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Research Article

Effect of Change in Ambient Temperature on Creep of Concrete

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Keywords

*Creep of concrete,
Basic creep,
Drying creep,
Transitional thermal creep,
Transient creep,
Steady-state creep,
Temperature effect.*

Abstract

This article reviews the studies on the effect of temperature on the creep of concrete. Indeed, the temperature is one of the most important factors, as its rise leads to an acceleration of creep of concrete and thus an increase in its value compared to concrete under normal temperature. However, creep increases significantly if concrete under load is exposed to a high temperature. Thus, the creep value becomes higher than that of concrete exposed to a constant temperature (of the same level). Unfortunately, some of the codes for predicting creep of concrete (for instance the Eurocode) do not take into account the effect of high temperature on the creep of concrete under load. To clarify the impact of heating concrete under load (on creep) and distinguish it from its effect where it is constant, this study was carried out.

1. Introduction

The creep of concrete is a time-dependent deformation under a sustained load. It is an additional deformation to the initial elastic strain that happens upon load application. Creep can be classified into two types; basic creep and drying creep. Basic creep is the deformation that occurs in a sealed specimen, which does not undergo drying, i.e., no water movement out of the concrete specimen. Drying creep is the additional strain, which occurs due to drying (immigration of water out of the specimen) [1,2].

Other than the strains occur due to loading (initial and creep), the else strains must be taken into consideration i.e., shrinkage (due to drying) and thermal deformation (due to change in temperature). These deformations are evaluated from companion-unloaded specimens stored under conditions similar to those of the loaded ones.

Many factors influence the creep of concrete. A part of them is intrinsic which is related to the characteristics of materials that are fixed as soon as the concrete is cast. The other part is extensive that may change after casting due to external conditions [3].

As well, some of these factors have an inverse relation with creep, such as aggregate content [4], age of loading [5,6,7], the volume-surface ratio [8], and ambient relative humidity [9,10].

Other factors have positive relation with creep, like water-cement ratio [4], stress/strength ratio [11,12,13,14], temperature [7] and water content in cement paste at time of loading [15].

Among the previously mentioned factors, temperature is considered one of the most important one that affects the creep of concrete. The elevated temperature leads to an acceleration of creep of concrete i.e., increasing its rate, and thus augmenting its value. However, the temperature has different effects on concrete creep in terms of whether it is constant or whether it is applied while concrete is under loading. Indeed, creep increases highly when concrete under load is heated. This increase in creep could appear (for instant) due to the heating in nuclear reactor vessels, storage tanks of hot water, and the (subsequent) effect of high summer temperature on concrete loaded in winter.

To better understand the effect of change in ambient temperature on the creep of concrete, it was suggested to conduct this work by compiling the previous research about this subject.

2. The effect of time of heating with loading application on creep

As it is previously mentioned, it should be distinguished between the impact of high temperature on creep when it is constant and when it is raised while concrete is under load. Therefore, the selected researches in this study were divided into two groups. For the first one, the high temperature was constant while for the other group, it was elevated while concrete is under load.

2.1. Constant elevated temperature

One of the earliest studies about the influence of temperature on creep was that of De la Pena in 1959 [16]. He noted that creep of cement mortar specimens stored underwater i.e., basic creep, is proportional to temperature in the range of 0°C -50°C.

The effect of another range of temperature (21°C to 96°C) on the basic creep was studied by Nasser and Neville [17]. The concrete specimens were exposed to the temperature from the age of 1 day and upward. At the age of 2 weeks, the specimens were loaded to three loading levels (stress/strength ratio) of 0.35,0.6 and 0.7. The results revealed that creep rate increases with temperature rise, reaching a maximum value at 71°C. Conversely, when the temperature is raised above 71°C, the creep rate decreases with the increase in temperature. It is believed that this behavior is due to the desorption of the water from the surface of the gel. Hence, the gel itself becomes gradually the sole deformable phase. However, the creep pattern is the same for all temperatures.

In addition to sealed concrete, it was necessary to study the effect of temperature on unsealed concrete i.e. allow the drying creep to take place as well as the basic creep. Thus was the work of Nasser and

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Marzouk [18]. In their search, concrete specimens were heated to different temperatures ranging from 21°C to 232°C and then loaded at the age of 35 days. At each temperature, three stress/strength levels of 0.35,0.6 and 0.7 were applied. Like the previous work of Nasser and Neville [17] on sealed concrete, the relationship between creep and heat is direct up to 71°C and then becomes an inverse.

Another different work, Vyas et al. [19] studied the influence of three temperature levels of 100°C, 200°C, and 300°C on unsealed concrete. The concrete specimens were heated and then loaded as the temperature reached the desired value and sustained during loading. The stress/strength ratio was 0.3 for all the specimens. Like the previous studies, the results revealed that creep strain of concrete under sustained higher temperature is greater than that under lower one.

The effect of different temperature ranges between 140°C to 724°C, on the creep of unsealed pure cement paste, gravel, and light-weight concrete was done by Khoury et al. [20]. The load, of up to 0.66 of cold strength was applied after the specimens were maintained at constant temperature for at least 24 h before the age of loading. A sharp increase in creep for the gravel concrete was noticed above 350°C. It was caused by a break-up of the aggregate. However, a sharp increase in creep for both lightweight concrete and cement paste above 600°C occurred in the cement paste.

The effect of temperature on high performance concrete was also investigated by Vidal et al. [21]. They studied the impact of temperature on basic creep in the compressive direction of four types of high performance concretes (with and without, fibers and silica fume). The specimens were cured underwater (20°C) until the age of loading where the stress-strength ratio was chosen to be 0.3. Before loading, the specimens were heated, either to 50°C or to 80°C, and the temperature was preserved during the creep loading test. The results showed that at 50°C, creep strain was about twice of that obtained at 20°C (after 300 days of loading) while at 80°C, the creep value was multiplied by a value between 4.4 and 9.2 (after only 20 days of loading) (see Figure 1 and 2).

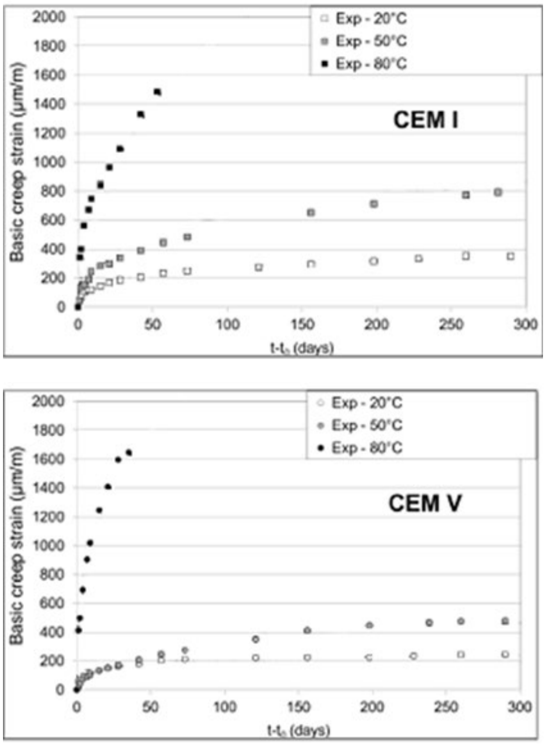
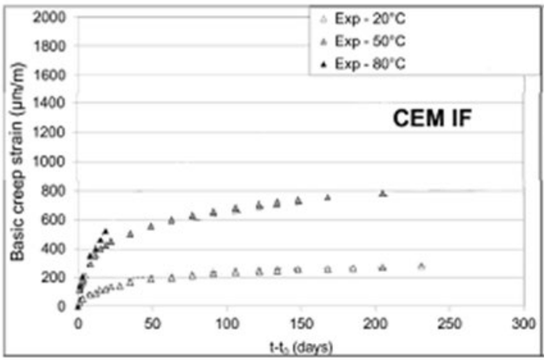
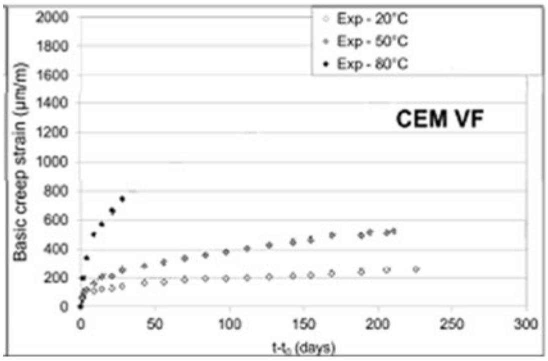


Figure 1. Basic creep for (a)CEM I and (b) CEM V at 20°C, 50°C and 80°C [21]



(a)



(b)

Figure 2. Basic creep for high performance cement: adding stainless fibers and silica fume to(a)CEM I and (b) CEM V at 20°C, 50°C and 80°C [21]

The effect of temperature on basic creep of concrete made of Portland blast-furnace slag cement at an early age (up to one week) was investigated by Ohashi et al. [22]. The impact of four constant temperatures of 20, 30, 40, and 50°C were studied. For each temperature, three compressive loading levels of 0.2, 0.3, and 0.4 were applied. The results revealed that for a given loading level, the specific creep (creep strain due to unit stress) increases as the temperature increases. The heating effect is clearly visible at 50°C since the specific creep of concrete under this temperature is much higher than that of concrete under lower temperatures.

It is clear from the previous researches that when the temperature is elevated before applying creep load and maintained constant thought the test lead to increase the creep strain whatever was the loading level. The mentioned researches about the effect of constant temperature are listed in Table 2.

Table 1. Summary of the presented researches about the creep of concrete under constant temperature

Research	Specimen Prsvn.*	Studied Temp. Range	Type of loading	Stress/ Strength
De la Pena [16]	Sealed	0-50˚C	Comp.	
Nasser and Neville [17]	Sealed	21-96˚C	Comp.	0.35,0.6,0.7
Nasser and Marzouk [18]	Unsealed	21-232˚C	Comp.	0.35,0.6,0.7
Vyas et al. [19]	Unsealed	25-300˚C	Comp.	0.3
Khoury et al. [20]	Unsealed	140-724˚C	Comp.	0.66
Vidal et al. [21]	Sealed	21-80˚C	Comp.	0.3
Ohashi et al. [22]	Sealed	20-50˚C	Comp.	0.2,0.3, 0.4

* Basic creep occurs in sealed concrete while drying creep occurs (as an additional component) in unsealed concrete.

2.2. Elevating temperature under loading

The previously mentioned researches concentrated on studying the effect of constant temperature throughout the whole period of loading on the creep, which is a case that rarely happens in normal conditions.

Hence, more important studies were done on the creep of concrete under varying temperatures. Interesting work was performed by Illston and Sanders [23,24]. They measured the shear creep of tube saturated mortar under a torsion load with maximum tensile stress at the external surface of the specimens of 0.67 N/mm2 which equals 0.16 of cylinder splitting strength. The specimens were subjected to variable temperature history, ranging from 20 °C to 94 °C.

From the acquiring results, it was noted that, while concrete is under load, if the temperature is raised for the first time, the rate of creep strain increases very highly. This increase in the strain was called transitional thermal creep [23,24].

Indeed, this creep component occurs when the temperature is elevated to a previously unattained level (neither before nor after applying the creep load). As well, the transitional thermal creep occurs rapidly during and immediately following a rise in temperature while it does not happen when the temperature is lowered or raised again to the same temperature level (Figure 3).

It was also mentioned that creep is composed of the components that occur at a constant temperature, i.e., the flow is irrecoverable while the delayed elastic component is recoverable. In addition, when the temperature is raised (for the first time), the transitional thermal creep takes place which was noted as an irrecoverable component [23,24].

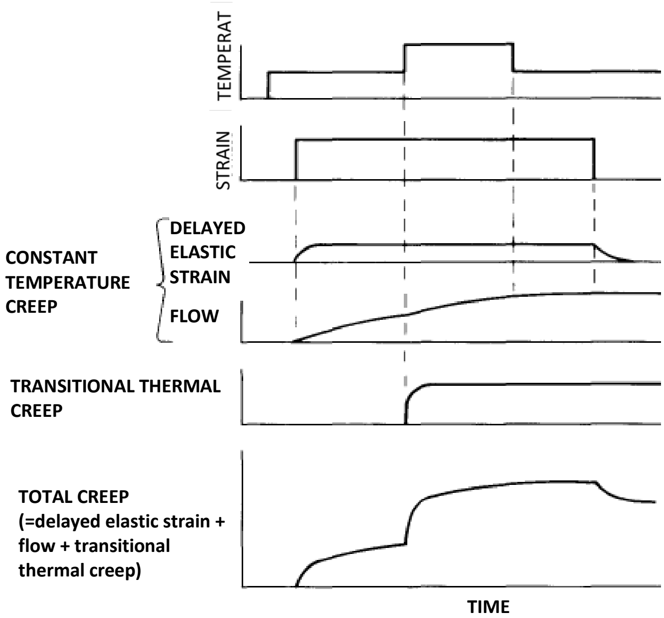


Figure 3. Diagrammatic summary of creep components under varying temperature [23,24]

Illston and Sanders [23,24] referred the transitional thermal creep as the perturbation that happens due to the temperature rise. Another explanation was presented by Bazant and Wittmann [25]. They stated that transient thermal creep could be related to the thermal gradient that takes place due to the temperature change, which is followed by a moisture gradient resulting in internal stress redistribution which changes the creep rate.

In fact, before Illston and Sanders [23], the effect of heating on concrete under load was studied by other searchers. Even though, the transitional thermal creep component was not characterized precisely, as the work of Fahmi et al. [26], where the effect of cyclic temperature on creep was investigated. They studied the creep of hollow cylindrical concrete specimens in compression and torsion, for stress/strength ratios of 0.3 and 0.4 respectively, and under a constant relative humidity of 50% and 100%. The specimens were subjected to either a cycle of (60-23-60) °C or sustained 60 °C temperatures. The results showed that an increase in creep was observed when the concrete was first heated to 60 °C, which agrees with the work of Illston and Sanders [23]. However, the increase in creep rate was related to the increase in the elastic strain with elevating in temperature due to a decrease in the concrete elastic modulus [26].

As well, the transitional thermal creep was studied by Hauggaard et al. [27]. The work investigated the effect of temperature on the basic creep of concrete under compressive load. The concept was to approach a state in a massive concrete structure with a time of heating followed by a time of cooling. Two groups of specimens were prepared with two loading levels of 0.24 and 0.29, for the first and the second group, respectively. The first group of specimens was kept at room temperature of 20 °C through the test while the second group, the temperature was elevated from 20°C to 40°C under the creep load, (see Figure 4).

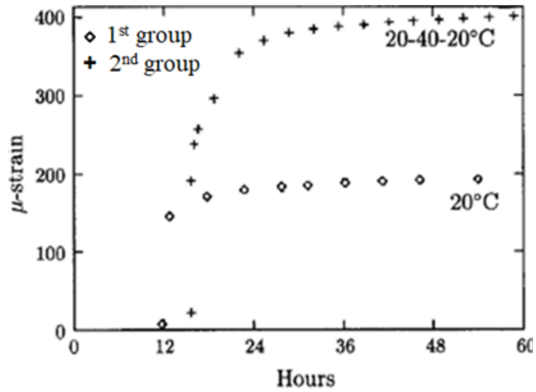


Figure 4. Creep of Concrete Subjected to Thermal Gradients [27]

It is clear from Figure 4 that the second group has a higher creep than the first group due to heating that caused the transitional thermal creep. On the other hand, the creep rate does not change when the temperature is decreased or re-elevated which conforms to the characteristic of transitional thermal creep component explained by Illston and Sanders [23,24].

It is worth mentioning that in the researches that were carried on drying creep, the term transient creep has been adopted (to represent transitional thermal creep and drying creep) [28]. Later on, the term “transient creep” was used in the literature for sealed and unsealed concrete to represent the increase in creep due to heating (concrete under load). However, the term “transitional creep” is still sometimes used for non-drying concrete [29].

Kammouna [30] studied the creep in compression of unsealed concrete exposed to ambient conditions similar to that of Baghdad climate. In winter, the average temperature is 21 °C and the R.H. is 50% while in summer, the average temperature is 42 °C and the R.H. is 23%. The applied loading level was varied between 0.26 and 0.3.

The results presented in Figure 5 revealed that at the beginning of loading (up to 20 days), the creep of concrete loaded in summer (series 2) is higher than that loaded in the winter (series 3). To represent the effect of summer later, after 20 days, the specimens of series 3 were heated. Thus, the transient creep component manifested itself and made the creep value of concrete loaded in winter (series 3) much higher than that loaded in summer (series 2).

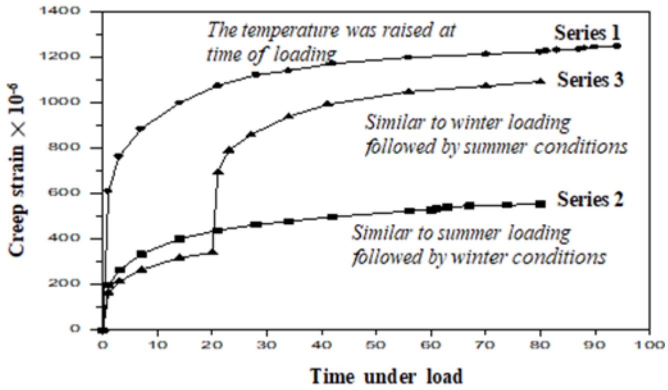


Figure 5. Comparison of the observed creep strain vs. time load for series 1, 2 and 3 [30]

On the other hand, it could be seen that the creep strain of series 3 approaches to the values of series 1 in which the temperature was elevated to 42 °C just after loading.

Another work on unsealed specimens was done by Lee et al. [31] where the creep of high strength concrete was studied. Three compressive strengths of 80,130 and 180 MPa were investigated. After applying the compressive creep load with a stress level of 0.25, the temperature was raised. A wide range of temperatures from room temperature to 700 °C. was adopted. Like the previous study on normal strength concrete, it was mentioned that the transient creep value increases with heating (for the three types of high strength concrete

The transient creep of alkaline activated concrete (also known as geopolymer concrete where the cement is rich in silica and alumina) was investigated as well, by Junaid et al. [32]. In their work, the temperature was raised to 100°C then the unsealed concrete specimens were loaded with stress equivalent to 0.18 of the ultimate strength. A non-linear deformation, which can be classified as steady-state creep (creep under constant temperature) [33], occurred and appeared to tend towards a stable slope. After 1.5 h, the temperature was raised again to another level of 200°C. The loaded specimens showed an increase in the strain which is associated with the temperature gradient (from 100°C to 200°C). Thus, it was concluded that similar to OPC, geopolymer concrete shows transient creep. As well, transient creep is much larger than steady-state creep (see Figure 6).

Another study on the transient creep of unsealed high-strength concrete was performed by Yoon et al [34]. In that study, three different high-strength concrete (three percentages of water-binder ratio, Nylon fiber, ground granulated blast furnace slag and fly ash) were used. The adopted stress/strength ratio was 0.33. To evaluate the temperature effect (on creep strain) where concrete is under load, the loaded specimens were heated up to 200, 400, 600, and 800°C. The results revealed that for all the concrete specimens, the value of transient creep is proportional to temperature. However, due to the development of cracks in the concrete exposed to 800°C, very high creep strain occurred in the specimens of the lowest strength and failure (during the test) in the outer specimens.

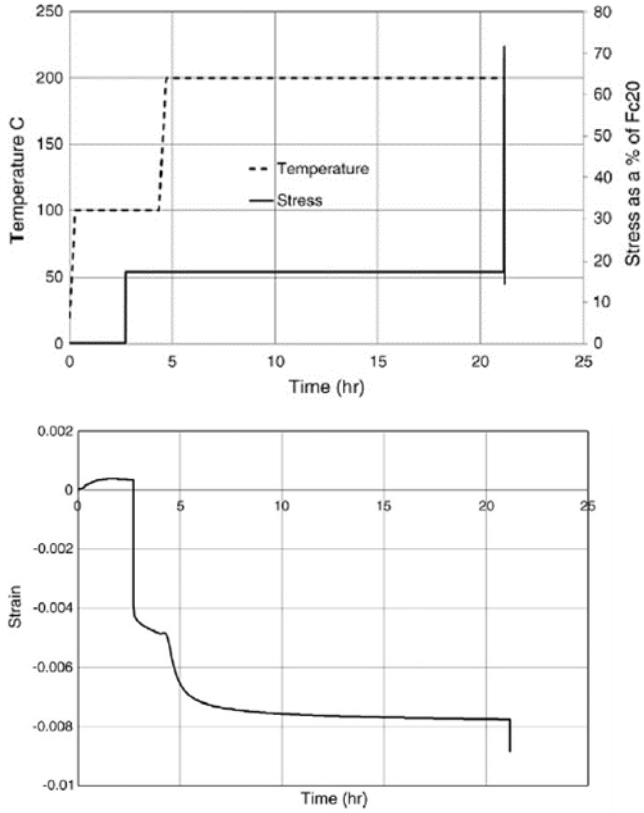
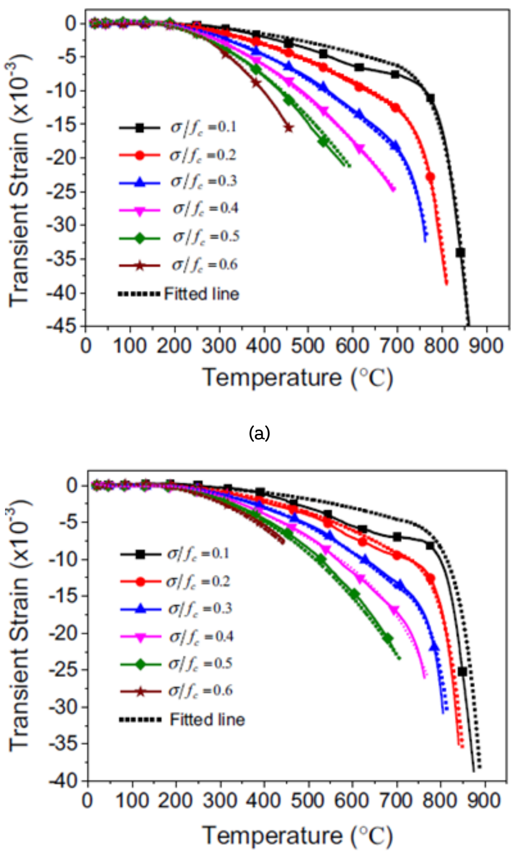


Figure 6. Evidence of transient creep of geopolymer concrete [32]

The transient creep of fiber reinforced concrete was also studied by Alogla et al. [35]. The study included four types of unsealed concrete; normal strength concrete (with and without steel fiber), and high strength concrete (with and without polypropylene fiber). A series of creep tests were performed using a wide range of loading levels (0.1,0.2,0.3,0.4,0.5,0.6 and 0.7) and temperatures (from 20°C up to 800°C). The results revealed that normal strength concrete shows higher transient creep than that with steel fiber, while high strength concrete reveals lower transient creep than that with polypropylene fiber. Indeed, this the last shows the highest transient creep of all the tested concrete types. It was also observed that the fast rate of heating speeds up the occurrence of the transient creep but its magnitude is less than that when a slow heating rate is applied (for a given temperature and stress levels).

Hou et al. [36] studied the transient creep of reactive powder concrete (including silica fume, slag and seclusions aggregate) reinforced with Polypropylene fiber for the first group, and with Hybrid Fiber (steel and Polypropylene) fibers for the second group. Before loading, the specimens were placed in an accelerated steam curing box at 90°C, and then in laboratory conditions and finally in an oven at 105 °C. Variant compressive creep loading levels of 10, 20, 30, 40, 50, and 60% were used in the study. For each loading level, the concrete specimens were exposed to a range of heating of 120, 300, 500, 700 and 900 °C.

The results reveal that transient creep of reactive powder concrete including Hybrid Fiber is higher than that including Polypropylene fiber. This was attributed to the fact that the thermal expansion coefficient of steel fibers is unequal to that of reactive powder concrete matrix (see Figure 7).



(a)

(b)

Figure 7. The transient creep of reactive powder concrete reinforced with (a) Polypropylene fiber (HRPC) and (b) with Hybrid Fiber (PRPC) [36]

The transient thermal creep of High Performance Concrete was studied by Cagnon et al. **[37].** Compressive loading level of 0.3 was applied on sealed creep specimens. Different chronologies of heating between 20°C and 40°C were used. The specimens were separated into two groups. The specimens of first group were heated just before loading while for the second group they were loaded and then heated. The transient creep occurred only in loaded then heated samples and not in those heated then loaded. This result confirms that transient creep occurs only when concrete under load is heated. This phenomenon was returned to the transient change of C-S-H viscoelastic behavior due to thermal dilation of the inter-sheet water visible only during a short period corresponding to the dissipation time of interlayer water overpressure.

As it was seen, all the mentioned studies confirm that transient creep has a significant value. Thus, the creep value becomes higher than that of concrete under a constant temperature (of the same level). Even though, some of the codes for predicting the creep of concrete, like Eurocode [38], do not take the transient creep into account as they compute concrete under constant temperature throughout the time of loading.

The mentioned researches about the effect of heating on concrete under load are listed in Table 2.

Table 2. Summary of the presented researches about the transient creep

Research	Specimen Prsvn.*	Temp.** Range	Type of loading	Stress/ Strength
Illston and Sanders [23,24]	Sealed	20-94°C	Torsion	0.16
Fahmi et al. [26]	Unsealed	23-60°C	Comp. and Torsion	0.3,0.4
Hauggaard et al. [27]	Sealed	20-40°C	Comp.	0.24,0.29
Kammouna [30]	Unsealed	21-42°C	Comp.	0.26,0.3
Lee, Y.W. et al [31]	Unsealed	20-700°C	Comp.	0.25
Junaid et al. [32]	Unsealed	100-200°C	Comp.	0.18
Yoon et al [34]	Unsealed	20-800°C	Comp.	0.33
Alogla et al. [35]	unsealed	20-800°C	Comp.	From 0.1 up to 0.7
Hou et al. [36]***	Unsealed	25-900°C	Comp.	From 0.1 up to 0.6
Cagnon et al. [37]	Sealed	20-40°C	Comp.	0.3

* Basic creep occurs in sealed concrete while drying creep occurs (as an additional component) in unsealed concrete.
** Adopted temperature range while concrete is under load.
*** The concrete was heated (up to 105°C) and then cooled to 25°C before loading.

3. Conclusions

From the previously mentioned studies, the following notes could drown:

a) Steady-state creep (creep of concrete under constant temperature) is higher under high temperature (≥40°C) than that under low temperature (≤25°C).
b) When concrete is exposed to high temperature for the first time under load, the transient creep component manifests itself which is significantly higher than the creep of concrete exposed to constant temperature (of the same level).
c) When the temperature is raised to an unattained level either in one step or in several steps, the value of the transient creep remains the same.
d) The magnitude of transient creep does not occur if the temperature is decreased or raised again to the same level.
e) As creep of concrete under constant high temperature is higher than that under constant low temperature, concrete loaded in summer shows higher creep than that loaded in winter.

However, concrete loaded in winter will show transient creep due to the high temperature of the next (summer) season. Thus, concrete loaded in winter finally shows higher creep than that loaded in summer (under constant high temperature).

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1.] Bazant, Z.P., Panula, L., Practical Prediction of Time-Dependent Deformations of Concrete Part (3)-Drying Creep, Materials and Structures, RILEM, 11 (1978) 415-434

[2.] Neville, A.M., Theories of Creep in Concrete, ACI Journal, 27 (1955) 47-60.

[3.] Bazant, Z.P., Wittmann, F.M., Creep and Shrinkage in Concrete Structures, A Wiley-Interscience Publication, (1982).

[4.] Neville, A.M., Brooks, J.J., Concrete Technology, Pearson Educated Limitted, 2nd Edition, London, (2010).

[5.] Atrushi, D.S., Tensile and Compressive Creep of Early Age Concrete: Testing and Modeling, Thesis Submitted to The Norwegian University of Science and Technology for Ph.D. Degree, Trondheim, Norway, (2003).

[6.] De Schutter, G., Degree of hydration based Kelvin model for the basic creep of early age concrete, Materials and Structures, 32 (1999) 260-265.

[7.] Neville, A.M., Properties of Concrete, Pearson Education Limited-England,5the edition, (2012).

[8.] Bryant, A.H., Vadhanavikkit, C., Creep, Shrinkage, - Size and Age at Loading Effects, ACI Materials Journal, 84 (1987) 117-123.

[9.] Troxell, G. E., Raphael, J. M., Davis, R. E., Long-time creep and shrinkage test of plain and reinforced concrete, ASTM Proceeding, 58 (1958) 1101-1120.

[10.] Zou, D., Liu, T., Teng J., Du, C., Li, B., Influence of creep and drying shrinkage of reinforced concrete shear walls on the axial shortening of high-rise buildings, Construction and Building Materials, 55 (2014), 46-56.

[11.] Paulson, K.A., Nilson, A.H., Hover, K.C., Long-Term Deflection of High-Strength Concrete Beams, ACI Material Journal, 88 (1991) 197-206.

[12.] Ranaivomanana, N., Multon, S., Turatsinze, A., Tensile, compressive and flexural basic creep of concrete at different stress levels, Cement and Concrete Research, 52 (2013).

[13.] Smadi, M.M., State, F.O., Nilson, A.M., Shrinkage and Creep of High-, Medium-, and Low-Strength Concrete, Including Overloads, ACI Materials Journal, 84 (1987) 224-234.

[14.] Zongjin, Li., Advanced concrete Technology, John Wiley and Sons, Inc., Hoboken, New Jersey, (2011).

[15.] Neville, A.M., Diliger, W., Creep of Concrete Plain, Reinforced and Prestressed, North-Holland, Publishing Company-Amsterdam, (1970).

[16.] De la Pena, C, Shrinkage and creep of specimens of thin section, RILEM Bulletin, (1959) 60-70.

[17.] Nasser, K.W., Neville, A.M., Creep of Concrete at Elevated Temperature, ACI Journal, Proceedings 62 (1965). 1567-1579.

[18.] Nasser, K.W., Marzouk, H.M., Creep of Concrete at Temperature from 70 to 450oF Under Atmospheric Pressure, ACI Journal, 78 (1981) 147-150.

[19.] Vyas, N.C., Kalani, M., Limay, R.G., Creep of Concrete at Different Temperatures, Indian Concrete Journal, (1979) 190-195.

[20.] Khoury, G.A., Dias, W. Ps, Sullivan, J.E., Deformation of Concrete and Cement Paste Loaded at Constant Temperature from 140 to 724°C, Materials and Structures, RILEM, (19) (1986) 97-104.

[21.] Vidal, T., Sellier, A., Ladaoui, W., Bourbon X., Effect of temperature on basic creep of high performance concretes heated between 20°C and 80°C, Third International Conference on Sustainable Construction Materials and Technologies, Japan, (2013).

[22.] Ohashi, K., Arai, J.-I., Mizobuchi, T., Study on estimation of creep behaviour of concrete at early age considering temperature effect, 7th International Conference on Concrete Repair, 289 (2019)

[23.] Illston, J.M., Sanders, P.D., The Effect of Temperature Change Upon the Creep of Mortar under Torsional Loading, Magazine of Concrete Research, 25 (1973) 136-143.

[24.] Illston, J.M., Sanders, P.D., Characteristics and Prediction of Creep of a Saturated Mortar under Variable Temperature, Magazine of Concrete Research, 26 (1974) 169-179.

[25.] Wittmann F.H., Creep, shrinkage mechanisms, in: Bazant Z.P., Wittmann F.H., Creep and Shrinkage in concrete Structures, Wiley, (1982) pp. 129-161.

[26.] Fahmi, Hani. M., Polivka, M. , Bresler, Effects of sustained and cyclic elevated temperature on creep of concrete , Cement and Concrete Research, 2 (1972) 591-606.

[27.] Hauggaard, A.B., Damkilde, L., Hansen, P.F., Transitional thermal creep of early age concrete, Journal of Engineering Mechanics, 125 (1999) 458- 465.

[28.] Khoury, G. A., Grainger, B. N., Sullivan, P. J., Strain of concrete during first heating to 600 °C under load. Magazine of Concrete Research, 37, (1985), 195–215.

[29.] Rilem, T. C., 129-MHT, Test methods for mechanical properties of concrete at high temperatures. Recommendations: Part 7: Transient creep for service and accident conditions, Materials and Structures 31 (1998).

[30.] Kammouna, Z., Development of a mathematical model for creep of concrete with reference to Baghdad Climate, Thesis Submitted to University of Baghdad for M.Sc. Degree, Baghdad, Iraq, (2001).

[31.] Lee, Y.W., Kim, G.Y., Gucunski, N., Choe, G.C., Yoon, M.H., Thermal strain behavior and strength degradation of ultra-high-strength-concrete, Materials and Structures, 49 (2015), 3411–3421.

[32.] Junaid, M.T., Khennane, A., Kayali, O.,Sadaoui, A, Picard, D. , Fafard, M, Aspects of the deformational behaviour of alkali activated fly ash concrete at elevated temperatures, Cement and Concrete Research, 60 (2014) 24-29.

[33.] Rilem T.C., 129-MHT, Test methods for mechanical properties of concrete at high temperatures: Part 8 Steady-state creep and creep recovery for service and accident conditions, Materials and Structures, 33, (2000), 6-13.

[34.] Yoon M, Kim G, Kim Y, Lee T, Choe G, Hwang E, Nam J., Creep behavior of high-strength concrete subjected to elevated temperatures, Materials, 10, (2017), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5551824/?report=classic.

[35.] Alogla, S.M., Kodur, V., Temperature-induced transient creep strain in fiber-reinforced concrete in the range 20°C–40°C, Cement and Concrete Composites 113 (2020)

[36.] Hou, X., Abid, M., Zheng, W., Hussain, R. R., Effects of Temperature and Stress on Creep Behavior of PP and Hybrid Fiber Reinforced Reactive Powder Concrete, International Journal of Concrete Structures and Materials, 13, (2019), https://doi.org/10.1186/s40069-019-0357-9

[37.] Cagnon, H., Vidal, T., Sellier, A., Bourbon, X., Camps, G, Transient Thermal Deformation of high performance concrete in the, Cement and Concrete Research, 116 (2019)

[38.] Eurocode 2, Design of concrete structures – Part 1-2: General rules – Structural fire design, Brussels: European Concrete Platform, (2004)

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