Influence of Rice Husk Ash (RHA) on the drying shrinkage of mortar at high replacement ratio

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Abstract

The possibility of using of rice husk ash (RHA) in the mortar was studied by performing shrinkage experiments. The impact of RHA physical properties and chemical composition on drying shrinkage of mortar is a potential problem, especially in the context of the increased use of new generation solutions and the development of new materials to ensure sustainability. In this study, the effects of RHA content, RHA particle size (fineness) and silica structure are evaluated. Comparisons are made at ages ranging from 3 days to 180 days. Incorporation of RHA resulted in lower drying shrinkage, where the drying shrinkage decreased with increasing crystalline silica content and coarse particles size when compared to the control Ordinary Portland Cement (OPC) mixture. Fine RHA exhibited the highest shrinkage value due to the effect of micro fine particles which increases its shrinkage values considerably.

Keywords: physical properties, chemical composition; fineness; drying shrinkage, crystalline silica

1.Introduction

Cracking in the concrete bridge decks is a well-documented problem. The problem is particularly severe for a large structure, such as a large concrete floor. Cracking contributes to the deterioration of the structures and allows the ingress of water to the reinforcement, which may lead to corrosion. Cracking increases the maintenance costs, reduces the service life and may result in disruptive and costly repairs. Experience shows that a combination of shrinkage and thermal stresses causes most structure cracking (Altoubat and Lange, 2001). Efforts have been made to reduce the cracking by designing concrete mixes for minimal shrinkage and improving methods of construction, placement, and finishing. Various admixtures such as silica fume (Xu and Chung, 2000), carbon fibres (Park and Lee, 1993) have been used to reduce the drying shrinkage. Moreover, recycled raw materials involved in the production process, eliminate wastes that impact the environment, and improve the technical properties of concrete, previous studies have demonstrated the feasibility of replacing cement with agro-industrial by-products. One such example is the ash obtained from burning rice husks, as rice is one of the most cultivated grains in the world. Research has shown that rice husk ash can improve concrete's mechanical properties (De Sensale, 2006) and durability (Cezar, 2011). However, few studies have focused on the influence of the rice husk ash content on drying mortar shrinkage.

2.Test procedures

The drying shrinkage of RHA mortar mixtures were measured according to the recommendations made by ASTM standards ASTM C 490 standard (ASTM Standard 2000). For each mix under investigation, four specimens with dimensions of 450mm×100mm×100mm as shown in Figure 1.a were determined for each mix composition. After preparing and mixing, each mixture was carefully filled into prism molds. The molds kept for 24h until de-molded, and then the first reading, which is the initial reading was recorded by used the apparatus measurement of drying shrinkage shown in Figure 1.b. The values of drying shrinkage represent the average of two specimens for each batch. The samples were stored in a room at 23 ± 2°C at a relative humidity of 50 ±

10% for air drying. Shrinkage readings were performed at 7, 14, 21, 28, 35, 56, 91, and 180 days. These readings were performed in an expandable comparator with a digital marker accurate to 0.001 mm.

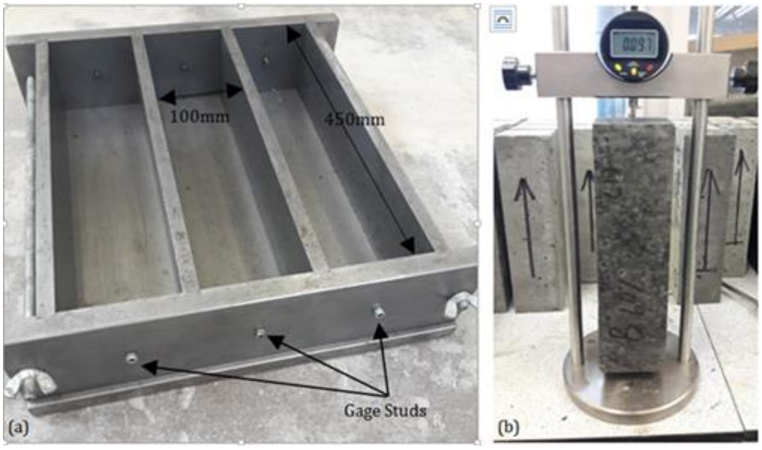

Figure1: Drying shrinkage test of OPC and RHA mortars mixtures; (a) Prism used to cast specimens, (b) Manual device used to determine the drying shrinkage change length.

3. Specimens length change measurement

To calculate the length, change in OPC and RHA mortars, the ASTM C 490 formula was used;

$$L = \frac{(Lx - Li)}{G} x100 \qquad (1)$$

Where:
L = Change in length at *x* age, %,
Lx = Comparator reading of specimen at *x* age minus comparator reading of reference bar at *x* age; in millimeters.
Li = Initial comparator reading of specimen minus comparator reading of reference bar at that same time; in millimeters
G = Nominal gauge length 250mm

4.Experimental Programme

4.1Materials

Three types of RHA (A, B and C) used in the experimental research were brought from India, RHA-D was obtained by re-burning RHA-C at relatively high temperatures (550ºC) for 6h. Properties of rice husk ash, the typical chemical composition and physical properties are given in Table 1.

Table 1: Physical properties and chemical composition of RHA samples.

Physical properties	RHA			
	A	B	C	D
Specific surface area (m^2/g)	0.537	0.587	0.692	0.808
Mean particle size (µm)	23.397	20.948	15.804	12.64

RHA sample	Chemical composition (% wt. of ash)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	P_2O_5	SO_3	MnO
RHA-A	92.10	1.066	0.241	0.719	1.366	0.403	0.076	0.109
RHA-B	89.31	1.389	0.391	0.987	1.813	0.747	1.104	0.166
RHA-C	84.30	1.066	0.175	0.729	1.522	0.675	0.083	0.144
RHA-D	93.49	1.186	0.202	0.971	1.587	0.663	0.084	0.115

4.2 Mix Proportion and Curing

The mix proportions of the batches are given in Table 2. Where the water to binder ratio (w/b) was constant at 0.50, and the fine aggregate (silica sand) used was 1320 kg/m^3.

Table 2: The mix proportion of RHA mortar drying - shrinkage test.

Batch No	Cement (kg/m^3)	RHA (kg/m^3)	Water (kg/m^3)	SP* (kg/m^3)	SP (% wt. of binder)
OPC	587	0	292	1.47	0.25%
5	558	29	292	1.47	0.25%
10	528	59	292	1.47	0.25%
15	499	88	292	1.47	0.25%
20	470	117	292	1.47	0.25%
30	411	176	290.56	2.94	0.50%
40	352	235	287.63	5.87	1.00%
50	293.5	293.5	281.76	11.74	2.00%
60	235	352	270.02	23.48	4.00%

SP*: Superplasticizer, by total weight of binder.

5. Results and discussion

The drying shrinkage results for the RHA mortars up to 60 replacement ratio are presented in Table 3 and plotted in Figure 2. These results correspond to the average micro deformations (mm/mm) of two specimens tested for each replacement ratio. In general, the drying shrinkage of all the mixes ranged from 32 to 1016 *10^{-4} mm/mm (RHA-A), 18 to 1052*10^{-4} mm/mm (RHA-B), 8 to 1242*10^{-4} mm/mm (RHA-C), 134 to 1391*10^{-4} mm/mm (RHA-D), compared to 424 to 1143*10^{-4} mm/mm (OPC mortar), over 180 days. The mixes containing RHA-A and RHA-B had values ranging from 18 to 1052 *10^{-4} mm/mm, which is considered low for OPC mortar even at 60% replacement ratio. The RHA-D displayed the highest values of drying shrinkage among all RHA mixes and even the OPC mortar reference at all replacement ratio and cured time.

Table 3: Drying shrinkage strain (mm/mm) of RHA mortars at different replacement ratios compared to OPC mortar at different ages.

Time (day)	5%RHA mortar				OPC mortar
	RHA-A	RHA-B	RHA-C	RHA-D	
3	0.0118	0.004	0.0388	0.0462	0.0424
7	0.0246	0.0224	0.0476	0.0644	0.0500
14	0.0386	0.0482	0.0580	0.0770	0.0590
28	0.0554	0.0714	0.0766	0.0990	0.0794
56	0.0758	0.0912	0.0996	0.1154	0.1004
91	0.0776	0.0980	0.1054	0.1264	0.1120
180	0.0796	0.0995	0.1068	0.1298	0.1143
Time (day)	10%RHA				
	RHA-A	RHA-B	RHA-C	RHA-D	
3	0.0112	0.0034	0.0172	0.0254	
7	0.0328	0.0214	0.0370	0.0408	
14	0.0414	0.0458	0.0502	0.0532	
28	0.0576	0.0612	0.0636	0.0742	
56	0.0646	0.0776	0.0832	0.0890	
91	0.0678	0.0816	0.0882	0.0882	
180	0.0689	0.0823	0.0891	0.1024	
	15%RHA				

Time (day)	RHA-A	RHA-B	RHA-C	RHA-D
3	0.0056	0.0018	0.0158	0.0300
7	0.0270	0.0158	0.0336	0.0396
14	0.0396	0.0390	0.0438	0.0530
28	0.0502	0.0550	0.0598	0.0680
56	0.0568	0.0662	0.0694	0.0794
91	0.0646	0.0762	0.0806	0.0862
180	0.0659	0.0785	0.0819	0.0881
Time (day)	20%RHA			
	RHA-A	RHA-B	RHA-C	RHA-D
3	0.0148	0.0046	0.0138	0.0178
7	0.0216	0.0232	0.0298	0.0358
14	0.0290	0.0362	0.0390	0.0506
28	0.0484	0.0536	0.0564	0.0660
56	0.0596	0.0646	0.0670	0.0780
91	0.0672	0.0700	0.0744	0.0840
180	0.0685	0.0711	0.0768	0.0852
Time (day)	30%RHA			
	RHA-A	RHA-B	RHA-C	RHA-D
3	0.0034	0.0032	0.0100	0.0152
7	0.0284	0.0246	0.0306	0.0400
14	0.0304	0.0334	0.0362	0.0512
28	0.0444	0.0484	0.0538	0.0648
56	0.0624	0.0670	0.0754	0.0788
91	0.0664	0.0706	0.0808	0.0890
180	0.0670	0.0723	0.0827	0.0910
Time (day)	40%RHA			
	RHA-A	RHA-B	RHA-C	RHA-D
3	0.0092	0.0110	0.0008	0.0134
7	0.0330	0.0282	0.0084	0.0406
14	0.0490	0.0464	0.0228	0.0529
28	0.0604	0.0664	0.0462	0.0730
56	0.0794	0.0848	0.0826	0.0966
91	0.0818	0.0868	0.0928	0.1016
180	0.0829	0.0881	0.0937	0.1043
Time (day)	50%RHA			
	RHA-A	RHA-B	RHA-C	RHA-D
3	0.0122	0.014	0.0076	0.0176
7	0.0388	0.035	0.018	0.0406
14	0.0590	0.056	0.0322	0.0656
28	0.0770	0.0786	0.0626	0.0856
56	0.0874	0.0892	0.0826	0.1076
91	0.0926	0.0994	0.1018	0.1164
180	0.0939	0.1002	0.1065	0.1198
Time (day)	60%RHA			
	RHA-A	RHA-B	RHA-C	RHA-D
3	0.0176	0.0144	0.0116	0.0234
7	0.055	0.0436	0.0312	0.0582

14	0.0644	0.0712	0.053	0.0768
28	0.0832	0.0872	0.0732	0.0944
56	0.0934	0.0972	0.108	0.1176
91	0.0994	0.1014	0.1242	0.1326
180	0.1016	0.1052	0.1267	0.1391

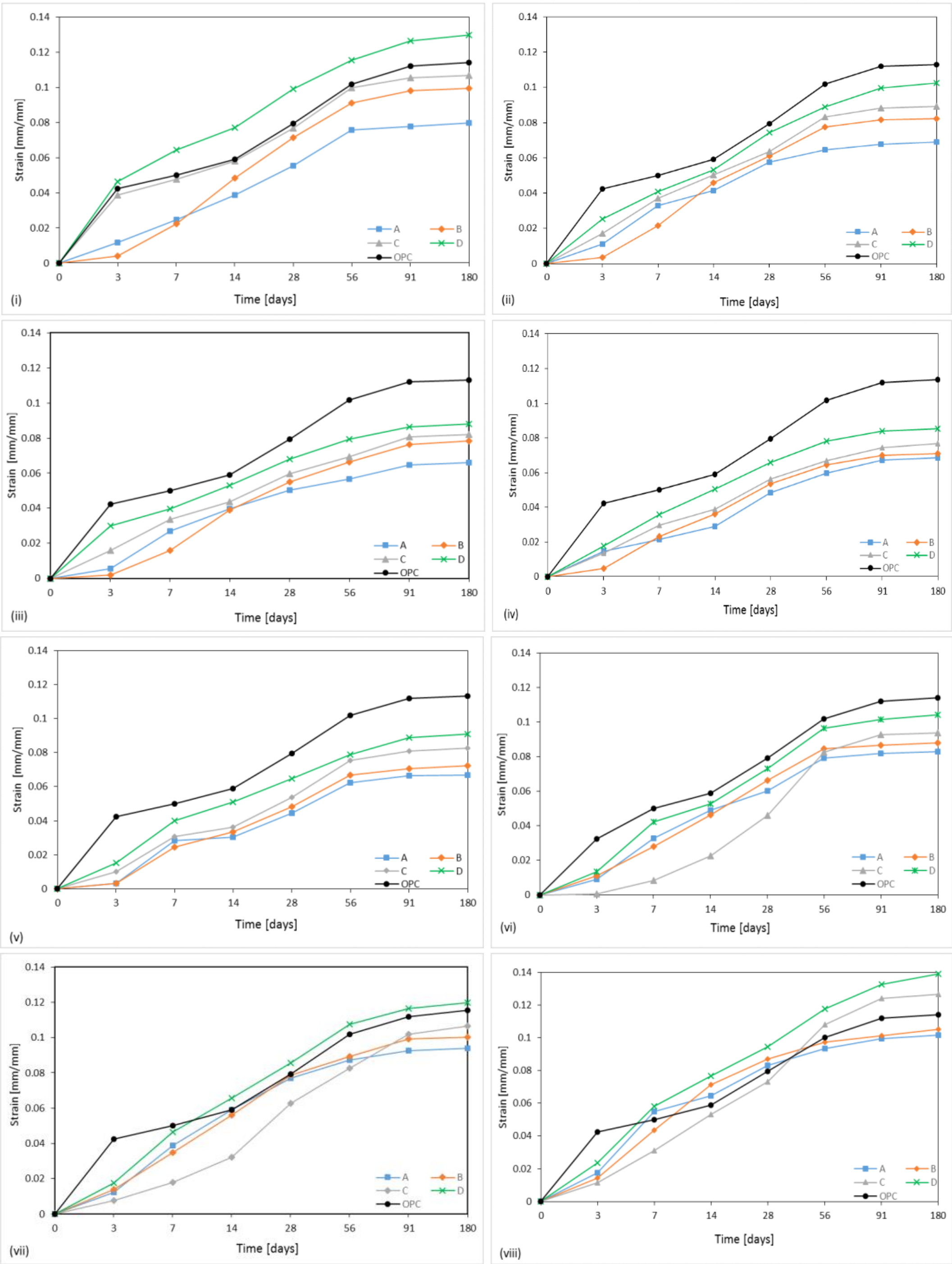

Figure 2: Effect of RHA properties to the replacement ratio on the drying shrinkage of RHA mortars compared to OPC at; (i) 5%, (ii) 10%, (iii) 15%, (iv) 20%, (v) 30%, (vi) 40%, (vii) 50%, and (viii) 60% replacement ratio.

6. Effect of RHA properties on the drying shrinkage of mortar

In consideration of Figure 3, there is a general trend on drying shrinkage decreasing with increasing replacement ratio up to 20%. This can be justified by the pozzolanic reaction and filler effects (Habeeb et al., 2009). This fact has been reported by other researchers (Zhang and Malhotra, 1996 and Chatveera and Lertwattanaruk, 2011). The results correspond to the average drying shrinkages (10^{-4} mm/mm) of the two specimens tested for each mix. Generally, it can be take in consideration that RHA-D at 5% replacement ratio exhibited higher drying shrinkage than that of reference mortar about 12.25% at all ages. The increases in drying shrinkage strain of RHA-D at 5%, can be justified by the pozzolanic reaction and filler effects (Habeeb et al., 2009). However, RHA-C (silica 100% amorphous) exhibited lower drying shrinkage compared to OPC mortar at 5% replacement ratio. This behavior of RHA-C specimens can be attributed to the high residual carbon content (loss on ignition). On the other hand, the drying shrinkage of RHA mortar specimens was noticeably reduced by the addition of RHA-A and B. Specimens at 180 days showed a reduction in drying shrinkage strain by 30.11% and 12.64% compared to OPC. Implementation of RHA partially crystalline silica with coarse particles size provides a positive effect on the drying shrinkage of mortar, which is attributed to the filler effect.

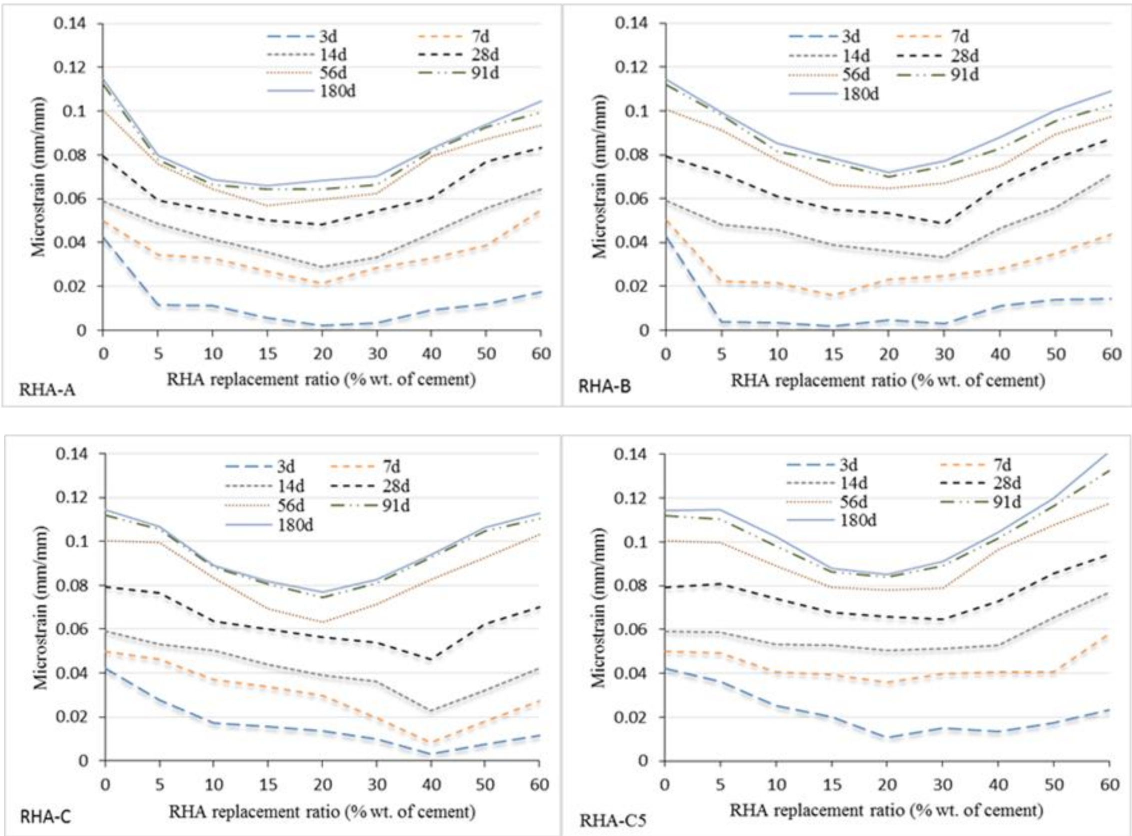

Figure 3: Correlation between drying shrinkage of OPC and RHA mortar to RHA replacement ratio.

7. Effect the fineness of RHA particles

Based on the experimental results the RHA mean particle size, amorphous silica percentage are particularly effective on the drying shrinkage of RHA mortars performance. Generally, there is a linear correlation between the mean particle size distributions to the development of drying shrinkage of RHA mortars which is presented in Figure 4. This correlation was determined for 20% RHA; however, it's same for other RHA replacement ratios. Mortar specimens containing RHA-C and D with a particles size of 15.804μm and 12.64μm, exhibited higher drying shrinkage compared to RHA-A and B with 23.397µm and 20. 948µm, respectively. According to Habeeb and Fayyadh (2009) RHA with fine particles significantly affected on the drying shrinkage of concrete mixtures containing 20% RHA, Thus, it can be concluded that the addition of RHA content higher amount of micro fine particles to mortar would increase the drying shrinkage.

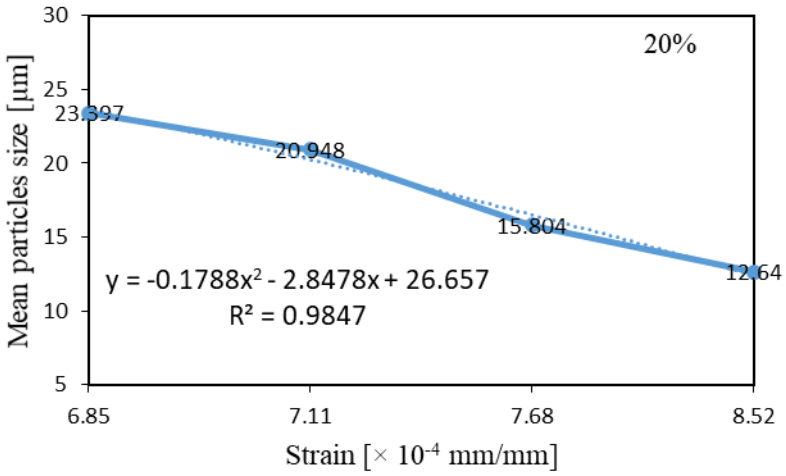

Figure 4: The relationship between particles size distribution to the silica structure of RHA particles on the drying shrinkage performance of RHA mortars.

8. Conclusion

i. The drying shrinkage was significantly affected by RHA silica structure and fineness of particles. RHA-D (finer particles) recorded the higher shrinkage value, while RHA-A exhibited lower values than the control, this could be due to the effect of the micro fine particles.
ii. Strains due to drying shrinkage are ranged from 1016 to 1391 $\times 10^{-4}$ (mm/mm) at 180 days.
iii. The parameters affecting the drying shrinkage strain are RHA silica structure, size of RHA grain particles and replacement ratio.
iv. The effective mean particle size of RHA on mitigating drying shrinkage of RHA mixtures was suggested based on the experimental results to be over 20.0µm. Where with coarser particles size less drying shrinkage reported.
v. Maximum drying shrinkage development registered was in between 3 to 7 days for all RHA mortars mixtures.
vi. As the proportion of replacement ratio increases from 5% to 15% RHA-A, and 20% RHA-B, C and D, the drying shrinkage of the mortar decreased, beyond this limitation the shrinkage increased again.

Table 4: Effect of RHA properties on the drying -shrinkage of mortar at different ages.

RHA%	Strain (mm/mm)													
	RHA-A							RHA-B						
	3	7	14	28	56	91	180	3	7	14	28	56	91	180
5	-0.0118	-0.0246	-0.0386	-0.0554	-0.0758	-0.0776	-0.0796	-0.004	-0.0224	-0.0482	-0.0714	-0.0912	-0.098	-0.0995
10	-0.0112	-0.0334	-0.0414	-0.0576	-0.0646	-0.0678	-0.0689	-0.0034	-0.0214	-0.0458	-0.0612	-0.0776	-0.0816	-0.0823
15	-0.0056	-0.0270	-0.0396	-0.0502	-0.0568	-0.0646	-0.0659	-0.0018	-0.0158	-0.0390	-0.0550	-0.0662	-0.0762	-0.0785
20	-0.0148	-0.0216	-0.0290	-0.0484	-0.0596	-0.0652	-0.0685	-0.0046	-0.0232	-0.0362	-0.0536	-0.0646	-0.0700	-0.0711
30	-0.0034	-0.0284	-0.0304	-0.0444	-0.0624	-0.0664	-0.0670	-0.0032	-0.0246	-0.0334	-0.0484	-0.0670	-0.0706	-0.0723
40	-0.0092	-0.0330	-0.0490	-0.0604	-0.0794	-0.0818	-0.0829	-0.0110	-0.0282	-0.0464	-0.0664	-0.0848	-0.0868	-0.0881
50	-0.0122	-0.0388	-0.059	-0.0770	-0.0874	-0.0926	-0.0939	-0.0140	-0.0350	-0.0560	-0.0786	-0.0892	-0.0994	-0.1002
60	-0.0176	-0.0550	-0.0644	-0.0832	-0.0934	-0.0954	-0.1016	-0.0144	-0.0436	-0.0712	-0.0872	-0.0972	-0.1004	-0.1052

RHA%	Strain (mm/mm)													
	RHA-C							RHA-D						
	3	7	14	28	56	91	180	3	7	14	28	56	91	180
5	-0.0388	-0.0476	-0.0580	-0.0766	-0.0996	-0.1054	-0.1068	-0.0462	-0.0644	-0.0770	-0.0990	-0.1154	-0.1264	-0.1298
10	-0.0172	-0.0370	-0.0502	-0.0636	-0.0832	-0.0882	-0.0891	-0.0254	-0.0408	-0.0532	-0.0742	-0.0890	-0.0996	-0.1024
15	-0.0158	-0.0336	-0.0438	-0.0598	-0.0694	-0.0806	-0.0819	-0.0300	-0.0396	-0.0530	-0.0680	-0.0794	-0.0862	-0.0881
20	-0.0138	-0.0298	-0.0390	-0.0564	-0.0670	-0.0744	-0.0768	-0.0178	-0.0358	-0.0506	-0.0660	-0.0780	-0.0840	-0.0852
30	-0.0100	-0.0306	-0.0362	-0.0538	-0.0754	-0.0806	-0.0827	-0.0152	-0.0400	-0.0512	-0.0648	-0.0788	-0.0890	-0.0910
40	-0.0008	-0.0086	-0.0228	-0.0462	-0.0806	-0.0928	-0.0937	-0.0134	-0.0406	-0.0592	-0.0730	-0.0966	-0.1016	-0.1043
50	-0.0076	-0.0180	-0.0322	-0.0626	-0.1064	-0.1018	-0.1065	-0.0176	-0.0424	-0.0656	-0.0856	-0.1076	-0.1164	-0.1198
60	-0.0116	-0.0312	-0.0530	-0.0732	-0.1120	-0.1242	-0.1267	-0.0184	-0.0532	-0.0768	-0.0944	-0.1176	-0.1296	-0.1421

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