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# Creep and Shrinkage Self-Compacting Concrete (SCC) Analytical Models

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**Abstract:** In the structures whose long-term behavior should be monitored and controlled, creep and shrinkage effects have to be included precisely in the analysis and design procedures. Creep and shrinkage, vary with the constituent and mixtures proportions, and depend on the curing conditions and work environment as well. Self-compacting concrete (SCC) contains combinations of various components, such as aggregate, cement, superplasticizer, water-reducing agent and other ingredients which affect the properties of the SCC including creep and shrinkage of the SCC. Hence, the realistic prediction creep and shrinkage strains of SCC are an important requirement of the design process of this type of concrete structures. In this study, three proposed creep models and four shrinkage models available in the literature are compared with the measured results of 52 mixtures for creep and 165 mixtures for shrinkage of SCC. The influence of various parameters, such as mixture design, cement content, filler content, aggregate content, and water cement ratio (w/c) on the creep and shrinkage of SCC are also compared and discussed.

**Key words:** Self-compacting concrete (SCC), conventional concrete (CC), creep, shrinkage, long-term behavior.

## 1. Introduction

Self-compacting concrete (SCC) basically consists of the same components as conventional concrete (CC) (cement, water, aggregates, admixtures, and mineral additions), but the final composition of the mixture and its fresh characteristics are different. In comparison with CC, SCC contains larger quantities of mineral fillers such as finely crushed limestone or fly ash, higher quantities of high-range water-reducing admixtures, and the maximum size of the coarse aggregate is smaller. These modifications in the composition of the mixture affect the behavior of the concrete in its hardened state, including the creep and shrinkage deformations.

Because SCC has higher paste volume (or higher sand to aggregate ratio) to achieve high workability and high early strength, several researchers have claimed relatively large creep and shrinkage of SCC for precast, prestressed concrete, resulting in larger prestress losses [1–4]. D'Ambrosia et al. [5] also claimed high autogenous shrinkage at early ages resulting in high early cracking of SCC with low w/c and high paste volume. However, the fast early strength gain mitigates the risk of cracking. Although mechanical properties of SCC are superior to those of CC, creep and shrinkage of SCC is significantly high [1].

Naito et al. [2] also found that SCC exhibits higher shrinkage and creep than CC, which is due to the high fine aggregate volume in the SCC. Naito et al. [2] found that the ACI 209 [6] prediction model overestimates the shrinkage of SCC and CC by 39 and 18 percent, respectively. The creep coefficient of SCC and CC was 40 and 6 percent higher than the ACI 209 [6] prediction model, respectively.

On the other hand, Schindler et al. [3] revealed that the shrinkage of SCC is similar or less than that of CC. At early ages AASHTO LRFD Specifications [7] underestimates the shrinkage values (7 and 14 days), while it overestimates the shrinkage at later ages (56 and 112 days) for both CC and SCC. When the shrinkage of SCC is compared to that of CC at 112 days, the sand to aggregate ratio effect is not significant for

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the shrinkage of SCC. The creep coefficients of SCC mixtures were also smaller than those of CC at all loading ages. This was attributed to the low w/c [3]. According to Sucksawang et al. [4], fly ash (Class F) and silica fume and slag may reduce the capillary porous that causes high shrinkage. Finally, fly ash is excellent among other SCMs in reducing shrinkage.

Because creep and shrinkage are sensitively affected by mixture proportions and environmental factors, the results vary and give different trends. Therefore, more data are necessary to understand the behavior of creep and shrinkage of SCC mixtures in order to compare with CC mixtures. Prediction models for creep and shrinkage of concrete account for internal and external factor. Mixture proportions are the internal factors, such as the ratio of fine aggregate and cement contents, admixtures, shape of coarse aggregate, and so on. Otherwise, environmental elements, such as relative humidity and temperature, are external factors. Each factor is not independent from the other factors. Because there are many internal and external factors affecting characteristics of creep and shrinkage, it is not easy to predict and determine creep and shrinkage accurately. That is why many prediction formulas have not been accepted widely as a reasonable prediction model.

In this study, three proposed creep and four shrinkage models available in the literature are compared with the measured results of 52 mixtures for creep and 165 mixtures for shrinkage of SCC. The influence of various parameters, such as mixture design, cement content, filler content, aggregate content, and water cement ratio (w/c) on the creep and shrinkage of SCC are also compared and discussed.

## 2. Database for Creep and Shrinkage Experimental Tests

The use of a database with experimental results from various published investigations is an important tool for studying the applicability of the various creep and shrinkage estimation models of SCC. To apply the models to a particular concrete mixture, it is necessary to use only investigations that adequately define the applied testing methodology. The experimental results included in the database proceed mainly from papers presented at various conferences on SCC and other published articles. The database includes information regarding the composition of the mixtures, fresh properties of SCC and testing methodology and conditions. It should be emphasized that this aspect has not been investigated as much as the other aspects of SCC, and the published experimental data is still not very extensive.

Using experimental data results from different sources can frequently be problematic for the following reasons: (1) there is often insufficient information regarding the exact composition of the concrete mixtures; (2) the size of the specimen, curing condition, and testing methodology vary between the different investigations and, in some cases, this information is not fully indicated; (3) in many cases it is difficult to extract the relevant experimental values because the published results are incomplete or are presented in graphical form and the data values have to be extrapolated. Tables 1–2 present a general summary of the concrete mixtures included in the database. The database includes test results from 11 different investigations, with a total of 52 SCC mixtures for creep and another 14 different investigations, with a total of 165 different SCC mixtures for shrinkage.

Tables 1–2 also include complimentary information regarding the applied stress to the creep specimens, age of concrete when shrinkage begins (days), final age of the concrete, relative humidity (R.H.), type of the specimen, type of the cement and filler.

## 3. Creep and Shrinkage Models for SCC

In Tables 3 and 4 various empirical models for calculating the creep and shrinkage of SCC are shown. These models vary in complexity, and precision in the calculations.

**Table 1 Creep database.**

| | Reference | NM* | ASCS* | FAC* | R.H. (%) | Type of specimen (mm) | Type of cement | Type of filler |
|---|---|---|---|---|---|---|---|---|
| 1 | Chopin et al. [8] | 5 | 40% or 60% of $f'_{c(28d)}$ | 365 | 50 | Cylinder (90 × 280) | CEM I | Limestone |
| 2 | Poppe and De Schutter [9] | 4 | 1/3 of $f'_{c(28d)}$ | 1400 | 60 | Prism (150×150×500) | CEM I 42.5 R, CEM I 52.5 | Limestone |
| 3 | Horta [10] | 6 | 40% of $f'_{c(28d)}$ | 70, 200 | 50 | Cylinder (150 × 300) | CEM I , CEM III | Fly ash and GGBFS |
| 4 | Larson [11] | 1 | 40% of $f'_{c(28d)}$ | 520 | 50 | Prism (101.6×101.6×609.6) and Cylinder (114.3×609.6) | CEM III | Limestone |
| 5 | Turcry et al. [12] | 2 | 20% of $f'_{c(7d)}$ | 65, 100 | 50 | Cylinder (110 x 200) | CEM I 52.5, CEM II 42.5 | Limestone |
| 6 | Cordoba [13] | 4 | 30% of $f'_{c(28d)}$ | 365 | 50 | Cylinder (101.6 × 203.2), (101.6 × 1057.8) | CEM I/II | Fly ash and GGBFS |
| 7 | Heirman et al. [14] | 7 | ±1/3 of $f'_{c(28d)}$ | 70 | 60 | Cylinder (120 × 300) | CEM I 42.5 R, CEM III/A 42.5 N LA | Limestone |
| 8 | Oliva and Cramer [15] | 11 | 40% of $f'_{c(28d)}$ | 495 | 50 | Cylinder (152.4 × 2133.6) | CEM I | GGBFS |
| 9 | Kim [16] | 4 | Changeable for each mixture | 150 | 50 | Cylinder (100×200) | CEM III | Fly ash and Limestone |
| 10 | Zheng et al. [17] | 7 | 30% of $f'_{c(28d)}$ | 150 | 60 | Prism (100×100×400) | CEM I | Fly ash |
| 11 | Loser and Leemann [18] | 1 | Changeable for each mixture | 91 | 70 | Prism (120×120×360) | CEM I 42.5 N, CEM II/A-LL 45.2 N | Fly ash and Limestone |
| Total of 52 mixtures | | 52 | * No. of SCC mixtures (NM) , Applied stress to the creep specimens (ASCS), $f'_c$: compressive strength, Final age of concrete (days) (FAC) | | | | | |

## 4. Results and Discussion

### *4.1. Comparison between SCC Creep Experimental Results and Calculated SCC Creep Models*

The comparison between SCC creep experimental results and calculated SCC creep models (Table 3) included in the database (Table 1) are shown in Figs. 1-3.

Fig. 1 shows comparison of the creep coefficient by Poppe and De Schutter [9] with the experimental results creep coefficient available in the literature (Table 1). It can be seen that this model overestimates the creep coefficient of both SCC and CC mixtures. Fig. 2 illustrates predicted creep coefficient by Larson [11] with the experimental results (Table 1). According to the Fig. 2, Larson's [11] creep prediction model is underestimates the creep coefficient of both SCC and CC mixtures. Fig. 3 presents the same comparison using Cordoba's [13] model. Based on the achieved results Cordoba [13] SCC creep prediction model is more conservative as its trend like to be underestimating for the creep coefficient of both SCC and CC mixtures.

### *4.2. Comparison between SCC Shrinkage Experimental Results and Calculated SCC Shrinkage Models*

The comparison between SCC creep experimental results and calculated SCC creep models (Table 4) included in the database (Table 2) are shown in Figures 4 to 7. Figs. 4 and 7 present comparison of the predicted drying shrinkage by Poppe and De Schutter [9] and Khayat and Long [23] models with experimental results available in the literature (Table 2).

These models underestimate shrinkage comparing with the experimental results of both SCC and CC mixtures. Figs. 5–6 show comparison of the predicted

**Table 2 Shrinkage database.**

| | Reference | NM* | ACSB* | FAC* | R.H. (%) | Type of specimen (mm) | Type of cement | Type of filler |
|---|---|---|---|---|---|---|---|---|
| 1 | Chopin et al. [8] | 5 | 1 | 365 | 50 | Cylinder (90 × 280) | CEM I | Limestone |
| 2 | Poppe and De Schutter [9] | 4 | 1 | 1400 | 60 | Prism (150×150×500) | CEM I 42, 5 R, CEM I 52,5 | Limestone |
| 3 | Horta [10] | 6 | 1 | 200 | 50 | Cylinder (150 × 300) | CEM I , CEM III | Fly ash and GGBFS |
| 4 | Larson [11] | 1 | 1 | 520 | 50 | Prism (101.6×101.6×609.6) and Cylinder (114.3×609.6) | CEM III | Limestone |
| 5 | Turcry et al. [12] | 3 | 1 | 120, 150, 210 | 50 | Prism (70×70×280) | CEM I 52.5, CEM II 42.5 | Limestone |
| 6 | Cordoba [13] | 4 | 1 | 365 | 50 | Cylinder (101.6 × 203.2), (101.6 × 1057.8) | CEM I/II | Fly ash and GGBFS |
| 7 | Heirman et al. [14] | 7 | 1 | 98 | 60 | Cylinder (120 x 300) | CEM I 42.5 R, CEM III/A 42.5 N LA | Limestone |
| 8 | Bhattacharya [19] | 6 | 1 | 90 | 50 | Prism (76.2×76.2×311.2) | CEM I | Limestone, Silica fume and Slag |
| 9 | Oliva and Cramer [15] | 11 | 1 | 350, 495 | 50 | Prism (101.6×101.6×285.75) | CEM I | GGBFS |
| 10 | Hwang and Khayat [20] | 10 | 1 | 56 | 50 | Prism (75x75×285) | CSA type Gub-F/SF, Gub-S/SF and quaternary blended cement | Fly ash and Limestone |
| 11 | Ma et al. [21] | 16 | 1 | 120, 150 | 60 | Prism (100×100×515) | CEM I | Fly ash |
| 12 | Loser and Leemann [18] | 13 | 1 | 91 | 70 | Prism (120×120×360) | CEM I 42.5 N, CEM II/A-LL 45.2 N | Fly ash and Silica fume |
| 13 | Güneyisi et al. [22] | 63 | 1 | 50 | 50 | Prism (70×70×280) | CEM I | Fly ash, GGBFS, Silica fume and Metakaolin |
| 14 | Khayat and Long [23] | 16 | 1 | 300 | 50 | Cylinder (150×300) | MS and HE (similar to ASTM C150 Type I/II and Type III) | Fly ash |
| Total of 165 mixtures | | 165 | *No. of SCC mixtures (NM), Age of concrete when shrinkage begins (days)(ACSB), Final age of concrete (days) (FAC) | | | | | |

**Table 3 Creep models for SCC.**

| Ref. | Creep Prediction Models | Main Model |
|---|---|---|
| Poppe and De Schutter [9] | $\varepsilon_{cr}(t,t_0)=\frac{\sigma_c(t_0)}{E_{ci}}.\left[1+\frac{\left(1-\left(RH/RH_0\right)\right)}{0.46\left(h/h_0\right)^{1/3}}\right].\frac{5.3}{\left(f_{cm}/f_{cm0}\right)^{1/2}}\frac{1}{0.1+\left(t_0/t_1\right)^{0.2}}.$ $.\left[\frac{\left(t-t_0\right)/t_1}{\left(150\left(1+\left(1.2\frac{RH}{RH_0}\right)^{18}\right)\frac{h}{h_0}+250\right)+\frac{t-t_0}{t_1}}\right]^{0.3}.\left[\frac{1}{0.01+1.37\left(c/p\right)}\right]$ Other symbols as in Model Code 1990, c/p (cement to powder ratio) | CEB-FIP (1990) |
| Larson [11] | For the specimens loaded at 1 day (for square and cylindrical specimens): $v_t=\frac{t^{0.7}}{16+t^{0.7}}(1.75)$ For the specimens loaded at 28 day (for square specimens): $v_t=\frac{t^{0.6}}{24+t^{0.6}}(2.00)$ | ACI 209R (1997) |
| Cordoba [13] | $v_t = \frac{t^{\psi}}{d+t^{\psi}}\, v_u$ [24] | ACI 209R (1997) |

**Table 4 Shrinkage models for SCC.**

| Ref. | Modified Shrinkage Prediction Models | Main Model |
|---|---|---|
| Poppe and De Schutter [9] | $\varepsilon_{shr}(t,t_s)=\left[\frac{160}{1-\alpha(w/c)}+10\,\beta_{sc}\left(9-\frac{f_{cm}}{f_{cm0}}\right)\right]\cdot\left[-1.55\left(1-\left(RH/RH_0\right)^3\right)\right]\cdot\left[\frac{(t-t_s)/t_1}{45.5(h/h_0)^2+(t-t_s)/t_1}\right]^{\gamma}$<br>$\alpha=4.1(c/p)-1.8 \quad \gamma=-2.5\,(c/p)+2.6$<br>Other symbols as in Model Code 1990, c/p (cement to powder ratio) | CEB-FIP (1990) |
| Larson [11] | For square specimens: $(\varepsilon_{sh})_t=\frac{t}{20+t}\times 550\times 10^{-6}$<br>For cylindrical specimens: $(\varepsilon_{sh})_t=\frac{t}{20+t}\times 600\times 10^{-6}$ | ACI 209R (1997) |
| Cordoba [13] | $(\varepsilon_{sh})_t=\frac{t^{\alpha}}{f+t^{\alpha}}(\varepsilon_{sh})_u$ [24] | ACI 209R (1997) |
| Khayat and Long [23] | $\varepsilon_{sh}=-k_s\,k_h\left(\frac{t}{55+t}\right)(0.56\times 10^3)\times A\,(steam-cured);\ k_s=\left[\frac{\frac{t}{26\,e^{0.0142\,(V/S)}+t}}{\frac{t}{45+t}}\right]\left[\frac{1064-3.70\,(V/S)}{923}\right]$<br>A is the cement factor: 0.918 for Type MS cement and 1.065 for Type HE + 20% fly ash. | AASHTO (2004) |

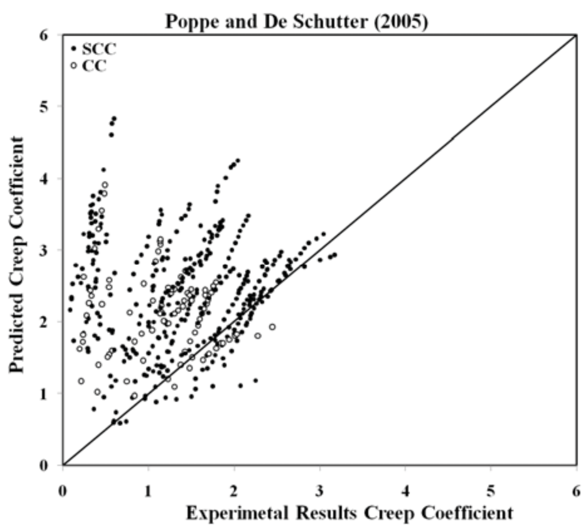


**Fig. 1 Comparison of the SCC creep coefficient from experimental results versus calculated values from Poppe and De Schutter [9] prediction model.**

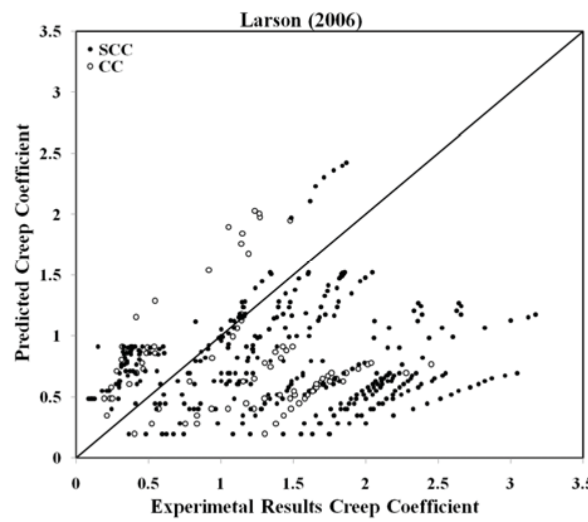


**Fig. 2 Comparison of the SCC creep coefficient from experimental results versus calculated values from Larson [11] prediction model.**

drying shrinkage by Larson [11] and Cordoba [13] models with experimental results available in the literature (Table 2). According to these comparisons, Larson [11] and Cordoba [13] models are fairly well agreed with the experimental results of both SCC and CC mixtures. Both Larson [11] and Cordoba [13] models are more suitable for CC drying shrinkage mixtures. Larson [11] model prediction for SCC drying shrinkage is more conservative than Cordoba [13] model for SCC because the trend of Cordoba [13] model is underestimating the drying shrinkage for SCC.

## 5. Conclusions

This study presents an extensive database of creep and shrinkage experimental results for SCC and CC and evaluates three SCC creep models and four SCC shrinkage models and their applicability. Even though a more extensive database with longer test durations would be advisable, nevertheless, there is a clear behavior pattern in the information that permits the following conclusions to be established:

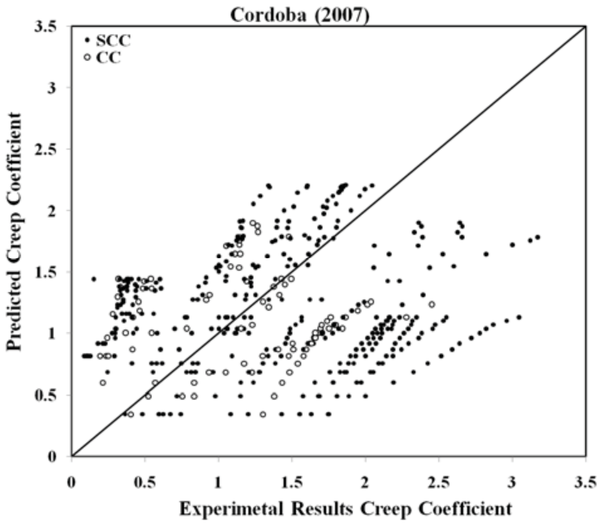


**Fig. 3 Comparison of the SCC creep coefficient from experimental results versus calculated values from Cordoba [13] prediction model.**

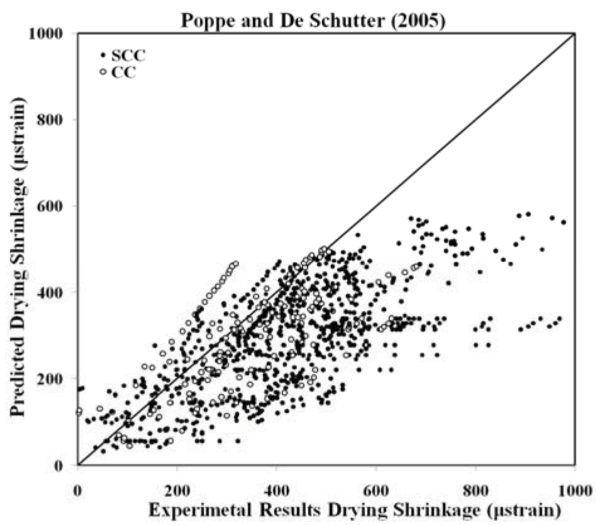


**Fig. 4 Comparison of the SCC drying shrinkage from experimental results versus calculated values from Poppe and De Schutter [9] prediction model.**

• By decreasing of water to binder ratio, increment in creep is observed. Increase in the proportion of the total aggregate in the mixture could cause decrease in the total creep. When the content of total aggregate and binder in concrete is held constant, the total creep decreases as coarse aggregate proportion increases.

• Increase in water to binder ratio causes increase in drying shrinkage. The proper use of fly ash in SCC can reduce drying shrinkage remarkably.

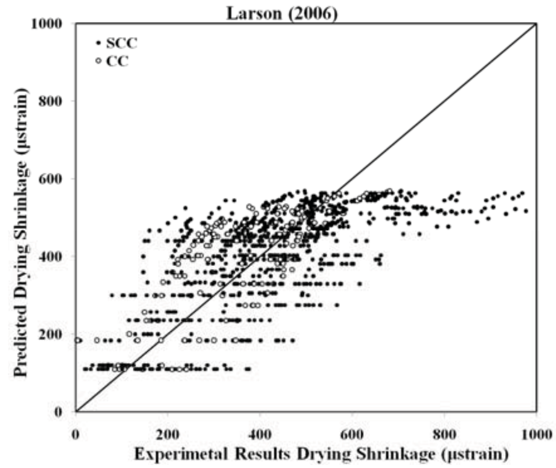


**Fig. 5 Comparison of the SCC drying shrinkage from experimental results versus calculated values from Larson [11] prediction model.**

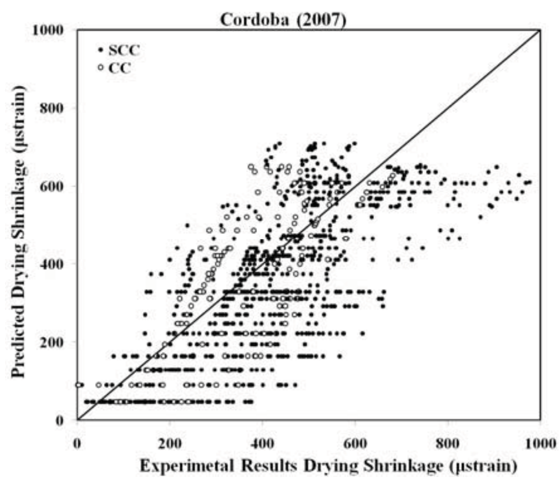


**Fig. 6 Comparison of the SCC drying shrinkage from experimental results versus calculated values from Cordoba [13] prediction model.**

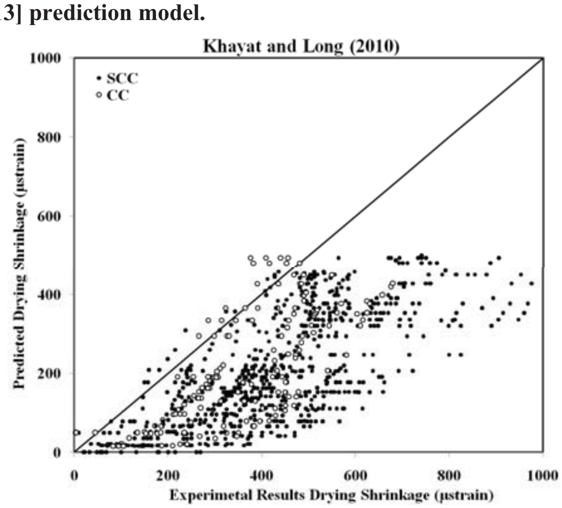


**Fig. 7 Comparison of the SCC drying shrinkage from experimental results versus calculated values from Khayat and Long [23] prediction model.**

• Increase in volume of coarse aggregate can reduce drying shrinkage significantly, in addition change of sand volume ratio has little effect on the drying shrinkage of medium strength SCC.

• Based on the presented results, Cordoba [13] SCC creep model is more conservative as its trend like to is underestimating of the creep coefficient of both SCC and CC mixtures.

• Based on the presented results, Larson [11] and Cordoba [13] SCC drying shrinkage prediction models are fairly well agreed with the experimental drying shrinkage of the SCC and CC mixtures.

• Both Larson [11] and Cordoba [13] models are more suitable for calculation of the CC drying shrinkage mixtures.

• Larson [11] model is more conservative than Cordoba [13] model for SCC drying shrinkage because the trend of Cordoba [13] model is underestimating the drying shrinkage for SCC.

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