Time curves to be obtained at 70°C:
(a) 25MPa,
(b) 35MPa and
(c) 40MPa.

3.2 The Test Specimens

The composite materials consisted of E-Glass Chopped Strand Random Mats fibre laminates and Woven Rovings laminates moulded in preaccelerated catalysed polyester resins at about 50% fibre volume content (V_f) without a modifier. Fibre orientation for the Woven Rovings was arranged parallel to the anticipated specimen axis. The Chopped Strand Mats typically have a random orientation, which is seudo-isotropic. Eight layers of ply reinforcement were moulded with wooden grips at the ends in each test specimen consisting of four layers of each ply type arranged alternately. The specimens were trimmed and sanded to coupon test sample size shown in Fig. 1. Hand lay-up contact moulding method was used for production of all samples. Three coupon test samples were produced for test at each stress level.

3.3 The Creep Test

The test rig consisted of an Electrical Resistance Heating Chamber, operating with an Electrical Temperature Regulator, a strain Guage, a Load Grip and Related

Accessaries. The test specimen was gripped in the heating chamber rig while the temperature regulator was adjusted to maintain the chamber temperature between 67°C and 74° so as to keep the specimen at 70°C. Having set up the creep test arrangement, the heating chamber circuit was turned on, so also was the temperature regulating circuit. The zero load error was checked for the strain gauge before application of the load for the 25MPa nominal stress on the test specimen for measurement of Strain - Time data. Three coupon samples were tested at each stress and the creep strains were averaged.

4 RESULTS AND DISCUSSIONS

As expected, the initial strain rate (corresponding to the primary creep) was high but after some hours the time interval between strain readings extended to several hours, indicating the transition to Secondary Creep. At 25MPa stress there was no visible indication of the transition to the tertiary creep stage after 400 hours. On account of the limitations in time the investigations were continued at higher Stress levels of 35 and 40 MPa. At 40MPa stress there were indications of some change to the tertiary creep, but they were not definite.

The resulting experimental creep curves as shown in Fig. 2. The Primary Creep stage lasted for about 12 hours (0.0432 x 10^6 seconds) as 25MPa stress level and 10 hours (0.0360 x 10^6 seconds) at 35 and 40MPa stresses. The Secondary Creep Stage, which is of primary interest in this investigation lasted over 360 hours (1.3 x 10^6 seconds) at all stress levels. At 25MPa the Secondary Creep Stage lasted from the 12th hour through the rest of the creep study.

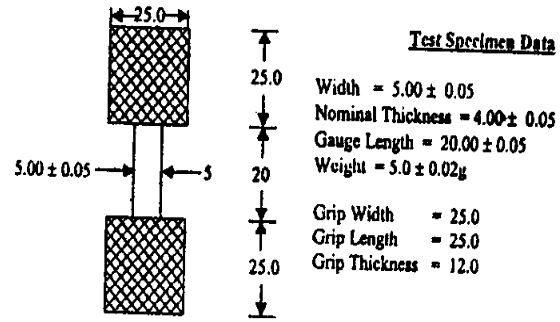

Fig. 1: Creep Test Specimen. All dimensions in mm

Although there were some indications of the transition to tertiary creep at 35 and 40MPa stress levels as shown by some increase in the creep rate the actual change to Tertiary Creep did not occur. At 40MPa stress a greater increase in creep rate occurred between 360 and 400 hours after the start of the creep test, but there was no actual transition to tertiary creep.

The Secondary creed rate was approximately steady at all stress levels and is represented by K (σ) in equations (2.3) and (2.4) of section 2. Approximate values of K (σ)and $\varepsilon_o(\sigma)$ are shown in Table 1, which also shows other data from Fig. 2. The constant $\varepsilon_0(\sigma)$ represents the point on the strain axis where the approximate straight line representing the Secondary Creep would cut the strain (ε) axis at time t =O. The approximate straight lines representing the Secondary Creep Strains in equation (2.3) are shown with the experimental creep curves in Fig. 3.

Table 1: Data from Creep Curve

Stress level σMPa	Creep rate K, micro-strain per Hr.	Intercept ε_0 milli-strain (10^{-3})	Duration of primary creepHrs.	Stain at end of primary creep milli-strain (10^{-3})
25.0	0.42	0.50	12.0	0.40
35.0	0.77	1.10	10.0	0.95
40.0	1.50	1.35	10.0	1.05

5.0 CONCLUSION AND RECOMMENDATIONS

An experimental study of the Secondary Creep behaviour of Hand Lay-up GRP composites at an elevated constant temperature of 70°C has been presented here at three stress levels. The Primary Creep was quite brief at all stress levels lasting less than 15 hours while the Secondary Creep stage dominated all creep curves at approximately constant creep rate. The creep rate was very low at the lowest stress level of 25MPa and was about 0.42 x 10^6 per hour, increasing to 0.77 x 10^6 per hour at 35MPa stress and 1.50 x 10^6 per hour at 40MPa.

Some indications of the transition from Secondary to Tertiary Creep were observed at 35 and 40MPa stress levels starting about 360 hours after the start of the creep test, but actual Tertiary Creep did not occur. The data in Table 1 and Fig. 2 summarize appropriate design and production information for Hand Lay-Up GRP composites.

Additional creep investigations are recommended, at other temperatures and stresses for more extensive design data on Hand Lay-up GRP composites for new generation composites for industrial applications.

LIST OF SYMBOLS AND NOTATION

A =A constant in the creep strain equation (1.1)
B =A constant in creep strain equation (1.1)
C =A constant in Primary Strain equation (2.2)
e = The base of the natural system of logarithms (=2.7182818284 .....)
K =A constant in the Secondary Creep equation representing the Secondary creep rate.
n = A constant in the Primary Creep Strain equation (2.2)
t = Time in hours (3600 seconds) in the creep strain equation.
ε = Total creep strain in milli-strain
ε_0=A constant in the secondary creep strain equation representing the point of e-axis where the Secondary Creep line would intersect the strain axis at time t = O.
ε_1 = Primary Creep strain in milli-strain
ε_2 = Secondary Creep strain in milli-strain
δ = Stress in Mega Pascals (10^6 *N/m*^{2}*).*

REFERENCES

1. Andrade, E.N. daC. On the Viscous Flow of Metal and Allied Phenomena. Proc. Roy Soc(London),A84,1910,P.1.
2. Chen, C.H and Cheng, C.H., *Micromechanical* Modeling of Creep Behaviour in *Praticle-Reinforced Silicone - Rubber Composites. Trans. ASME, Vol.* 64, December 1997, Pp 781 - 786.

3. Linsenmarul, D.R., Hybridization for Cost-effective Design. Proc. ASME Winter Annual Meeting on Composite *Materials* in *the Automobile* Industry, 1978.
4. Luo, H.A., and Wang, 0., Stress Concentration in an intermingled Hybrid Composite, Trans. ASME, *Vol.* 64, Dec. 1997, Pp. 38-742.

5. Laws, N. and McLaughlin, R., *Self*-consistent Estimates for the *Viscoelastic* Creep *Compliance* of Composite *Materials.* Proc. *Royal* Soc., London, England, 1978, A 359, Pp. 251 - 273.

6. Popovics, S., A Model for Deformation of Two-phase Composites under Load. Proc. int. Symposium on Creep and Shrinkage of Concrete. Math. Modeling (RILEM), ZP Bazant ed. Northwester Univ Evanston III 1986, Pp. 733-742.

7. Zhu, *X*, *Li,* z., Jin, *Y.,* and Shaw, W.J.D., Creep Behaviour of a Hybrid Fiber *(Glass-Carbon)* _ Reinforced Composite and its Application. Composite Science Tech., 50(4), 1994, Pp. 431 _ 439.

8. Morri, *T.,* Tanimoto, *T.,* Hirano, *T.,* Kiyosomi, K and Tsujii, *T., Weight* Changes of the Fiber - Matrix Interface in GRP Panels Immersed in Hot Water. Composites Science Tech. 50(3) 1994. *Pp.* 373 _ 379.

9. Toya, M., Aritomi, M., and Chosa, *A.,* Energy *Release* Rates for an Interface Crack Embedded in a Laminated Beam Subjected to Three - Point Bending. Trans. ASME, Vol. 64. June 1997, Pp. 375 _ 382.

10. Valentini, M., Serkov, *S.K.,* Bigoni, D., and Movchan, A.B., Crack Propagation in a Brittle *Elastic* Material with Defects. Trans, ASME, *Vol.* 66, March 1999, *Pp. 79* - 86.

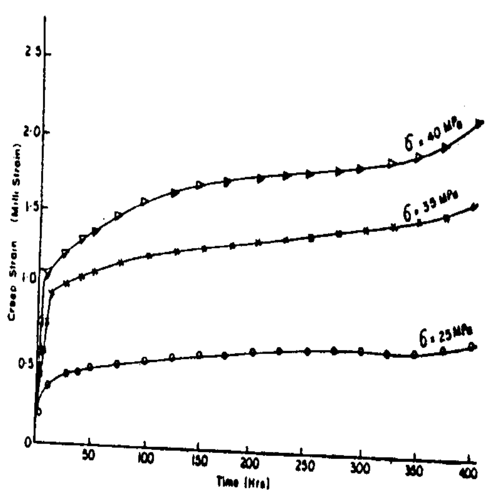

Fig. 2: GRP Creep Experimental Response

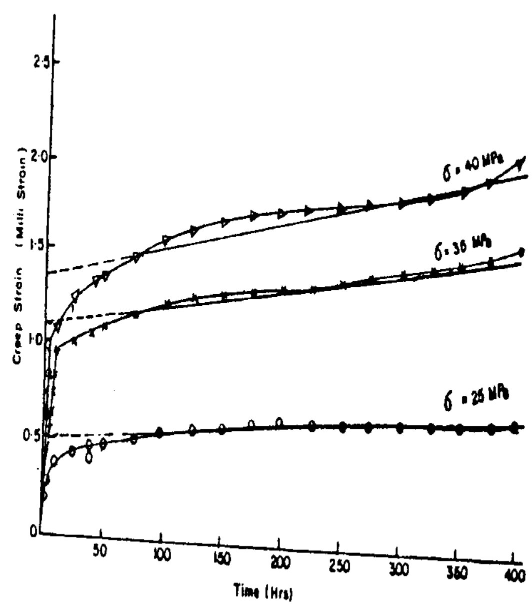

Fig. 3: Empirical Steady Creep Strain Rates Fitted on Experimental Courves