Creep and Shrinkage Behaviour of Normal Strength Concrete

Nor Maslina Mohsan
Khalimi Johan Abd Hamid
Nurul Huda Suliman

ABSTRACT

This paper investigates the creep and shrinkage behaviour of normal strength concrete in the Malaysian environment. The tests carried out were creep test and shrinkage test. The grades of normal strength concrete used in this test were grade 25 and grade 30. The testing was performed in a condition of 80% relative humidity and temperature of 27 °C to represent the Malaysia environment condition. The creep was measured from the age of concrete loaded at 7 days with stress/strength ratio of 30%. The creep tests were performed in accordance with ASTM C512-87. Results showed that for grade 30 concrete, there was no significant difference in shrinkage between two maximum aggregate sizes as compared to grade 25 concrete. However, there was significant difference in creep between two maximum aggregate sizes for grade 30 concrete. Results also indicated that the higher shrinkage and creep were obtained for grade 30 concrete. The maximum aggregate size and cement content were found to influence the shrinkage and creep in this study.

Keywords: *creep; normal strength concrete; relative humidity; shrinkage*

Introduction

Concrete is the most widely used material in construction and forms the basis of modern society. Even with the development of high strength concrete to match the increasing height of buildings, the normal strength concrete is still a highly versatile material used in construction. It is important to understand the behaviour and properties of concrete include the time-dependent deformations due to creep and shrinkage. Numerous studies about the prediction of creep and shrinkage of normal strength concrete have been reported for example, by Bazant and Baweja (1994), Ojdrovic and Zarghamee (1996) and Kovler (1997). However, little has been done with reference to the Malaysian environment. The creep value recommended by MS 1995 is total adoption of BS 8110. Therefore the creep value recommended by this code of practice is with reference to the United Kingdom environment. This circumstance generates some uncertainties as to whether these values given by the code of practice are applicable to the concrete in the Malaysian environment.

Creep Deformation of Concrete

The increase in strain in concrete with time under a sustained stress is termed creep (Gambhir, 1995). As illustrated in Figure 1, if a specimen is drying while under load, it is usually assumed that creep and shrinkage are additive; creep is thus calculated as the difference between the total time-deformation of the loaded specimen and the shrinkage of a similar unloaded specimen stored under the same conditions through the same period (Neville, 1995). Creep and shrinkage however are interrelated because the strain-time curves are very similar and parameters affecting creep also affect shrinkage and there are related to the hydrated cement paste. Creep is often described in terms of the creep coefficient which is a ratio of creep to the elastic deformation on loading (Neville, 1995). Specific creep allows creep to be compared for different concrete specimens loaded at different stress levels; a typical value being 150 x 10^{-6}/MPa (Mindess et al., 2003).

There are two types of creep as suggested by Neville (1995). Basic creep is a phenomenon occurring under conditions of no moisture exchange with the ambient medium (i.e. a condition of hygral equilibrium) and often used to describe creep of concrete stored in water (Neville et al., 1983). The second type of creep is a drying creep that is the additional creep caused by drying. Drying creep is used to explain the observed excess of total creep at drying over basic creep, which means the component of concrete creep under conditions of no moisture movement to or from the ambient medium (Kovler, 1999).

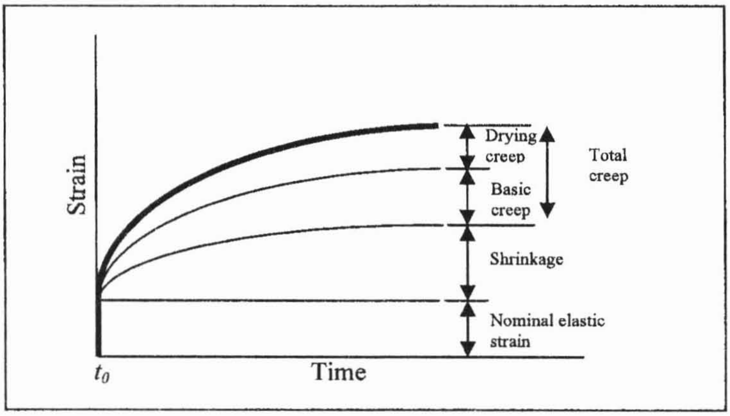

Figure 1: Creep of Concrete under Simultaneous Loading and Drying

Mechanism and Factors Influencing Creep

Under a compressive stress, the capillary voids structure of the hydrated cement paste are deformed and the water meniscus displaced outward to a point where the capillary diameter is larger so that the tension under which the capillary water is held is decreased. The tension in the capillary water rises and the compression in the solid phase increases to maintain equilibrium. The resultant deformation constitutes creep (Neville, 1970).

The seepage theory arises from the observation that hydrated cement paste is a rigid gel, and in such gels generally, load causes an expulsion of the viscous component from the voids in the elastic skeleton. Thus creep in concrete is taken to be due to seepage of gel water under pressure (Neville, 1970). Creep can also result from the diffusion of micropore water under stress. The thickness of the adsorbed water films that separate C-S-H particles depends on the relative humidity with which the system is in equilibrium. When the external stress is applied, the stress exerted on the water in the micropores is increased (Mindess et al., 2003).

The microcracking is responsible for only a part of the deformation associated with the sustained load that is creep (Neville et al., 1983). Mayers (1967) estimated that microcracking is responsible for 10% to 25% of the total creep deformation in compression while for creep in tension and creep under cyclic loading the contribution by microcracking is probably greater.

Plastic deformation is the result of slip along the plane of maximum shear in the crystal lattice. Glanville and Thomas (1939) suggested that creep at low stresses may be viscous and at high stresses in the form of crystalline slip. However, at very high stresses the deformation of concrete resembles somewhat plasticity (Neville, 1970). Viscous flow contributes in some measure to creep of concrete. Thomas (1937) considered concrete to consist of two parts, cementitious material and inert aggregate. When the concrete is loaded, the cement flow is resisted by the presence of the aggregate and as a result of this resistance the aggregate becomes more highly stressed while the stress on the cement paste decreased with time. Since the creep of cement paste is proportional to the applied stress, the rate of creep is progressively reduced as the load is transferred from the viscous to the inert material.

Factors influencing creep have been found to include stress and strength, concrete composition, water/cement ratio, curing history of the concrete, types of aggregate, ambient relative humidity and size of specimens.

Shrinkage Deformation of Concrete

Shrinkage is defined as an increase or decrease in a linear dimension of a test specimen that has been caused by any factors other than externally applied forces and temperature changes (ASTM C341, 1992). Shrinkage in concrete results when there is a gradual change in volume with a change in its adsorbed and intracrystalline water caused by drying out of concrete after casting (Akroyd, 1962). Shrinkage can be classified as plastic shrinkage and drying shrinkage. Plastic shrinkage is the contraction of concrete due to loss of water by evaporation and suction while the concrete is still in its plastic state (Akroyd, 1962). Drying shrinkage is a term generally reserved for hardened concrete where it represents the strain caused by the loss of water from the hardened material (Mindess et al., 2003). Han and Lytton (1995) considered drying shrinkage is strictly associated with moisture movement in concrete with water potential being the driving force for the moisture movement. There are two types of drying shrinkage. Autogeneous shrinkage occurs due to a process known as self-desiccate and it will only occur in a sealed or in dense concrete. Carbonation shrinkage occurs when hydrated cement reacts chemically with atmospheric carbon dioxide. It is greatest when carbonation occurs after drying rather than during drying except at low humidity (Mindess et al., 2003).

Mechanism and Factors Influencing Shrinkage

The three major shrinkage mechanisms are surface tension, disjointing pressure and hydrostatic tension in a capillary pore (Young 1982, Vos 1971, Nilson 1980). Surface tension or surface free energy depends on the amount of adsorbed water. Disjoining pressure is a pressure developed in a narrow place where adsorption is hindered. Hydrostatic tension is a pressure developed in a capillary pore when menisci are formed due to lost of water (Han & Lytton, 1995).

Factors influencing shrinkage have been found to include cement composition, aggregates, water/cement ratio, size and shape of specimens, curing regime and relative humidity.

General Climate of Malaysia

Malaysia lies near the Equator between the latitudes of 1° and 7° North and longitudes 100° and 119° East. Malaysia's climate is hot and humid all year round and the climate is dominated by the effect of two monsoons or "rainy seasons", which affect different parts of Malaysia to varying degrees. The temperature averages from 70° to 90° F (21-32°C) throughout the year. The annual variation is less than 2°C except in the east coast areas which are often affected by the North-East monsoon. Malaysia has high relative humidity ranging from 70% to 90% except in the highlands compared to UK with relative humidity ranging from 45 to 85 per cent for indoor and outdoor exposure (BS 8110: Part 2:1985). The range of mean monthly relative humidity of Malaysia varies from a minimum of 3% to a maximum of about 15% for any specific area.

Materials and Methods

Materials used in the experimental study were Ordinary Portland cement (ASTM Type 1), fine aggregates and crushed type of coarse aggregates of 10mm and 20 mm maximum size. Ordinary tap water was used as mixing water throughout the study. Concrete of characteristic strengths of 25 N/mm^2 and 30 N/mm^2 was design with 10 mm and 20 mm maximum aggregate sizes and cylindrical specimens of 100 mm in diameter and 200 mm in height was prepared. All specimens were cured in accordance with ASTM C192.

Cylindrical specimens were prepared for creep test of concrete in compression in accordance with ASTM C512. Four demec measurement points were fixed at 150 mm apart on four opposite sides of the concrete specimens prior to testing. The creep test was carried out using a creep test rig which was able to hold two concrete specimens in series. The sustained stress was applied by tightening the four tie rods as shown in Figure 2. Four measurements were recorded for each specimen in microstrains and the average of these measurements was used to calculate the total creep. Shrinkage was measured and creep tests were carried exactly at the same age of the concrete prepared and instrumented (see Figure 3).

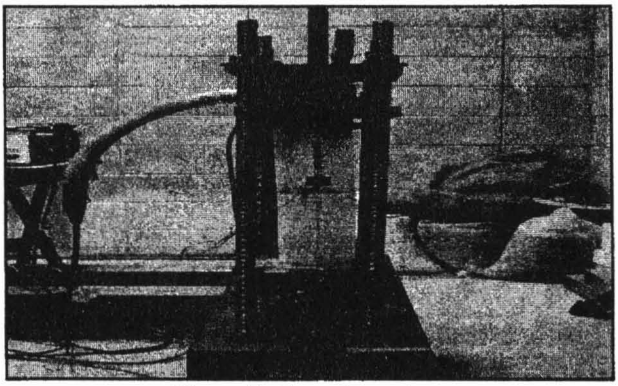

Figure 2: Creep Test rig

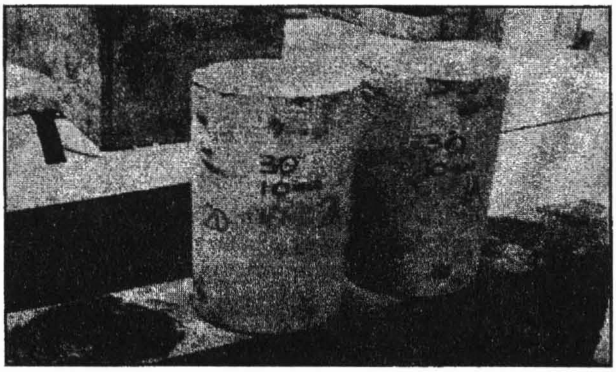

Figure 3: Specimens for Shrinkage Test

Results and Discussions

From this study, the values of total creep for normal strength concrete of Malaysian environment were obtained. Table 1 shows the abbreviations used in this paper. The results obtained in this study are shown in Figures 4, 5, 6, 7, 8 and 9.

Table 1: Abbreviation and Characteristic for Concrete Specimens

Concrete Characteristic/Abbreviation	G25/10	G25/20	G30/10	G30/20
Concrete grade	25	25	30	30
Maximum aggregate size (mm)	10	20	10	20
Water/cement ratio	0.56	0.56	0.54	0.54
Stress/strength Ratio (%)	30	30.6	29.9	30.3
Cylinder Strength at Loading (N/mm^2)	18.21	16.64	24.7	19.73
Slump (mm)	52	55	44	49

Shrinkage Test

Figure 4 indicates that there were measurable effects of maximum aggregate size to shrinkage for grade 25 concrete where the shrinkage value for 10 mm maximum aggregate size was larger compared to 20 mm. This trend was similar as mentioned by Akroyd (1962); to achieve minimum shrinkage, concrete should contain the maximum possible amount of large aggregate. However, for grade 30 concrete, there was no significant effect for maximum aggregate size as shown in Figure 5. The shrinkage values for grade 30 concrete were higher than grade 25 concrete for both maximum aggregate sizes. This may possibly be due to the higher amount of cement in the grade 30 concrete influencing shrinkage during hydration since the higher cement content promotes a faster rate of hydration resulting in more water loss. Similar trend was reported by Akroyd (1962), when the lower shrinkage resulting from a low water/cement ratio is balanced by the greater shrinkage due to the high cement content of the rich mix.

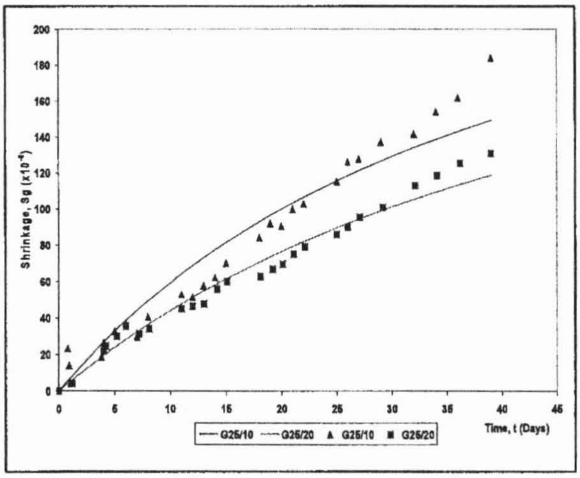

Figure 4: Shrinkage of Grade 25 concrete

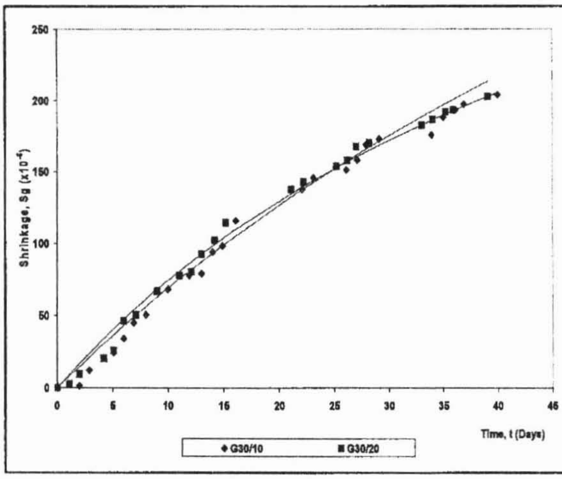

Figure 5: Shrinkage of Grade 30 concrete

Creep Test

Figures 6 and 7 show that for both concrete grades, the creep was slightly higher for concrete specimen of 10 mm maximum aggregate size as compared to 20 mm. There was significant effect for maximum aggregate size to concrete grades 30. This can possibly due to the higher resistance of the larger aggregate size for concrete specimen influencing creep. This trend was similar as mentioned by Akroyd (1962) that creep is reduced by using a large aggregate.

Figures 8 and 9 shows that, the creep is higher for concrete specimen grade 30 for both maximum aggregate sizes. There was measurable effect for cement content for grade 30 concrete. As mentioned above, one of the concrete creep mechanisms is a resultant deformation of capillaries structure of cement paste will constitute creep (Neville et al., 1983). The higher creep obtained for concrete specimen grade 30 can possibly due to more resultant deformation of capillaries structures of cement paste as compared to grade 25. This happened because of existence more cement paste in concrete specimen due to higher cement content for grade 30 as compare to grade 25. Neville (1970) mentioned that the higher cement paste content the higher the creep.

Hyperbolic expression was using as basic expression in this study because it gives the best fit to the experimental result throughout the testing duration. The best-fitted curves by the expression were given in equations [1] to [4]. The constant obtained from the hyperbolic expression were given in as follows:

G25/10	:	$C_r = t / (0.0133 + 0.0007t)$	[1]
G25/20	:	$C_r = t / (0.0169 + 0.0006t)$	[2]
G30/10	:	$C_r = t / (0.012 + 0.0004t)$	[3]
G30/20	:	$C_r = t / (0.012 + 0.0005t)$	[4]

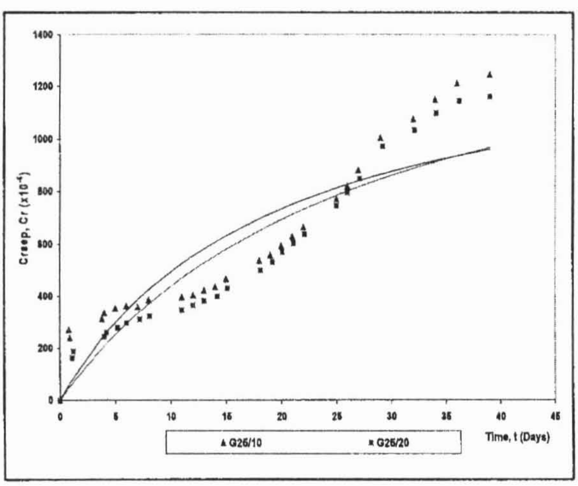

Figure 6: Creep of Grade 25 concrete

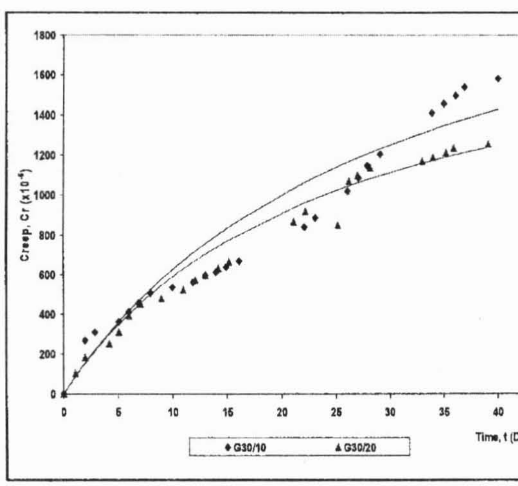

Figure 7: Creep of Grade 30 concrete

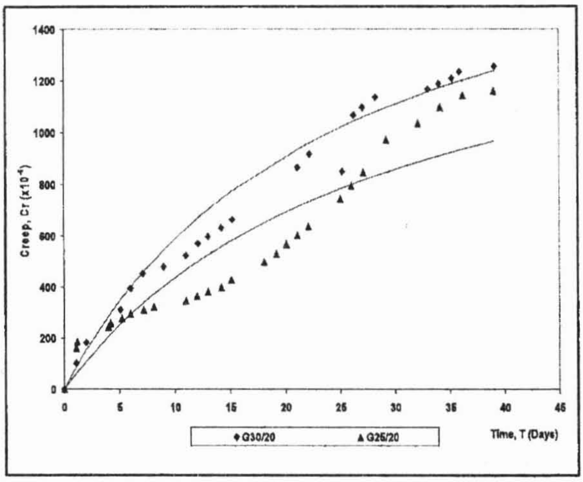

Figure 8: Creep of grade 25 and 30 concrete with an aggregate top size of 10 mm

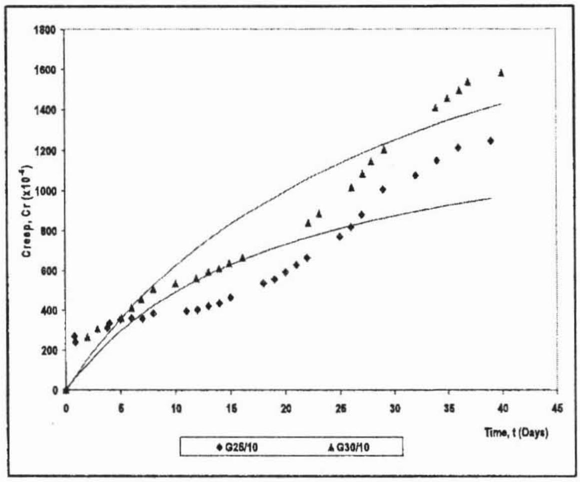

Figure 9: Creep of grade 25 and 30 concrete with an aggregate top size of 20 mm

Conclusion

From the results of this study, the following conclusions can be drawn:

1. There was measurable effect of maximum aggregate size to the shrinkage for grade 25 concrete but no significant effect for grade 30 concrete. There was also significant effect of cement content to the shrinkage for grade 30 concrete.
2. From the creep test, there was significant effect of maximum aggregate size and cement content to the creep value for grade 30 concrete but no significant effect for grade 25 concrete.

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NOR MASLINA MOHSAN & NURUL HUDA SULIMAN Faculty of Civil Engineering, Universiti Teknologi MARA Pahang. maslina252@pahang.uitm.edu.my

KHALIMI JOHAN B. ABD HAMID, Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang. khalimi@ump.edu.my