EXPERIMENTAL STUDY ON CREEP OF NEW CONCRETE MIXTURES

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ABSTRACT

The aim of this study was to experimentally investigate the creep behavior of developed concrete compositions in order to evaluate the possibility of using glass powder and small clay particles as active additives in concrete by replacing cement. Several concrete mixes were designed and prepared, then 160x40x40mm specimens of each batch were made and tested. The specimens were subjected to a uniform compression load kept constant over a long period of time in a constant room temperature and with a constant level of moisture. The specimens were hardened in two extreme environments: in one case there was 100% humidity provided by protecting the specimens from desiccation and in the other case the specimens were air-dried and protected from any moisture. The compression strength and modulus of elasticity of the developed concrete mixes were determined and compared with those of the reference concrete.

Keywords: creep, lamp glass powder, small clay particles, compression strength**,** modulus of elasticity

INTRODUCTION

In the design of concrete structures, the two main design objectives are strength and serviceability. A structure must be strong enough and sufficiently ductile to resist, without collapsing, the overloads and environmental extremes that may be imposed on it. It must also perform satisfactorily under the day-to-day service loads without deforming, cracking or vibrating excessively (Gilbert et al., 2011). Formulation of creep and relaxation models has been ongoing from more than hundred years. In the case of concrete, elastic behaviour of concrete was taken for granted for a long time. However, in 1907 Hatt wrote an article on a test performed on reinforced concrete beams subjected to constant load. Hatt discovered that the deflection increased significantly with time (Westman, 1999).
Creep of concrete originates in the hardened cement paste that consists of solid cement gel containing numerous capillary pores. The cement gel is made up of colloidal sheets of calcium silicate hydrates separated by spaces containing absorbed water. Creep is thought to be caused by several different and complex mechanisms not yet fully understood. (Neville et al., 1983) identified the mechanisms for creep. Recent research relates the creep response to the packaging density distributions of calcium-silicate-hydrates. At high stress levels, additional deformation occurs due to the breakdown of the bond between the cement paste and aggregate particles. (Gilbert et al., 2011; ACI Committee 209, 2008; Neville, 1995; Neville, 1970; Neville et al., 1983; Bazant et al., 1983; Gilbert, 1988; Vandamme et al., 2009).
Therefore, designers and engineers need to know the creep properties of concrete and must be able to take them into account in the structure analysis. After all, the end product of an engineer's endeavours is a structure the strength of which is adequate, but not wastefully excessive, the durability is commensurate with the conditions of exposure, and serviceability ensures fitness for the purpose. Consideration of creep is a part of a rational approach to satisfying these criteria. Deformation characteristics of materials are an essential feature of their properties, and a vital element in the knowledge of their behaviour. After all, it is the subject that matters: creep is important if its deformation increases with time under a constant stress (Neville et al., 1983).
In the last few years it has been recognized that one of the main sources of environmental pollution is waste. It has become a major environmental problem because many types of waste do not break down, that is, essential physical, biological and chemical changes do not take place. One of the possibilities of utilizing waste is recycling, which would not only save natural resources, but also decrease the amount of deposited waste. Glass waste requires recycling. Since there are different types of glass with different chemical compositions, there are also different possibilities of its use.
In accordance with the decision of the European Committee, all simple incandescent lamps are to be replaced by fluorescent lamps until 2012, therefore, after a couple of years the problem of their recycling and utilization will become more severe (Korjakins et al., 2010).

One of the solutions would be to recycle the lamp glass by using it in concrete production, where it can partly replace fine sand or cement and thus help create a new construction material. Using lamp glass powder (LGP) in concrete is an interesting possibility for economy on waste disposal sites and conservation of natural resources (Mageswari et al., 2010).
One of the main constituents of the reference concrete is cement. Every year approximately 2.35 billion tons of cement are produced — that is almost 1 m^3 of cement for every person in the world. The carbon dioxide released into the atmosphere during the cement production process accounts for approximately 5-10% of the overall CO_2 production in the world. Its release into the atmosphere contributes to the global warming and the development of holes in the ozone layer. If the CO_2 production in cement factories could be decreased by 10%, the overall release into the atmosphere would decrease by 5.2%.
The use of waste glass and small clay particles in concrete production can make the construction industry more environmentally friendly.

MATERIALS AND METHODS

One of the goals of the experiment was to find out whether the new concrete composition can be competitive and whether its physical and mechanical properties are equivalent to those of the reference concrete. The object of this experimental study was concrete made with lamp glass powder (LGP) obtained from fluorescent lamp waste and concrete made with small clay particles (SCP) partially replacing cement. The other raw materials used for this study were natural coarse aggregate, fine aggregate and normal cement CEM I 42.5 N (Kunda).
The experiment consisted of replacing cement with lamp glass powder (LGP) in amounts of 0, 20 and 40 per cent and small clay particles (SCP) in amounts of 1per cent of the total cement volume. Standard sample cubes of 100x100x100 mm were produced in order to investigate the mechanical characteristics of the material. Concrete mixtures were cast into oiled steel moulds and compacted at the vibrating table. After two days the moulds were removed. Standard hardening conditions (temperature +20 ± 2 °C, RH > 95%) were provided. After the hardening period, the specimens were measured and tested in standard conditions. Their compression strength was determined in conformity with LVS EN 12390-3:2002. A testing machine with accuracy +1% was used, and the rate of loading was 0.7 MPa/sec.
Creep experiments were carried out on prismatic 40x40x160 mm specimens that had been weighted both before and after the test.
The creep (time-dependent strain) was measured in hardened concrete` specimens.
Consider a point in a concrete specimen subjected to a constant, sustained compressive stress σ_{c0} applied at time τ_0 and equal to 40 per cent of the characteristic compressive strength of concrete, i.e. $\sigma_{c0}= 0.4\ f_c$. The load was applied gradually in 4 steps and as quickly as possible.
The instantaneous strain that occurs immediately upon application of the stress may be considered to be elastic at low stress levels, and therefore:

$$\varepsilon_{e(t)} = \sigma_{c0} / E_{c(\tau 0)} \qquad (1)$$

where $E_{c(\tau 0)}$ is the elastic modulus at time τ_0,
$\varepsilon_{e(t)}$ is the instantaneous strain,
σ_{c0} is the compressive stress.

The capacity of concrete to creep is usually measured in terms of the creep coefficient, $\square_{(t,\tau)}$. In a concrete specimen subjected to a constant sustained compressive stress, $\sigma_{c(\tau)}$,first applied at age τ, the creep coefficient at time t is the ratio of the creep strain to the instantaneous strain and is given by:

$$\square_{(t,\tau)} = \varepsilon_{cr(t,\tau)} / \varepsilon_{e(\tau)} \qquad (2)$$

where $\square_{(t,\tau)}$ is the creep coefficient,
$\varepsilon_{cr(t,\tau)}$ is the creep strain,
$\varepsilon_{e(\tau)}$ is the instantaneous strain (Gilbert *et al.*, 2011).

At the beginning of the test, the specimens were 51 and 57 days old. They were kept under constant load for 90 days. The tests were conducted in two extreme conditions. In one case no moisture exchange with the environment was permitted, which was ensured by protecting the specimens against desiccation, and in the other case drying was permitted under conventional conditions, by protecting the specimens against moisture (Rilem TC 107-CSP, 1998).
In this paper these batches shall be called Reference (dry), Reference (moist), 20% LGP (dry), 20% LGP (moist), 40% LGP (dry), 40% LGP (moist), SCP (dry) and SCP (moist)". In order to prevent humidity exchange between the specimen and the environment, the surface of the specimens was coated with two protective silicone layers.

Figure 2. Specimens with aluminium plates.

Before this sealing, four steel plates were centrally and symmetrically glued onto two sides of the test prism in order to provide a basis for the strain gauges (see Fig. 2).

The distance between two plates was 50 mm. Two +/-0.01 mm precision strain gauges were symmetrically connected to each specimen, and then the specimens were put into a creep lever test stand and loaded (see Fig. 3).

Figure 3. Specimens in the creep lever test stand

They were kept in dry atmosphere of controlled relative humidity in standard conditions: temperature 23 ± 1ºC and relative humidity 25 ± 3%.

RESULTS AND DISCUSSION

Strength tests were carried out on the cubes after 7, 28, 42 and 58 days (see Table 1) of hardening in standard conditions. The various compression strengths of concrete specimens in different ages containing LGP and SCP were then compared to those of the reference concrete specimens.

Table 1

Compression strength of concrete compositions

Specimen	Age, days	Compression strength, MPa
Reference	7	55
Reference	28	63
Reference	58	71
20% LGP	7	42
20% LGP	28	60
20% LGP	58	70
40% LGP	7	32
40% LGP	28	55
40% LGP	58	65
Reference	7	59
Reference	42	40
SCP	7	89
SCP	42	60

The concrete containing a LGP showed lower strength in the first 7 days, but on the 28th and 58th day the strength increased and was very similar to that of the reference concrete. The specimens with 40% LGP showed 103% increase of the compression strength, while the specimens with 20% LGP showed 66% increase of the compression strength. The reference specimens, however, showed only 30% increase of the compression strength. Fine lamp glass powder caused a long-term hardening effect (see Fig. 4).

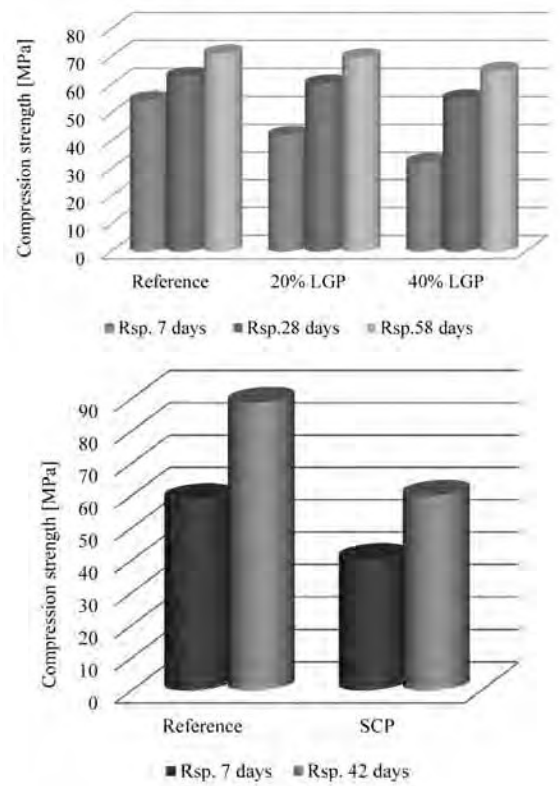

Figure 4. Compressive strength of new concrete mixtures at different ages [MPa].

In the first 7 days, the strength showed by concrete containing SCP was lower than the reference concrete strength by 31.4% and on the 42nd day the strength was lower by about 32.4%. The specimens with SCP showed 48.5% increase of the compression strength, but the reference specimens showed 50.8% increase of the compression strength (see Fig. 4).

The modulus of elasticity (see Fig. 5) was determined by measuring the deformations on the sides of the specimens according to Hooke's law. For the reference concrete the difference between the specimens hardened in moist and dry conditions is approximately 2.8%. For the specimens with 20% LGP this difference is approximately 12.4% and for the specimens with 40% LGP it is 27.4%. The comparison of the modulus of elasticity of the reference concrete specimens and the specimens with 40% LGP shows that for the specimens hardened in moist conditions this difference is 11.7%, while for the specimens hardened in dry conditions it is 32.6%.

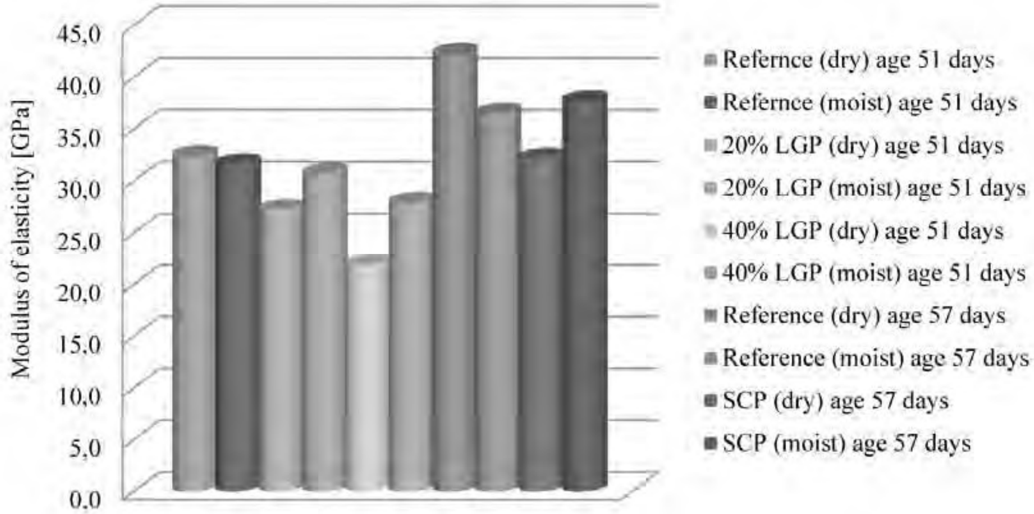

Figure 5. Elasticity modulus of different concrete.

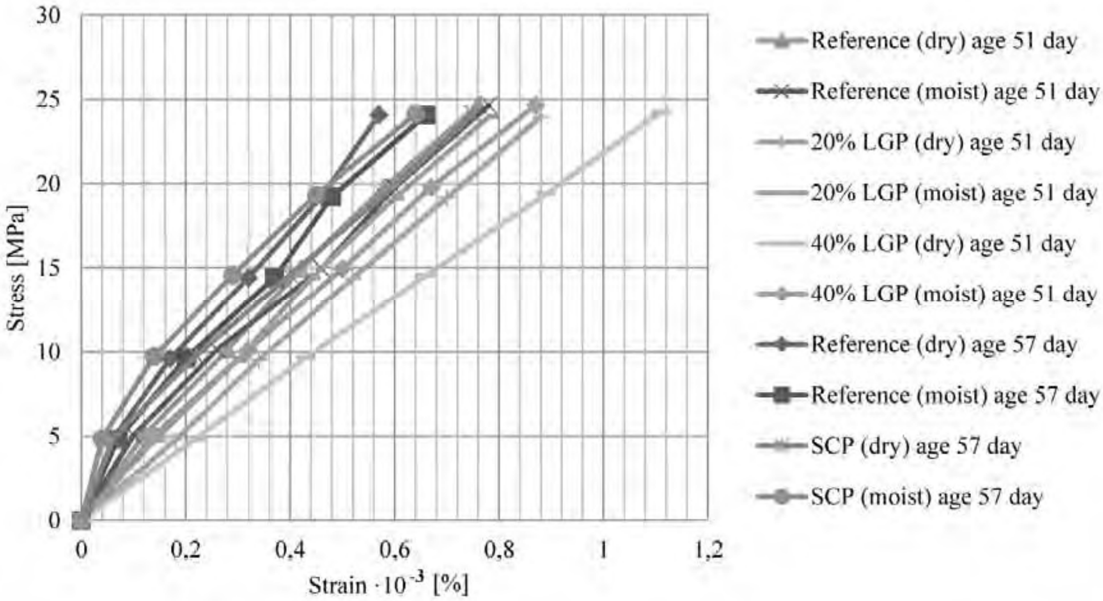

Figure 6. Relation between stress and strain..

The corresponding differences between the reference concrete specimens and the specimens with 20% LGP is 2.9% and 16.3% respectively.

For the reference concrete and the specimens with SCP this difference between the specimens hardened in moist and dry conditions is approximately 17% and 16% respectively (see Fig. 5). The comparison of the modulus of elasticity of the reference concrete specimens and the specimens with SCP shows that for the specimens hardened in moist conditions this difference is 3.3%, while for the specimens hardened in dry conditions it is 24%. The same tendency can also be seen from the stress-strain relation (see Fig. 6).

When concrete is subjected to a sustained stress, creep strain develops gradually in time as shown in Fig. 7. Creep increases with time at a decreasing rate. In the period immediately after initial loading, creep develops rapidly, but with time the rate of the increase slows considerably.

In a loaded specimen that is in hygral equilibrium with the ambient medium (i.e., no drying), the time-dependent deformation caused by stress is known as *basic creep* (Neville et al., 1983).

The graph in Figure 7 shows elastic strain plus linear basic creep and shrinkage. From the gathered data it is evident that the smallest creep is exhibited by the concrete specimens with 40% LGP (dry). The average difference between basic creep of the reference concrete specimens hardened in moist and in dry conditions is approximately 47.4%. For the specimens with 20% LGP this difference is approximately 52.4% and for the specimens with 40% LGP it is 12%.

Table 2

Mechanical properties of concrete compositions

Specimen	Age, days	Modulus of elasticity, GPa	Elastic strain ε $(\cdot 10^{-3})$	Basic creep ε $(\cdot 10^{-3})$	Creep coefficient (90 days)
Reference	51	32,5 (dry)	0,8 (dry)	2,0 (dry)	2,7 (dry)
Reference	51	31,6 (moist)	0,8 (moist)	3,9 (moist)	5,0 (moist)
20% LGP	51	21,9 (dry)	0,9 (dry)	3,5 (dry)	4,0 (dry)
20% LGP	51	27,9 (moist)	0,8 (moist)	2,3 (moist)	2,9 (moist)
40% LGP	51	27,2 (dry)	1,1 (dry)	2,1 (dry)	2,8 (dry)
40% LGP	51	30,7 (moist)	0,9 (moist)	2,4 (moist)	2,8 (moist)
Reference	57	42,3 (dry)	0,6 (dry)	2,4 (dry)	4,2 (dry)
Reference	57	36,5 (moist)	0,7 (moist)	3,0 (moist)	4,6 (moist)
SCP	57	32,2 (dry)	0,8 (dry)	2,9 (dry)	3,9 (dry)
SCP	57	37,7 (moist)	0,6 (moist)	3,4 (moist)	5,3 (moist)

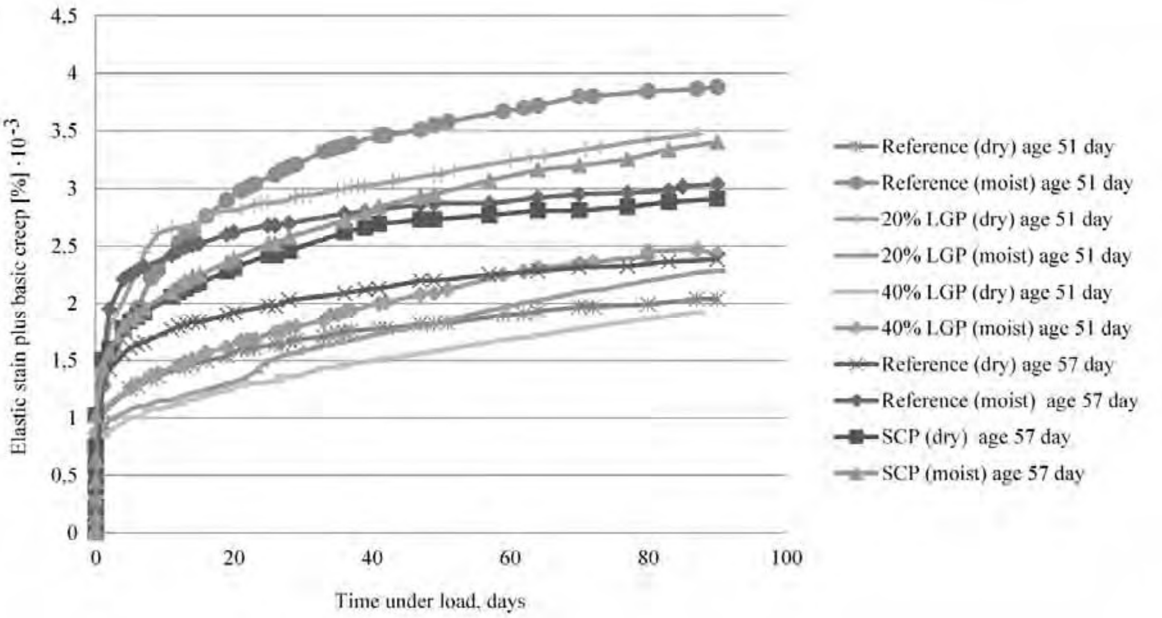

Figure 7. Elastic strain and basic creep of new concrete mixtures.

By comparing the average difference between the reference concrete specimens and the 20% LGP it can be seen that for the specimens hardened in moist conditions this difference is 41%, and for the specimens hardened in dry conditions it is 71%. In comparison with the 40% LGP specimens, the difference is 37.4% and 4.7% respectively. The results of the experiments are presented in Table 2.

In the graph in Figure 7 it is evident that the smallest creep is exhibited by the reference concrete specimens in dry conditions. The average difference between basic creep of the reference concrete specimens hardened in moist and in dry conditions is approximately 21%. For the specimens containing SCP this difference is approximately14.5%. By comparing the average difference between the reference concrete specimens and the SCP, it can be seen that for the specimens hardened in moist conditions this difference is 12.8%, and for the specimens hardened in dry conditions it is 22%. The results of the experiments are presented in Table 2.

Under constant mechanical loading, the strain of the reference concrete increases significantly with the loading duration, the increase reaching 2.68 to 4.97 times the value of the instantaneous strain. The strain increase of the concrete specimens with 20% LGP reaches 2.93 to 3.95 times the value of the instantaneous strain and for the specimens with 40% LGP it reaches 2.79 to 2.84 times.

The strain of the reference concrete increases significantly, the increase reaching 4.15 to 4.61 times the value of the instantaneous strain, and for the specimens containing SCP it reaches 3.88 to 5.32 times. The creep coefficient increases with time at an ever-decreasing rate.

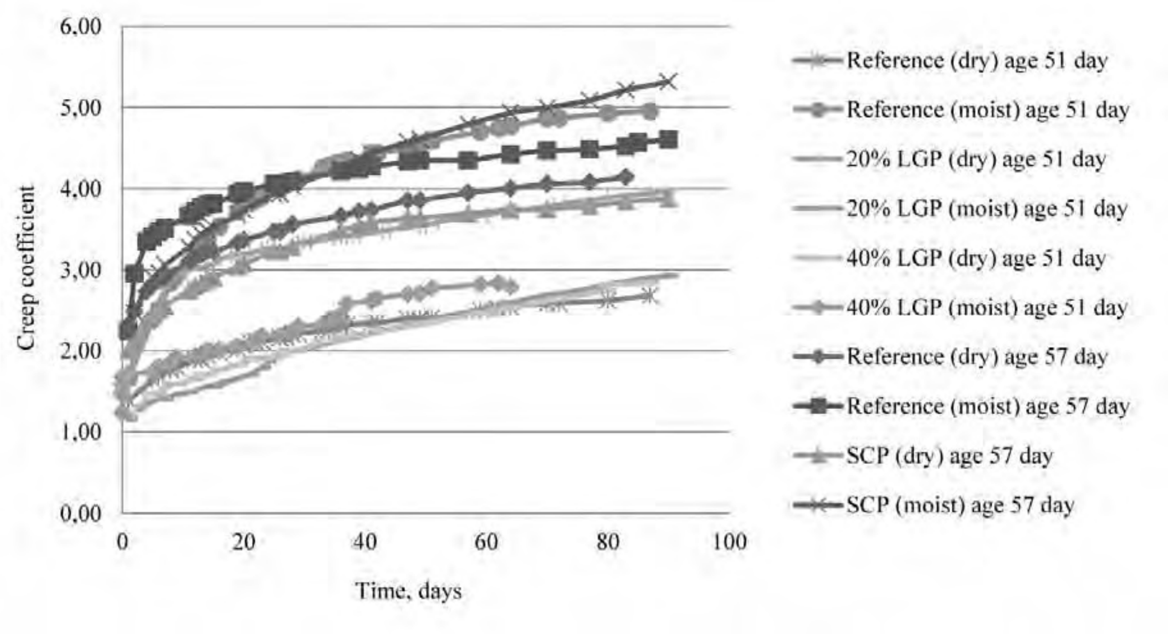

Figure 8. Creep coefficient of high strength concrete mixtures.

The final creep coefficient is a useful measure of the creeping capacity of concrete.

The graph in Figure 8 shows the increase of the creep coeficient in time. The comparison of the creep coefficients of the reference concrete specimens and 20% of LGP specimens shows that the creep coefficient for the reference concrete specimens in dry conditions is smaller, but for the reference specimens in moist conditions it is larger than for the specimens with 20% and 40% of LGP. The average difference between the reference concrete specimens in moist and in dry conditions is approximately 46%, but for the specimens containing 20% of LGP this difference is approximately 35%. For the specimens containing 40% of LGP this difference is approximately 2%. If we compare the average difference between the reference concrete specimens and the ones containing 20% of LGP we can see that for the specimens hardened in moist conditions this difference is 41%, and for the specimens hardened in dry conditions it is 47.4%, while for the specimens containing 40% of LGP this difference is 44% and 6% respectively.The comparison of the creep coefficients of the reference concrete specimens and SCP specimens shows that the creep coefficient of the specimens containing clay particles and hardened in dry conditions is larger but in the moist conditions the creep coefficients are larger than the reference concrete. The average difference between the reference concrete specimens in moist and in dry conditions is approximately 10%, but for the SCP specimens this difference is approximately 27%. If we compare the average difference between the reference concrete specimens and the ones containing SCP we can see that for the specimens hardened in moist conditions this difference is 15.4%, and for the specimens hardened in dry conditions it is 6.5%.

CONCLUSIONS

This experimental study proves that lamp glass powder and small clay particles can be successfully used in the production of concrete, thus potentially decreasing the amount of deposited waste and the use of cement, which would lead to a reduction of carbon dioxide release into the atmosphere. In order to decrease the dispersion of the results, the number of specimens and tests should be increased.

In the future, the physical and mechanical properties of this new concrete containing lamp glass powder and small clay particles should be investigated in a more detailed way. The results of this experiment can be used to predict creep deformations.

Long-term deformations testing was carried out, and the modulus of elasticity, the compression strength of ordinary concrete and of concrete containing lamp glass powder and small clay particles were determined. The basic creep test results were summarized on the 90th day.

Lamp glass powder caused a long-term hardening effect. The specimens in which cement was partially replaced by lamp glass powder showed a larger increase of the compression strength than the reference concrete specimens, and the compression strength of 58 days old concrete specimens containing LGP was larger than that of the reference concrete specimens.

The reference concrete specimens and specimens containing SCP showed a similar increase of the compression strength at both ages.

The modulus of elasticity in dry conditions was

larger for the reference concrete specimens. For the specimens containing LGP the larger modulus of elasticity was achieved by hardening in moist conditions.
The modulus of elasticity in dry conditions was larger for the reference concrete specimens but in moist conditions the larger modulus of elasticity was for the specimens containing SCP.
Creep strain increases with time at a decreasing rate. In the period immediately after initial loading, creep develops rapidly, but with time the rate of increase slows significantly. The concrete specimens cured in moist conditions showed larger increase of basic creep deformations.
Under constant mechanical loading, the strain of concrete increases significantly with the loading duration. The creep coefficient increases with time at an ever-decreasing rate.The final creep coefficient is a useful measure of the creep capacity of concrete. On the 90th day of testing the value of the basic creep coefficient reaches 2.68 to 5.32 times the value of the instantaneous strain.

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