The Influence of Environmental Conditions on Creep Behaviour of Polymer Mortars

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ABSTRACT

The results of a study on the influence of environmental conditions on the creep behaviour of polymer mortars are presented. The compression creep behaviour is examined on six types of filled epoxy resins systems commonly used in the construction industry, using a simple spring-loaded system. The creep behaviours are examined at 10°C and 30°C with 45% and 60% RH. The creep behaviour at laboratory ambient condition is also included. Compressive strength results are also determined.

The results indicate that the composition of polymer influences the creep behaviour of polymer mortars. The influence of temperature is more significant than the humidity on the creep behaviour.

INTRODUCTION

The increasing used of epoxy resins in the structural engineering, as repair materials, has resulted in an increase in the number of investigations being performed. In particular if the resins are exposed to the extreme environmental conditions. The combined effects of sorbed moisture and the thermal environment can cause significant changes in the mechanical properties [1,2,3].

At present, epoxy resins are extensively being used as repair materials which act as part of the load bearing structures such as in column repair [4]. However, relatively few tests have been conducted on the behaviour of polymer mortars under sustained loading. When such research has been conducted, inconsistent results have been reported.

For example, Johnson [5] in his studies on the creep in epoxy resin joints in concrete prisms concluded that the creep of three of the four types of epoxy resin adhesives used was far less than those used in earlier test [6]. He found that if tertiary creep took place, it occurred between five and ten weeks after the first loading. In contrary to his results, Staynes [7] reported no tertiary stage creep in specimens loaded to 6000 psi (41.37 N/mm^2) for 90 days. Therefore establishing the creep understanding is of particular significance for distinguishing the properties needed when selecting type of epoxy resin system for structural or cosmetic repair.

Further studies have also shown that the environmental conditions, in particular the temperature, influence the engineering properties of polymer mortar composites [8]. For instance, thermosetting materials such as epoxy resins, below the glass transition temperature (Tg) the thermal energy is insufficient to activate movement of chain segments and it behaves like a 'glassy' solid, i.e. high modulus. Whereas above Tg, segments of the polymer chain are free to move because of thermal agitation and it behaves like 'rubbery' materials, i.e. relatively low modulus.

Boudraa [9] found that creep rate of epoxy resin concrete increases as the temperature rises above 20°C. Hugenschmidt [10] and Hancox and Minty [11] have also found that creep increases with increase in temperature. However, Johnson [12] has shown that, at 150 days, creep of specimens tested at 38°C was found to be less than those of specimens tested at 19°C. These findings reveal that creep of epoxy resins does not necessarily increase with temperature. It is therefore essential to investigate the influence of the environmental conditions on the creep behaviour of polymer mortars, which are extensively being used in repair works.

This paper reports the results of a laboratory study on the influence of environmental conditions on creep behaviour of polymer mortars. The short-term compression creep behaviour is examined on six types of filled epoxy resins systems commonly used in the construction industry. The creep behaviours are examined at 10°C and 30°C with 45% and 60% RH. The creep behaviour at the laboratory ambient condition (20°C and 65% RH) is also included. The compressive strength of the polymer mortars tested at the age of loading is also determined.

SIGNIFICANCE OF RESEARCH

The significance of this research is to establish a study on different types of epoxy resin systems presently available in the market and their effects on the creep behaviour of the polymer mortar particularly when loaded in compression. The effect would be more complex if the combined effects of temperature and humidity is taken into consideration. The result of this study provides data for determination of the critical parameters of the epoxy resin system during selection of polymer mortar as repair material, particularly for columns.

EXPERIMENTAL PROGRAMME

Materials and Mix Design

Six types of commercially available epoxy resins were used in this study. The polymer mortars were prepared and mixed according to the proportions specified by the manufacturers. Table 1 shows some informations on the composition of the epoxy resin systems used in the study.

Creep Apparatus

The creep tests were conducted using the compression creep apparatus designed to ensure the ability to maintain a constant known stress with a minimum of maintenance and subsequent manual adjustment. Furthermore the loading system has to be reasonably compact to make it possible to operate in a cabinet with controlled temperature and humidity. Figure 1 shows the simple spring-loaded system, which was adopted in this study.

Environmental Conditions

The environmental conditions used in this study were ambient condition and four environmental conditions of constant temperature and humidity. These four conditions were 10°C and 30°C with both 45% RH and 60% RH.

The climatic test cabinet used in this study consists of a chamber for the controlled temperature and humidity conditions and a refrigeration unit for providing condition of subzero temperature. The cabinet temperature range is from -20 to 100°C ± 0.1°C and the humidity range of 0 to 100 % RH ± 0.1% RH. The cabinet is capable of providing conditions of fixed temperature and humidity as well as conditions with cyclic temperature or humidity or both.

Compressive Strength

The compressive strength tests were carried out using specimens of 40 mm cubes in accordance with BS 6319 : Part 2 [13]. Three specimens were tested for each type of epoxy resin system used. The loading was applied at the rate of 45 N/mm^2 per minute.

Creep in Compression

Cylindrical specimens of 17.5 mm and 15.5 mm diameters were used in the compression creep tests for achieving the applied stresses of 10 N/mm^2 and

14 N/mm^2 respectively. Both the specimens were 100 mm in length. Three specimens were tested for each type of epoxy resin system at each set of the environmental condition. Prior to testing, the specimens were ground at both ends to obtain flat surfaces perpendicular to their sides. Demec studs were fixed on the sides of the cylinder at four equidistant points. The initial readings of the distant between the two demec studs were taken using the demec gauge of 50 mm gauge length before the specimen was loaded. The load was then applied by tightening down the nuts in a circular pattern, to ensure the uniformity of the load applied.

RESULTS AND DISCUSSION

Compressive Strength

The compressive strength and the density values determined in this study are presented in Table 2. Each value represents the average values obtained from three specimens originating from the same mix.

The results show that Type G polymer mortar possesses the highest compressive strength of 80 N/mm^2 and the lowest is Type L polymer mortar with 49 N/mm^2. Type C, Type E and Type H polymer mortars show similar compressive strength values of approximately 72 N/mm^2 while Type J exhibited a lower strength of 60 N/mm^2. These results, however, are 1.6 to 2.7 times higher than the typical compressive strength values of Portland cement mortar, which is 30 N/mm^2.

Type H and Type J polymers were manufactured using different binders but the same sand was taken in the same proportion of approximately 88.9% and 89.5% respectively. These two polymer mortars show a significant difference in their compressive strength values. This tends to suggest that the compressive strength of epoxy resin mortars, like ordinary cement mortars, is governed by their matrix phase in which both systems have different resin composition (Table 1). Bendeddouche [14] reported a similar finding when investigating the development of flexural strength of epoxy resin mortars.

The results also show that no correlation between the compressive strength values and the density values can be established. This observation is in agreement with that reported by Staynes [7]. Observations on the crack pattern of the failed specimens have shown that the mode of failure is similar to the typical pyramid pattern of failure, i.e. the brittle mode of failure.

Creep in Compression

The creep strain values reported in this paper are derived from the strain measurements taken at various ages starting from 10 minutes after the completion of the loading to 14 day age.

On each specimen, four strain measurements were recorded at each time, i.e. four opposite sides of the cylindrical specimen. Three specimens were used for each type of polymer mortar at each environmental condition.

The creep strain was derived from equation :

$$\varepsilon_c = \varepsilon_t - \varepsilon_e$$

Where:

ε_c = creep strain
ε_t = total strain
ε_e = elastic strain

The total strain (ε_t) was obtained from the recorded strain measurement while the elastic strain (ε_e) was assumed to occur during the application of the load.

Figures 2 to 10 show the creep behaviour of polymer mortars tested in this study. The curve represents the creep strain as well as the elastic strain. In general the creep behaviour of the polymer mortars tested at constant temperature and humidity produce curves of similar pattern as to the typical creep-time curve of ordinary concrete. However, some of the curves representing the creep behaviour tested at ambient condition (Fig. 2 and Fig. 7) tend to show the influence of variation of temperature or humidity or both on their creep behaviour. The results reveal that Type E and Type J polymer mortars are materials which have consistent creep behaviour in all the conditions adopted.

The results show that the creep of the polymer mortars tested increases slowly at 10°C with both 45% RH and 60% RH (Fig. 3 and Fig. 4). The only exception is for Type L polymer mortar, where under these conditions the creep is comparatively higher. On the other hand, the creep of all polymer mortars tested increases significantly at 30°C at both humidities (Fig. 5, 6, 9 and Fig. 10). This tends to suggest that the temperature have more influence than the humidity on the creep behaviour of polymer mortars.

The creep strain for most of the polymer mortars are highest at test condition of 30°C with 60% RH (Fig. 6 and Fig. 10). These results supported the conclusion of Clement [15] which states that the environmental characterisation is important particularly under 'worst state' conditions such as 'hot wet'. The creep strain at 14 days at working stress of 10 N/mm^2 with the above condition (Fig. 6) are 15.3 x 10^{-3}, 2.6 x 10^{-3}, 13.4 x 10^{-3} and 2.3 x 10^{-3} for Type C, Type E, Type G and Type J polymer mortars respectively. Other polymer mortars failed before the end of the period of testing. The creep strains for Type E and Type J polymer mortars at working stress of 14 N/mm^2 (Fig. 10) are 2.7 x 10^{-3} and 5.1 x 10^{-3} respectively.

Two modes of failures are observed on the failed specimens, i.e. crushing and shear failures. Both failures can be considered as local failure as they occur at a quarter of the way along the specimen. The local shear mode of failure had a similar pattern to the mode of shear failure in the compressive strength test using the cylindrical shape specimen.

Type H and Type J polymer mortars were made from epoxy resin systems with different binders, precisely with and without diluent, but the same sand was used with approximately same proportions. The results show that their creep behaviour varies significantly (Fig. 5, 6, 9 and Fig. 10). This tends to indicate that the creep behaviour of epoxy resin mortars is primarily governed by the composition of the epoxy resin system.

CONCLUSIONS

1. The composition of epoxy resin systems influence significantly on the compression creep behaviour and the compressive strength of polymer mortars.

2. The creep behaviour of polymer mortars is influenced by the environmental conditions. Temperature shows more significant effect than humidity on the creep behaviour.

3. Slower increase in creep strain at 10°C and faster rate of increment at 30°C indicate the importance of different formulation of epoxy resin system for different environment.

4. Creep is an important parameter in considering selection of epoxy resin system for repair material particularly in column repair at hot-humid environment.

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Table 1 Composition of epoxy resin system.

Type	Epoxy resin	Hardener	Diluent
C	Bisphenol A epichlorohydrin	Isophorone diamine	-
E	Diglycidyl ether of bisphenol A	Polyamide	Butyl glycydyl ether, aliphatic monoglycidyl ether, cresyl glycidyl ether nonpentyl glycol diglycidyl ether
G	Bisphenol A epichlorohydrin	Trimethyl hexamethylene diamine	-
H	Bisphenol A, bisphenol F mixture modified similar Type E	-	-
J	Bisphenol A, bisphenol F mixture unmodified	-	-
L	Cresyl glycidyl ether	Polyamide compounds	-

Table 2 Compressive strength at 7 days in ambient temperature.

Type	Density, x 10^{-3} (g/mm^3)	Compressive strength (N/mm^2)
C	2.07	72.06
E	1.88	73.19
G	2.11	80.44
H	2.07	72.03
J	1.92	60.35
L	2.03	48.88

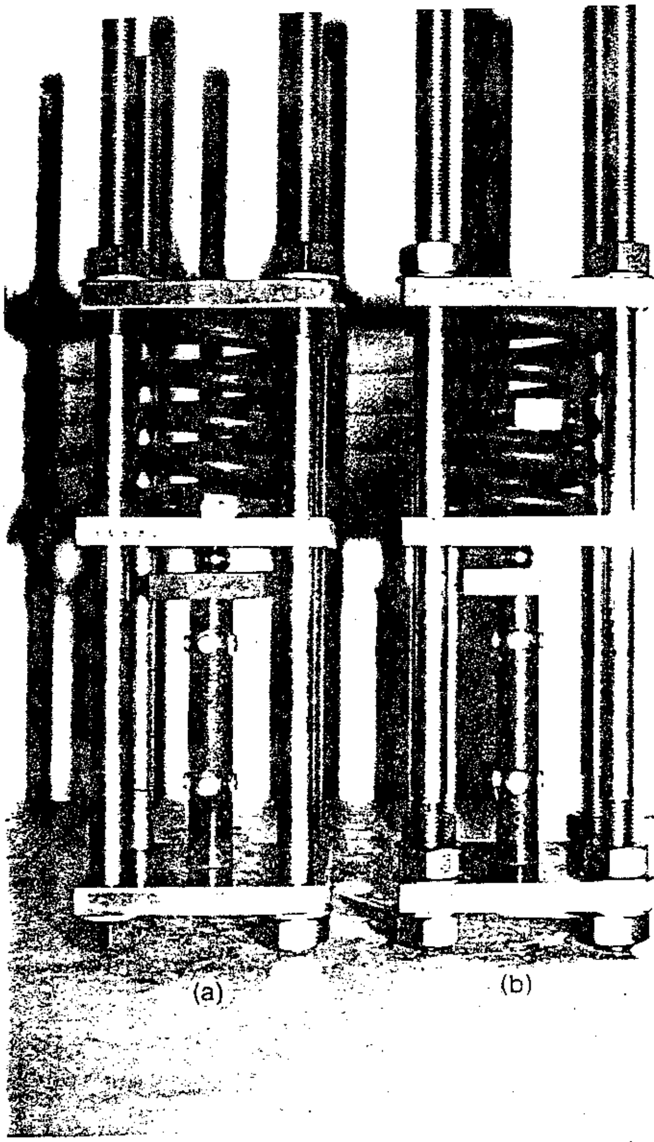

Fig. 1 A Simple spring loaded system
(a) Free bottom end plate
(b) Fixed bottom end plate

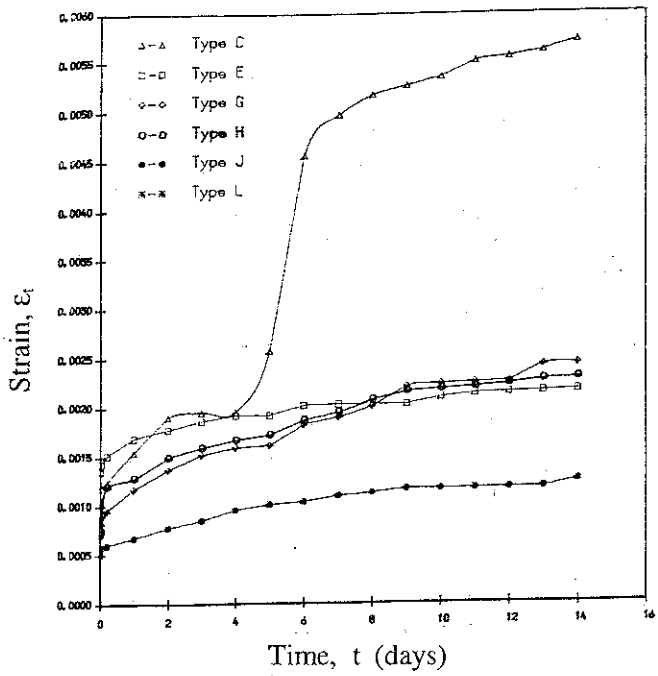

Fig. 2 Creep Behaviour of Epoxy Resins
($10\ N/mm^2$ @ Ambient)

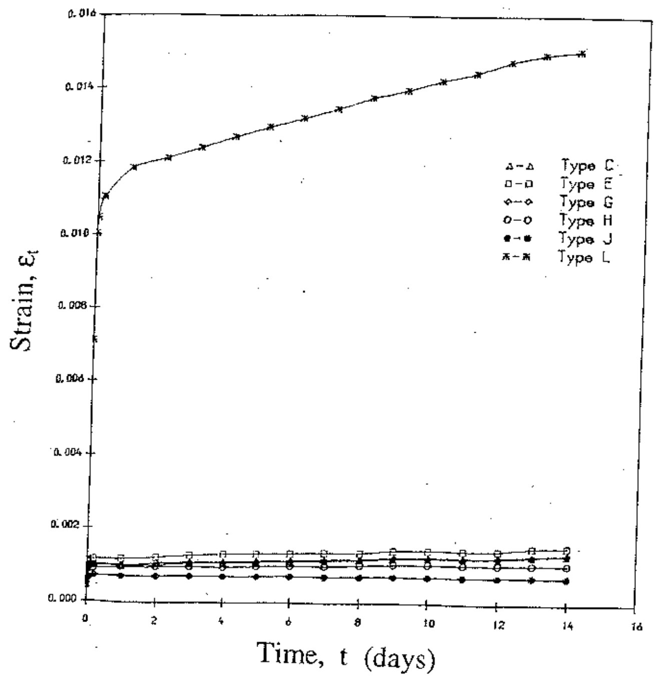

Fig. 3 Creep Behaviour of Epoxy Resins
($10\ N/mm^2$ @ 10°C, 45% RH)

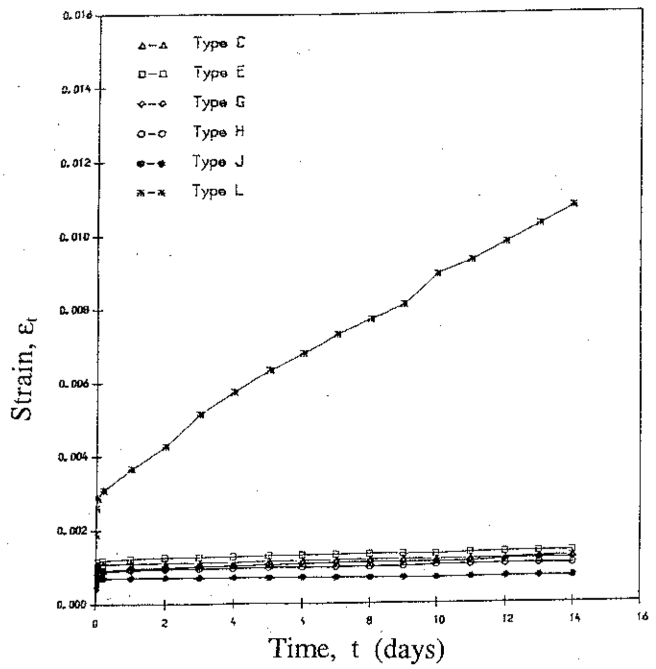

Fig. 4 Creep Behaviour of Epoxy Resins
(10 N/mm^2 @ 10^{o}C, 60% RH)

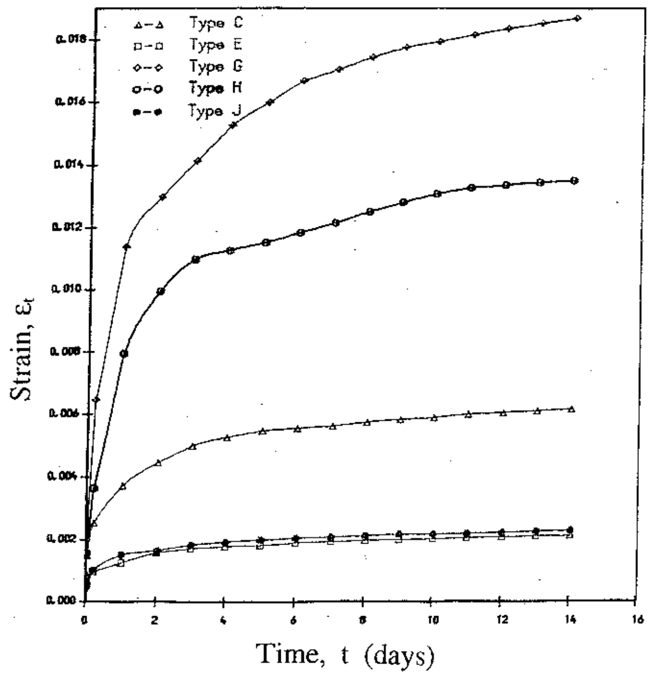

Fig. 5 Creep Behaviour of Epoxy Resins
(10 N/mm^2 @ 30^{o}C, 45% RH)

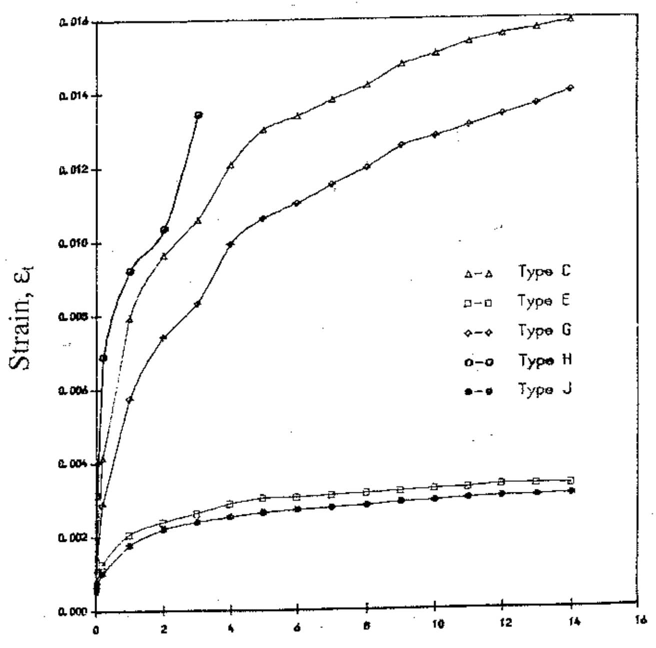

Fig. 6 Creep Behaviour of Epoxy Resins
(10 N/mm^2 @ 30°C, 60% RH)

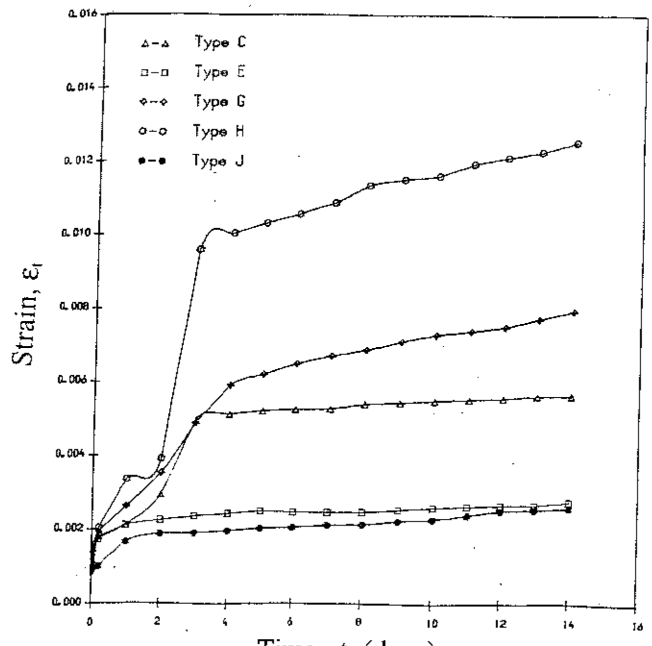

Fig. 7 Creep Behaviour of Epoxy Resins
(14 N/mm^2 @ Ambient)

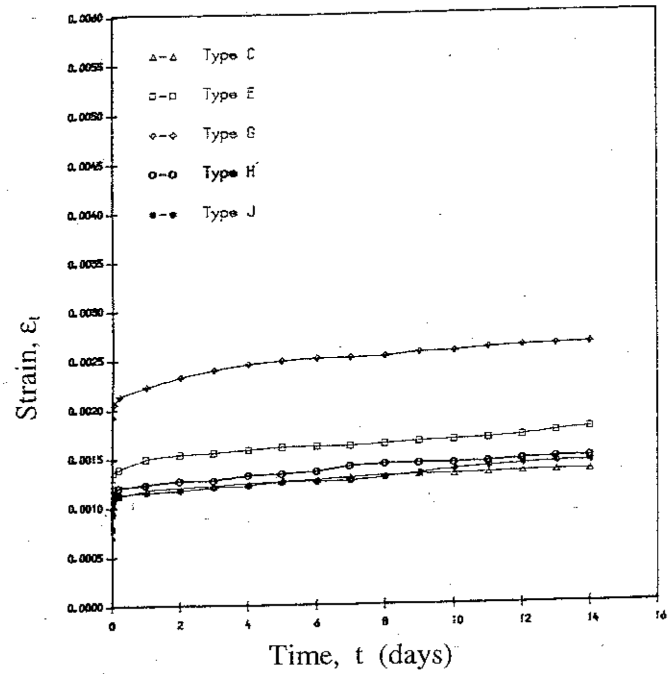

Fig. 8 Creep Behaviour of Epoxy Resins
(14 N/mm^2 @ 10°C, 60% RH)

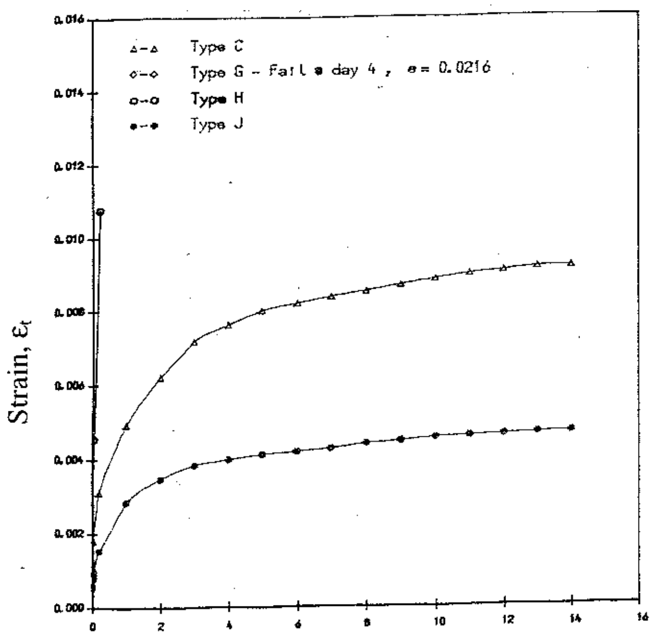

Fig. 9 Creep Behaviour of Epoxy Resins
(14 N/mm^2 @ 30°C, 45% RH)

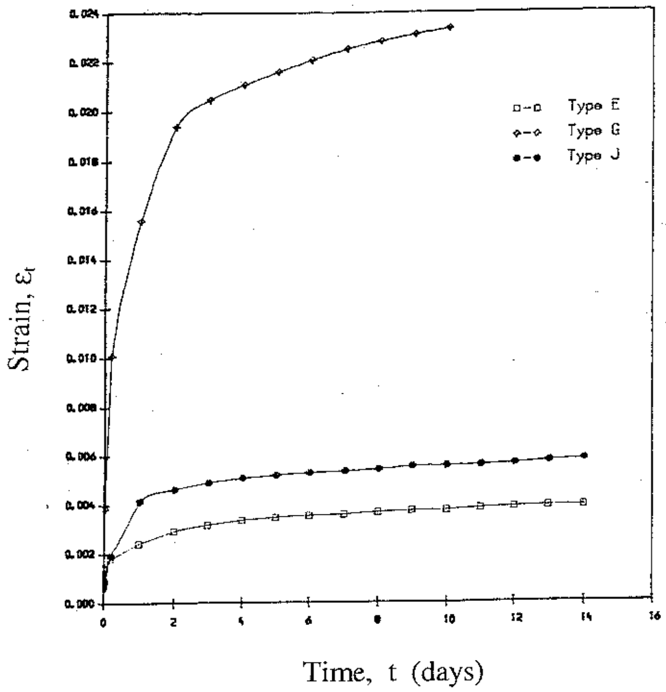

Fig. 10 Creep Behaviour of Epoxy Resins
($14\ N/mm^2$ @ 30°C, 60% RH)