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Assessment of Shrinkage Strain Reduction SSR for RC Slabs with Different Thicknesses Strengthened with Different Layers of Geogrid

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ABSTRACT

This study presents experimental work to evaluate the efficiency of using the biaxial geogrid as a shrinkage reinforcement for RC slabs instead of using upper shrinkage steel reinforcement. Geogrid distinguish from steel reinforcement in its low cost and it doesn't rust. The present work studies and assesses the shrinkage strain of RC slabs considering different parameters, slab thickness, number of geogrid layers, and thickness of the upper concrete cover. The shrinkage strain is measured, while shrinkage strain reduction SSR% is determined considering plastic and dry shrinkages, along with temperature and humidity are recorded weekly for 15 specimens of 50*50 cm slabs over 91 days. All specimens have lower steel reinforcement with/without upper geogrid reinforcement. The results prove the efficiency of geogrids reinforcement to resist the shrinkage stains in RC slabs, where, two layers of geogrids with 3 cm of upper cover gives the lowest shrinkage stain, i.e., largest shrinkage resistance. The results also show that as the RC slab thickness decrease as the shrinkage strain and SSR% value increase and vice versa. But there is no noteworthy effect of geogrid on the SSR% value.

1. INTRODUCTION

Shrinkage in concrete can be defined as the change in the concrete volume due to moisture loss and water evaporation from the concrete as well as the wetting of its components over time [1]. Concrete shrinks due to the restrictions imposed by its supports, adjunct materials or connected members, this leads to the generation of tensile stresses in the concrete. When these stresses exceed the tensile strength, it leads to cracks in the concrete. These cracks reduce the load capacity of the structure and allow other chemical factors such as salts to pass through the covering layer which leads to corrosion of the reinforcement steel. This occurs effectively in large surfaces exposed to drying, such as slabs [2]. Many factors affect the degree of shrinkage such as the cement content, aggregate properties, the mixture composition, temperature and the relative humidity of the environment, the age of the concrete and the size of the structure [3]. Four types of shrinkage occur in concrete, autogenous shrinkage, plastic shrinkage, drying shrinkage and carbonation shrinkage [4].

Gao Xiaojian et.al [5] carried out experimental work to study the drying shrinkage of concrete specimens with different reinforcement configurations that were measured at various depths from the exposed surface. They concluded that the high reinforcement ratio leads to a significant restriction of concrete shrinkage near the reinforcing steel and with the increasing distance from reinforcing rebar, the

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degree of concrete shrinkage restriction decreases. The relationship between shrinkage strain and reduction of relative humidity in plain concrete is different from that in reinforced concrete. Güneyisi et al. [6]; Wei et al. [7]; and Kim and Chun [8] study the influence of the internal curing technique of pre-wetted lightweight fine and coarse aggregates on the drying and autogenous shrinkage performance for concrete. Even though the use of this method could reduce the shrinkage of cured concrete, the rate of shrinkage growth was quick in comparison with the control concrete. In addition, the concrete early strength and its modulus of elasticity were reduced. Xiang Hu et al. [9] studied the drying shrinkage of concrete under drying conditions and examined ternary cement systems containing Portland cement, fly ash, and slag. They concluded that drying shrinkage decreased with the content of fly ash and the addition of superplasticizers and increased with the increase of the slag content. The drying shrinkage of concrete is controlled by the slag content in the mixture ratio. Jun Zhang et al. [10] studied the effect of coarse aggregate content on drying shrinkage. They found that the drying shrinkage is greatly affected by the addition of coarse aggregate, as it is reduced with the increase of coarse aggregate. The study was carried out by Huan Zhang et al. [11] to investigate the autogenous shrinkage of recycled aggregate concrete (RAC) made with Fine and Coarse Recycled Aggregate (termed FRA and CRA). They found that both CRA and FRA considerably reduced the RAC autogenous shrinkage and the effect of FRA is more significant with increasing CRA content, and vice versa.

Tianshi Lu et al. [12] investigated the effect of Supplementary Materials e.g., silica fume, fly ash, and blast furnace slag (BFS) on the autogenous shrinkage of cement paste. The experimental results showed that the autogenous shrinkage decreased with the addition of fly ash. The autogenous shrinkage of silica fume cement paste is not significantly bigger than that of ordinary Portland cement paste. The measured BFS cement paste autogenous shrinkage is much bigger than that of Portland cement paste. Hanghua Zhang et al. [13] performed experimental work to study the plastic shrinkage and cracking of 3D printed mortar mixed with recycled sand as fine aggregates. The experimental results showed that the plastic shrinkage increased with the increase of recycled sand content. The plastic cracking of 3D printed mortar under restraint conditions showed a higher cracking depth, with a higher replacement ratio of recycled sand. Lower cracking risk showed when the replacement ratio of recycled sand is 25% under free conditions and 50% under constraints. The study was carried out by Muhammad Nasir et al. [14] to investigate the effect of concrete placement temperature and curing method on the plastic shrinkage of plain and pozzolanic cement concretes. They concluded that the utilization of a water-based curing compound was useful in reducing the plastic shrinkage strain compared to curing by covering with a plastic sheet. The optimum temperature for all cementitious materials was either 32˚ or 38˚ C while the critical placement temperature was both 25 and 45˚ C.

Geogrid is considered geosynthetic material that is original of polymer materials such as polyester, polypropylene, and polyethlene and consists of regular apertures such as square, rectangular and triangular openings [15, 16]. Geogrid is used for strengthening weak soils to improve foundations beneath railway structures and roads [17, 18]. Many characteristics and advantages lead to the use of geogrid, such as being very light in weight, high corrosion resistance, high resistance to attack by chlorides and sulfates, ease of transportation from one place to another, easy to cut and use, relatively low cost and high tensile resistance [19,20, 21,22]. There are three main types of geogrids: uniaxial, biaxial, and triaxial. It depends on the number of directions in which the ribs extend, and therefore the directions that they reinforce [23].

Al-Hedad et al. [24] performed experimental work to study the effect of geogrid reinforcement on the flexural behavior of ordinary portland cement (OPC) concrete slabs pavements. The static loads were applied at three different locations: corner, edge and interior of the geogrid reinforced concrete slabs. The experimental results showed that the flexural performance of OPC concrete slabs reinforced with the geogrid improved and the propagation of cracks was significantly delayed. The study was carried out by Al-Hedad et al. [25] to investigate the influence of geogrid on the drying shrinkage performance of normal strength concrete pavements. They found that geogrid reduces the drying shrinkage of concrete by about 15% in concrete slabs and by about 20% in concrete prism samples. Al-Hedad et al. [26] studied the effect of geogrid reinforcement on the drying shrinkage and thermal expansion of geopolymer concrete. They concluded that the geogrid significantly decreased the thermal expansion and drying shrinkage of geopolymer concrete (GPC) samples.

In this paper, an experimental study was done to verify the effect of biaxial geogrid on the shrinkage behavior of reinforced concrete slabs under the surrounding environmental conditions. The shrinkage behavior are assessed by recording the shrinkage strain and determining the shrinkage strain reduction SSR.

2. EXPERIMENTAL PROGRAM

Table. 1 presents the different geogrid reinforcement configurations of the investigated RC slab samples in the current study. All the RC slabs are reinforced by a lower steel reinforcement of 5Ø10/m in each direction as main reinforcements. Moreover, the biaxial grogrid is used as an upper shrinkage resisting reinforcement.

The slabs dimensions are 500*500 mm considering three different thicknesses 120, 150, and 180 mm as shown.

Table 1: Configurations of test RC slabs

Slab	Slab Thickness	No. of geogrid layers	Upper cover
S12_1	120 mm	———	———
S12_2		1	30mm
S12_3		2	30 mm
S12_4		1	50mm
S12_5		2	50 mm
S15_1	150 mm	———	———
S15_2		1	30 mm
S15_3		2	30mm
S15_4		1	50 mm
S15_5		2	50 mm
S18_1	180mm	———	———
S18_2		1	30 mm
S18_3		2	30 mm
S18_4		1	50 mm
S18_5		2	50 mm

3. MATERIAL PROPERTIES

The properties of the concrete, steel reinforcement, and biaxial geogrid reinforcement are accurately determined before the study. Table 2 shows the design mix of the used concrete, along with the average compressive strength of the tested three standard 150*150*150 mm cubes. The used steel reinforcement is St40/60 with a yield strength of 400 N/mm^2, and tensile strength of 600 N/mm^2. Table 3 shows the geometric and mechanical properties of the used biaxial geogrid reinforcement.

Table 2: Concrete mix design

Concrete ingredient	Units	Dosage Value
Cement	kg/m^3	300
Water	kg/m^3	160
Gravel	kg/m^3	1120
Sand	kg/m^3	720
The average result of three cubes of compressive strength	N/mm^2	25.2

Table 3: Properties of biaxial geogrid

Index properties	Units	Value
Aperture dimensions from centre to centre	Mm	37
Rib thickness	Mm	2
Tensile strength	N/mm^2	0.03
Elongation	%	11
Weight	N/mm2	$3.2*10^{-5}$
Roll width	mm	500
Roll length	mm	4000

4. CASTING, CURING AND TEST SETUP

The concrete ingredients mixed well using a mechanical mixer according to the specified mix design, then cast and placed in the mould in layers with good compaction till reaching the level of the geogrid layer. Then the geogrid is placed carefully in its specific place followed by casting the upper concrete cover avoiding any effect on the geogrid layers, as shown in Fig. 1. After that, the surface is levelled well and the four metal pieces are inserted into the concrete.

Fig. 1 placing geogrid layer through the casting process

The RC samples and cubes were covered with plastic sheets for 24 hours, then unmolded and labelled, as shown in Fig.2. The cubes are cured by submerging in clean water for 28 days before performing a compression test, on the other hand, the RC slabs aren't cured for the sake of considering the plastic shrinkage along with dry shrinkage.

Fig. 2 Labelled RC samples after unmolding

The shrinkage of concrete was measured weekly from the next day of casting tell 91 days, by measuring the length between the metal pieces, using a vernier calliper of 0.01mm tolerance as shown in Fig. 3. The shrinkage length is measured for both directions of every sample.

In addition, the temperature and humidity values are recorded weekly at measuring time. The samples are kept in the same place, where they are cast till the last day or recording without any movement or any external effect.

Fig. 3 Measuring the length between the two metal pieces

5. RESULTS AND DISCUSSION

Table 4 shows the cumulative recorded strains of all samples. The shrinkage strain value for each record represents the average measured strain value for both directions of each RC slab. The cumulative strain value for a certain direction reflects the value of diminishing in the length between the two metal pieces in this direction with respect to the original length measured between these two pieces in the first record. Fig. 4 shows the final shrinkage strain results for RC slab samples without and with one layer of biaxial geogrid as a shrinkage reinforcement considering 30 mm, and 50 mm as an upper cover thickness. As shown in the results, using geogrid reinforcement has an obvious effect on the shrinkage. In addition, the results show that the slabs with a thickness of 120 mm have the largest shrinkage strain among other slabs, and as the slab thickness gets larger as the shrinkage strain gets lower. Moreover, the slabs with an upper cover of 30 mm for the geogrid shrinkage reinforcement give more shrinkage resistance in comparison with the same slabs with 50 mm as an upper cover.

Table 4: Weekly recorded cumulative shrinkage strain $*10^{-3}$

	Day	0	7	14	21	28	35	42	49	56	63	70	77	84	91
	T °C	25.8˚	23.5˚	21.8˚	20.6˚	19.6˚	18.6˚	20.0˚	19.2˚	18.8˚	16.3˚	18.5˚	20.5˚	22.8˚	19.6˚
	RH %	58	57	67	57	62	63	65	61.5	59	55	60	62	64.5	66
t= 120 mm	S12_1	0	5.04	6.77	8.24	9.45	10.44	11.17	11.35	11.51	11.65	11.74	11.83	11.87	11.9
	S12_2	0	4.67	6.34	7.76	8.96	9.9	10.63	10.81	10.94	11.07	11.17	11.26	11.31	11.34
	S12_3	0	4.36	6.02	7.41	8.57	9.5	10.21	10.38	10.54	10.66	10.76	10.82	10.88	10.9
	S12_4	0	4.82	6.51	7.97	9.16	10.12	10.86	11.02	11.19	11.31	11.41	11.48	11.54	11.58
	S12_5	0	4.62	6.25	7.66	8.83	9.76	10.46	10.64	10.78	10.9	11	11.08	11.14	11.14
t= 150 mm	S15_1	0	4.06	5.41	6.59	7.56	8.34	8.94	9.07	9.21	9.32	9.39	9.47	9.5	9.53
	S15_2	0	3.75	5.08	6.21	7.16	7.93	8.51	8.63	8.77	8.86	8.95	9	9.05	9.07
	S15_3	0	3.51	4.8	5.93	6.85	7.6	8.16	8.31	8.43	8.53	8.6	8.67	8.72	8.73
	S15_4	0	3.87	5.22	6.36	7.34	8.09	8.67	8.83	8.96	9.06	9.14	9.2	9.23	9.25
	S15_5	0	3.69	5	6.12	7.07	7.8	8.37	8.51	8.63	8.73	8.81	8.86	8.9	8.93
t= 180 mm	S18_1	0	3.37	4.51	5.5	6.31	6.96	7.46	7.57	7.67	7.76	7.83	7.89	7.91	7.94
	S18_2	0	3.13	4.23	5.19	5.97	6.6	7.08	7.2	7.3	7.39	7.47	7.51	7.54	7.56
	S18_3	0	2.91	4.02	4.94	5.71	6.34	6.8	6.92	7.01	7.1	7.16	7.22	7.26	7.28
	S18_4	0	3.22	4.36	5.3	6.12	6.76	7.23	7.37	7.47	7.54	7.61	7.68	7.69	7.72
	S18_5	0	3.09	4.18	5.1	5.89	6.5	6.96	7.1	7.2	7.27	7.34	7.4	7.41	7.43

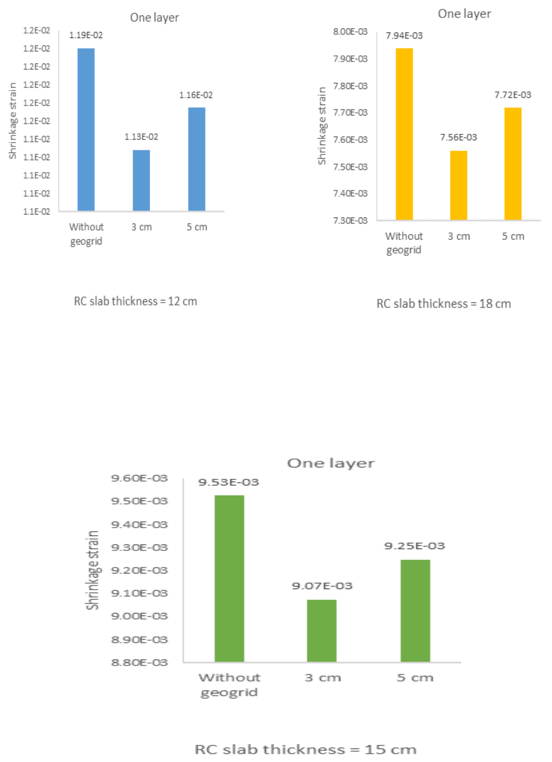

Fig. 4: Shrinkage strain for the RC slabs without and with one layer of geogrid reinforcement

Fig. 5: Shrinkage strain for the RC slabs without and with two layers of geogrid reinforcement

Moreover, Fig. 5 shows the final shrinkage strain results for RC slab samples without and with two layers of geogrid shrinkage reinforcement considering 30 mm, and 50 mm as an upper cover thickness. The results are similar to the previous results of the RC slab samples without and with two layers. Furthermore, slabs with two layers of geogrid shrinkage reinforcement have more resistance for shrinkage strain, and that proves the effect of geogrid reinforcement on shrinkage resisting.

Finally, As it is obvious in the results, the best case that has the lowest shrinkage strain at all thicknesses is the case where two layers are used with 30mm as an upper cover.

On the other hand, SSR % ,which is the parameter determines the shrinkage strain reduction percentage, is determined for 150mm and 180mm slabs corresponding to 120mm slab. The SSR % is determined based on the following equation.

$$SSR\% = \left(1 - \frac{\varepsilon_{12} - \varepsilon_t}{\varepsilon_{12}}\right) * 100 \qquad (1)$$

where Ɛ12 is the shrinkage strain of slabs with a thickness of 120mm at time t, and Ɛt is the shrinkage strain of slabs with a thickness of 150 or 180 at the same time t.

Table 5 shows the SSR% value for 150, and 180mm slabs in comparison with 120mm slabs along with different recording days.

In addition, Figs. 6, 7, and 8 show the final SSR% value for different samples corresponding to analogue one in the 120mm group. The results show that the slabs with 150mm thickness obtain around 80% of SSR% corresponding to 120mm slab thickness. But the slabs with 18 cm thickness obtain around 66.7% of SSR% compared with 120mm slab thickness. The previous results prove the relation between the slab thickness and the shrinkage strain, whereas at constant dimensions of the slab area, the shrinkage strain decrease as the slab thickness increases and verse versa [27], and [28]. The previous results show also that the ratio between the external surface area exposed to shrinkage and the volume of the slab significantly affects the shrinkage value and SSR% value, where, as this ratio decreases as the shrinkage value and SSR% increase and verse versa. Moreover, the existing geogrid or the number of its layers has an insignificant effect on the SSR% value.

Table. 5: SSR% for 150, and 180 mm slabs corresponding to 120 120mm slabs

Day			0	7	14	21	28	35	42	49	56	63	70	77	84	91
Temperature C			T=25.8°	T=23.5°	T=21.8°	T=20.6°	T=19.6°	T=18.6°	T=20°	T=19.2°	T=18.8°	T=16.3°	T=18.5°	T=20.5°	T=22.8°	T=19.6°
Humidity			RH=58%	RH=57%	RH=67%	RH=57%	RH=62%	RH=63%	RH=65%	RH=61.5%	RH=59%	RH=55%	RH=60%	RH=62%	RH=64.5%	RH=66%
strain Cumulative (average for both sides)	**t= 150mm**	**Without**	0.00%	80.39%	79.89%	79.96%	80.03%	79.87%	80.01%	79.91%	80.01%	80.02%	79.95%	80.05%	80.02%	80.03%
		one-30mm	0.00%	80.22%	80.12%	79.93%	79.89%	80.16%	80.06%	79.90%	80.16%	79.99%	80.08%	79.99%	80.00%	80.01%
		two-30mm	0.00%	80.49%	79.84%	80.05%	79.90%	79.99%	79.96%	80.07%	79.99%	80.05%	79.94%	80.10%	80.12%	80.12%
		one50mm	0.00%	80.27%	80.19%	79.82%	80.10%	79.96%	79.89%	80.16%	80.10%	80.08%	80.06%	80.16%	80.02%	79.89%
		two-50mm	0.00%	80.01%	79.91%	79.89%	80.05%	79.86%	80.04%	80.06%	80.08%	80.15%	80.08%	79.99%	79.90%	80.09%
strain Cumulative (average for both sides	**t= 180mm**	**Without**	0.00%	66.87%	66.55%	66.74%	66.79%	66.70%	66.78%	66.72%	66.58%	66.57%	66.73%	66.69%	66.64%	66.69%
		one-30mm	0.00%	66.96%	66.77%	66.87%	66.62%	66.67%	66.63%	66.65%	66.68%	66.79%	66.82%	66.71%	66.68%	66.65%
		two-30mm	0.00%	66.67%	66.79%	66.65%	66.56%	66.74%	66.66%	66.72%	66.57%	66.64%	66.59%	66.72%	66.69%	66.79%
		one50mm	0.00%	66.85%	66.88%	66.52%	66.76%	66.79%	66.58%	66.85%	66.75%	66.65%	66.68%	66.84%	66.65%	66.69%
		two-50mm	0.00%	67.02%	66.86%	66.58%	66.67%	66.55%	66.55%	66.75%	66.81%	66.73%	66.69%	66.75%	66.58%	66.67%

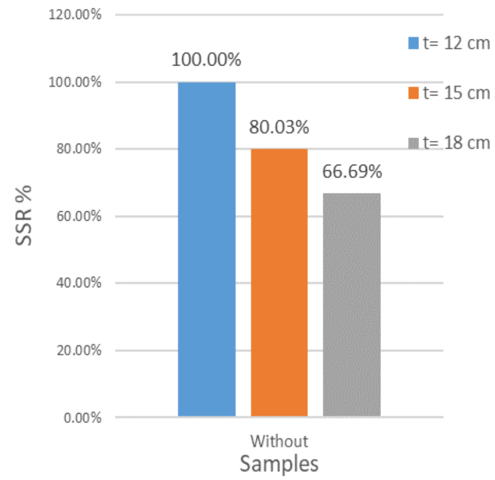

Fig. 6: Shrinkage strain reduction SSR for RC slabs without geogrid reinforcement

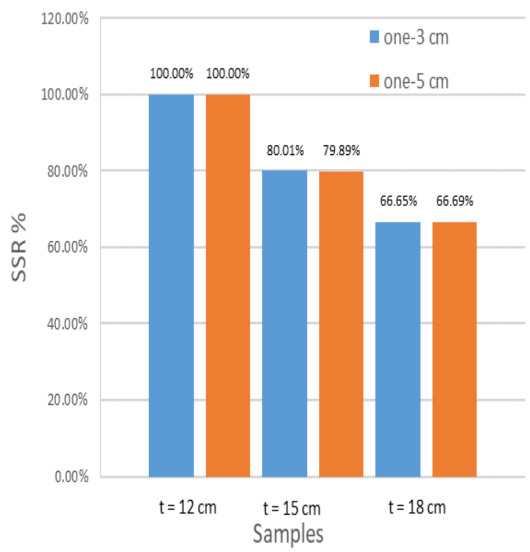

Fig. 7: Shrinkage strain reduction SSR for RC slabs with one layer of geogrid reinforcement

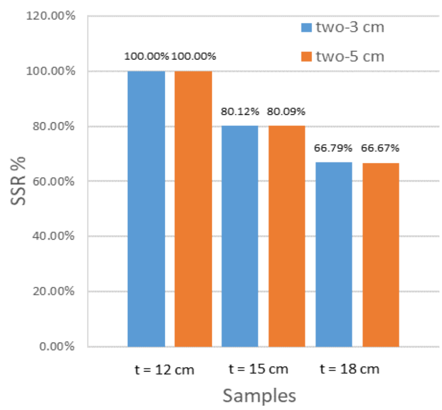

Fig. 8: Shrinkage strain reduction SSR for RC slabs with two layers of geogrid reinforcement

Table 6 shows a comparison between the shrinkage strain of the current study sample with previous similar literature studies that used geogrid as a shrinkage reinforcement.
As shown in the results, using geogrid as a shrinkage reinforcement is effective in resisting either plastic or dry shrinkage strain. It saves much cost in comparison with using steel reinforcement, in addition, no rust problem exists, which in turn allows to minimize concrete cover as possible and make geogrid very near to the surface to resist shrinkage and prevent any surface cracks.

Table. 6: Shrinkage strain for results of some literature studies compared with the current study

Study	Sample	Dimensions	Shrinkage	Final shrinkage strain
Al-Hedad et al. [26]	PC slabs	280*280mm with thickness =30mm	Dry	$1.52*10^{-3}$
	PC beams	75*75*280mm	Dry	$1.65*10^{-3}$
Al-Hedad et al. [25]	Geopolymer concrete beams	75*75*280 mm	Dry	$4.44*10^{-3}$
The current study	RC slabs	500*500mm with thicknesses = 120,150, and 180mm	Plastic + Dry	$7.28*10^{-3}$ to $1.16*10^{-2}$

6. CONCLUSIONS

An experimental study was conducted to investigate the efficiency of the geogrid as an upper shrinkage reinforcement for the RC slab. The study considered the effect of different values of slab thicknesses, the number of reinforcement layers, and upper concrete cover. The following conclusions can be written from this study:

- Geogrid reinforcement gives an obvious capability for resisting shrinkage strain.
- Slabs with the lowest thickness have maximum shrinkage strain and verse versa.
- As the upper cover of the geogrid shrinkage, reinforcement reduces as it is better to reduce the shrinkage strain value.
- Increasing the number of used geogrid layers increases shrinkage resisting and reduces shrinkage strain value.
- As a result of no rust in geogrids, that allows putting geogrid very near the surface which leads to more capability of shrinkage resisting and preventing surface cracks

- There is no significant effect of either geogrid existing or the number of geogrid layers on the SSR% value.

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