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EFFECT OF WATER-CEMENT RATIO ON PERFORMANCE OF SEAWEED-MODIFIED MORTARS

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Abstract

The influence of water-cement ratio and cement content on the performance of seaweed-modified (Gracilaria Sp.) mortar was investigated in this study. The experiment was performed using seaweed-modified and unmodified mortars with different water-cement ratios. The modified mortars contained different cement percentages ranged between 21%-30%. The water-cement ratio varied from 0.33-0.6. The flexural strengths of unmodified samples responded insignificantly to the change of water-cement proportion or cement rate. Compressive and flexural strengths of the modified mortars were increased with the higher cement proportions. For higher cement portions and low water-cement proportions, the adhesion strength of the modified samples was enhanced under the wet condition. Shrinkage and water absorption of the modified samples increased with growth of cement proportion and constant water-cement ratio. The scientific application of this green technology can make the concrete environment friendly and greatly reduce the carbon-di-oxide emission as well. The commercial application of this technology can contribute to the cost reduction of the production process.

Keywords: Seaweed powder (Gracilaria Sp.); Water-Cement Proportion; Cement Portion.

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1. Introduction

The effect of the water-cement proportion and cement percentage on the performance of the mortars is apparent (Singh, Munjal, & Thammishetti, 2015). The cement producers have reported that higher water content decreases compressive strength of concrete, but low moisture content leads to poor workability (Popovics & Ujhelyi, 2008).The effect of cement proportion and w/c proportion on the flexural strength of seaweed- modified mortars has not been studied yet, (Lee, Cho, Choi, & Kim, 2016) reported an apparent relationship between compressive and flexural properties of concrete.

2. Problem Statement

In particular, flexural strength changes in a range of 5 to 8 N/mm^2. This strength reduces to a greater magnitude with the increase of W/C ratios compare with compressive properties of concrete (Mohamed, 2016). The effect of cement proportion and w/c ratio on adhesion strength of the seaweed-modified composites has not been studied yet, (Yoo, Kim, Park, Park, & Kim, 2017). reported the effect of higher cement proportion and W/C ratio while the shrinkage of cement mortars was enhanced. In the present work, if all these literatures stated above are still valid when seaweed-modified mortars are used. The experiments were performed by modified and unmodified samples. Particulars of the experiments have been discussed in materials and methods subdivision. Also, the effect of Seaweed powder (Gracilaria Sp.) at a solid resin: cement proportion of 0.1 and the effect of shrinkage decreasing proxy at fixed admixture: cement proportion of 0.006 were added. The seaweed- modified mortars may be used for the renovation of concrete.

3. Research Questions

What is the effect of W/C ratio and cement proportion on the performance of seaweed modified mortar has not been studied till to date?

4. Purpose of the Study

To study the effect of W/C ratio and cement proportion on the performance of seaweed modified mortar was the main objective of this paper.

5. Research Methods

All the experiments were carried out with a portland cement CEM l strength class 42.5 N and a sand mixture according to MS EN 197-1. The following were also used:

Seaweed powder (Gracilaria Sp.) (Supplied by Eastern Pretech (Malaysia) Sdn Bhd), shrinkage reducing agent MAPECURE SRA 25, wetting agent (INNOVA PA 920), defoamer (BEVALOID 581B), fly ash (ST-Filler, Keller Dortmund) Micro-silica (Newreach).

The sand proportion was constantly fixed to attain hundred portions.

5.1. Design 1

Table 01. Properties of Design 1

Component	**Percentages**			
CEM I 42.5N	21	24	27	30
Sand Mixture	71.5	68.3	65.1	61.8
Seaweed Powder (Gracilaria Sp.)	2.1	2.3	2.5	2.8
Fly ash	3.9	3.9	3.9	3.9
Defoamer	0.18	0.18	0.18	0.18
Microsilica	1.1	1.1	1.1	1.1
Wetting agent	0.11	0.11	0.11	0.11
Shrinkage Reducing Agent	0.11	0.11	0.11	0.11

5.2. Design 2

For the unmodified mortars the MS EN 197-1 standard was followed and continued with sand mix by MS; design was maintained to hundred portions with a different proportion of sand portion. The cement proportion ranged within 16–50% of mixture. Mixing of the mortars was performed according to MS EN 197-1 in a Rometa-Mixer machine. The properties of mortar workability were listed in Table 1 which were determined by MS EN 197-1 standard. The moisture absorption capacity was determined by using 40.40.160 mm bars kept for 3 weeks in ideal condition (24° C, fifty percent relative humidity, seven days beneath water). The modified samples were kept under four unlike curing states and experimented at several periods for compressive and flexural strength, and shrinkage. Both of these strengths were determined by following MS EN 197-1 standard. The adhesion bond has been determined by adding the mortar of 10 mm layer on a composite block. The adhesion strength has been determined according to MS EN 197-1 standard. The samples were subjected to core-drill by mortars into the substrate before the experiment. A metal disc was installed at the edge of the core by an adhesive. The samples have been subjected to direct tension test at a loading condition of two hundred and fifty Newton per second. Shrinkage was tested by MS EN 197-1 standard using bars of 40. 40. 160 mm.

6. Findings

6.1. Compressive strength

Table 3 showed that a decrease in water-cement proportion produced an increased compressive strength of the modified samples for all states. Air content of the mortars remained fixed (Table 2). Outcomes showed that polymer-modified samples act similarly as unmodified samples (Table 5). Weighing design 1 with and without seaweed powder (Gracilaria Sp.) at the similar water-cement proportion of 0.48, thermoplastic polymer decreases compressive strength of the sample (Łukowski, 2016). Figure 1 revealed that after 90 days of storage in typical condition the cement ratio in the samples was not a critical issue for compressive force. In particular, for the equal water-cement proportion, the modified samples of the increased cement ratio showed less compressive strength. The same result has been observed in Table 4 for the unmodified samples. The various slump characteristics were listed in Table 2.

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Table 02. Workability of preparation 1

	W/C Ratio	Air Content (%)	Slump Values (cm) without/with strokes
Cement 21%	.48	7.4	9/14.4
	.52	5.7	9/15.4
	.56	4.9	9/16
	.6	4	10/17.5
Cement 24%	.41	5.9	9/13
	.45	5.7	9/14
	.49	5.5	9/16
	.52	4.9	9.5/17
Cement 27%	.37	6.9	9/12
	.4	6.4	9/13
	.43	5.7	9/14
	.46	5.1	9/15.5
Cement 30%	.33	6	9/11
	.36	5	9/12
	.38	4.1	9/13.5
	.41	4.5	9/15
Without Seaweed Powder (Gracilaria Sp.) cement 21%	.48	4	9/11.5

6.2. Flexural strength

The effect of water-cement proportion on flexural strength of extremely modified samples changes for distinct storing environments. The changes were shown in Table 5. During always-dry state (First 28 days and then 90 days in normal weather) a slight enhancement in the flexural strength was observed with lower water-cement proportion at a fixed cement concentration in mix-design. During storing in water and Calcium hydroxide, a significant enhancement of flexural strength with the lower water-cement proportion. Figure 2 showed these effects at a 27% cement concentration in design 1. Besides, the unmodified mortars showed a slight increase in the flexural strength with lower water-cement proportions from 0.41–0.61 (Table 4). Thus, the flexural strength was low in comparison with modified samples at the same water-cement proportions and cement concentrations (Figure 2). Moreover, in design 2 a slight enhancement of flexural strength was observed for higher cement levels (Table 4). It has been reported that the flexural strength was enhanced by a polymer addition to a re-dispersible powder (Argyrou, Thompson, Cho, & Berzins, 2016). The polymer was attached to the pore structure of toughened mortar and reinforced it (Siddique & Wahid, 2017). For the higher water-cement proportions of the samples with same polymer concentration, the amount of polymer per volume was reduced. Moreover, this was factual in the dry condition as the more water level generated more pore size of dry sample. The influence of the polymer was decreased, because of the small polymer degree in the mortar. During wet condition, a second influence had to be considered. Figure 3 showed that for the lower water-cement proportion, water absorption of the sample was decreased, i.e. the mortars contained lower water. The force among the polymeric substance in mortar and mineral substance of nature were from van der Waals, acid/base feature and were highly dominated by water with higher dielectric force. By reducing water intake of the

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sample by decreasing water-cement proportion, dwindling influence of water on the dynamic binding strengths in modified sample was refrained. The variation of flexural strength between dry and wet condition became insignificant for an absorption rate of less than 3% (Fig. 3).

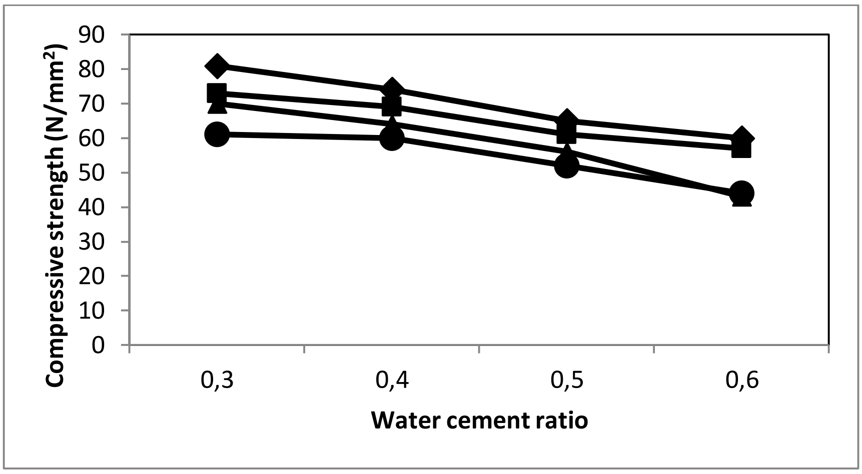

Figure 01. Compressive strengths for preparation 1 at 90 days of normal climate, where ♦- 30% cement, ■-27% cement, ▲- 24% cement and ●- 21% cement.

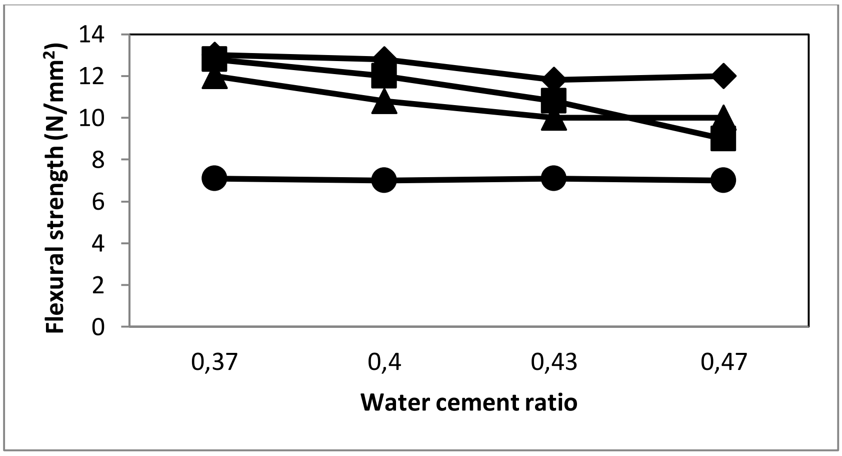

Figure 02. Flexural strengths for preparation 1 with 27% cement and preparation 2 with 26% cement, where ♦- 28 days in normal climate, ■-21 days in normal climate, 7 days in water, ▲- Calcium hydroxide, 28 days at normal climate and ●- preparation 2 normal climate.

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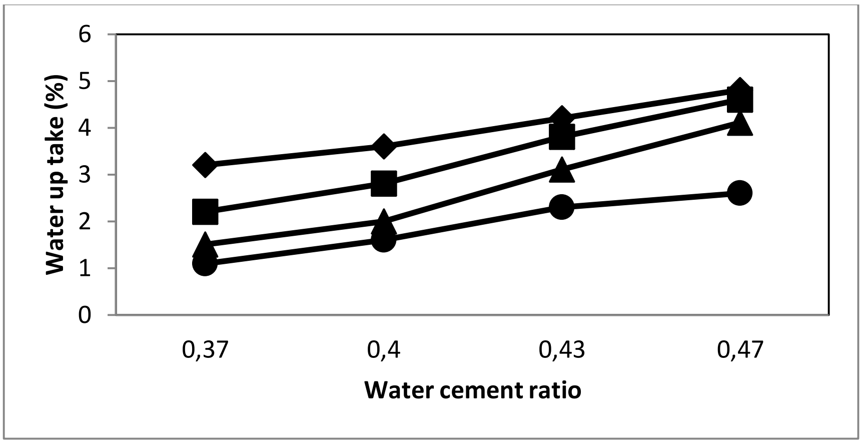

Figure 03. Water absorption at 7 days for preparation 1 at 21 days of normal climate, where ♦- 30% cement, ■-27% cement, ▲- 24% cement and ●- 21% cement.

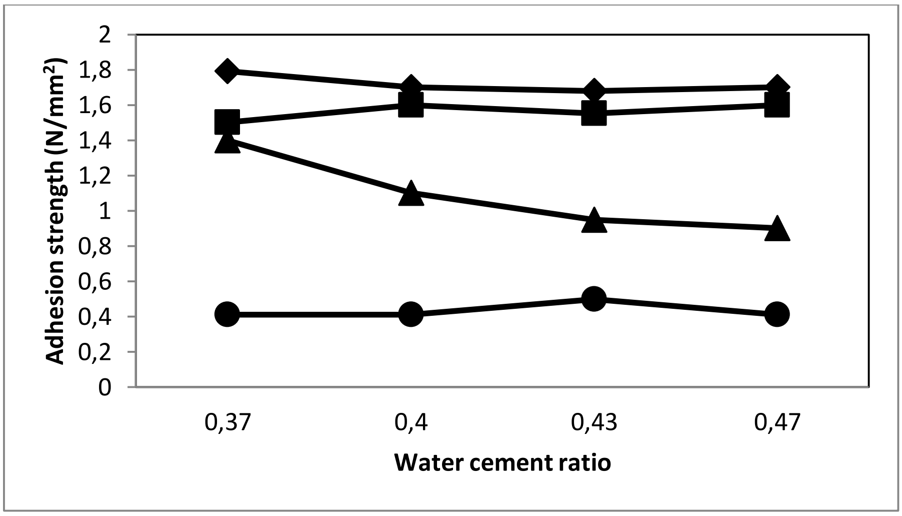

Figure 04. Adhesion strengths of preparation 1 with 27% cement and preparation 2 with 26% cement, where ♦- 28 days in normal climate, ■-21 days in normal climate, 7 days in water, ▲- Calcium hydroxide, 28 days at normal climate and ●- preparation 2 normal climate.

6.3. Adhesion strength

The addition of mortars to film developing thermoplastics, such as seaweed powders, increased the adhesion bonding on different materials significantly. This was the principal cause for the global application of this material (S.-J. Lee, Kim, & Won, 2017). Due to the less adhesion and the weaknesses integral bonding of the unmodified sample in the thin coating on roofs, the bond strength after storing with Calcium hydroxide state could not be measured as the mortars were already damaged after core-drilling. The adhesion strength of these modified mortars after the pull-off test was approximately 0.15–0.4 N/mm2. This strength was significantly increased after the polymer modification (Table 6). In addition, Table 6 showed that the adhesion strength of the modified sample under dry condition (kept at normal weather for 28 to 90 days) with the equivalent cement concentration was independent of the water-cement proportion of the design (for an instance, with 21 to 24% of cement concentration and the standard deviation of result). With the increase of the cement proportion, the adhesion strength was also

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improved, but the effect of the polymer was much greater than the effect of the cement ratio. The adhesion strength of the modified sample was weaker than that of the dry state under wet condition (kept in the typical weather for 21 days and subsequently one week under water), but still greater than that of the adhesion of the unmodified mortar (Figure 4). No effect of the water-cement proportion was observed above a water-cement proportion of 0.41. The adhesion strength was improved for a water-cement proportion lower than 0.41. This result was compared to the flexural strength of the lower water absorbing mortars. The influence was likely the same as clarified previously for flexural strength.

6.4. Shrinkage

Shrinkage of the mortars depends on the water-cement proportion and the cement concentration (Piasta & Zarzycki, 2017). With the increase of the water-cement ratio, in addition to an increased cement portion of the mortar, shrinkage of the toughening sample was enhanced (Figure 5).

Table 03. Compressive strength (N/mm2) of preparation 1, bars 40.40. 160 mm

	W/C ratio	28 days in normal climate (N/mm^2)	21 days in normal climate, 7 days in water (N/mm^2)	28 days at normal climate* (N/mm^2)
Cement 21%	0.48	52±1	46±1	60±1
	0.52	48±1.5	41±1.5	57±0.9
	0.56	44±0.3	38±1.5	43±0.9
	0.6	38.1±0.7	31.1±1.5	43±1
Cement 24%	0.41	56.7±1.5	51±1.5	65±0.9
	0.45	52.4±1.5	46.2±1.5	61±1
	0.49	48.1±1	42±1.5	56±1
	0.52	45±.6	37±1	52±0.5
Cement 27%	0.37	62±1	56±1	74±1
	0.4	58±1.5	53±1.5	69±0.5
	0.43	54±1	47±1	64±1
	0.46	49±0.5	42±0.5	60±1
Cement 30%	0.33	67±1.5	57±0.5	81±0.3
	0.36	62±1.5	55.2±0.5	73±1
	0.38	59±0.5	53±1	70±1
	0.41	53±0.5	45±0.3	61±1.5
Without Seaweed powder (GracilariaSp.) cement 21%	0.48	58±1.5	54±1.5	61±1.5

Table 04. Flexural and Compressive strength (N/mm2) of preparation 2, bars 40.40. 160 mm

Cement Content (%)	W/C ratio	Air Content (%)	Flow (N/mm^2)	Flexural strength (N/mm^2)	Compressive strength (N/mm^2)
16	0.68	7.8	9/14	6.2±1	22.1±2.4
21	0.54	5.4	9/16	6.7±0.9	29±2.7
26	0.49	4.8	9/17	7.2±0.9	33±2.7
31	0.44	3.8	10/19	7.3±0.9	40±2.6
36	0.41	2.9	9/17	7.3±1	41±2.6

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41	0.37	2.9	9/17.5	7.5±1	45.5±2.5
46	0.34	3.5	10/20	7.7±1	49.2±2.6
51	0.34	2.9	9.5/20	7.4±1	49.4±2.5
26	0.40	3.5	9/9	7.2±1	52.3±2.6
26	0.43	3.7	9/12.5	7.6±0.5	46.5±1
26	0.46	4	9/14	7.3±1	41.5±1
26	0.49	3.9	9/15.5	7.2±1	37.4±1.5
26	0.54	2	9.5/19	6.8±0.9	30.5±1.5
26	0.59	1.2	13/21.5	7±1	26.8±1

** Both series were produced with different cement lots. Storage 28 days normal climate

6.5. Water absorption

Water enters into the pores of the mortar. Thus, a mortar sample having a lower pore size had a lower liquid absorption. The water absorption of the modified samples was decreased with a lower water-cement proportion when compared with the unmodified samples (figure 4). For the higher cement concentration samples with the fixed water-cement proportion, the absorption increased.

Table 05. Flexural strength (N/mm^2) of preparation 1, bars 40.40. 160 mm

	W/C ratio	**28 days in normal climate (N/mm^2)**	**21 days in normal climate, 7 days in water (N/mm^2)**	**90 days normal climate* (N/mm^2)**	**28 days at normal climate* (N/mm^2)**
Cement 21%	0.48	12.3±0.5	9.45±1	12.8±1	9.6±1
	0.52	11±1	8.4±1.5	12±0.9	9.5±0.9
	0.56	11±0.5	7.12±1	10.5±0.9	8.9±0.9
	0.6	9.7±0.5	7.12±1	10.5±1	6.5±1
Cement 24%	0.41	12.8±1.5	10.4±0.5	13±0.9	9.9±0.9
	0.45	12.4±1.5	9.5±1	12.5±1	9.7±1
	0.49	11.3±1.5	8.2±1	11.3±1	8.7±1
	0.52	11.1±0.5	7.5±1.5	11.6±0.5	8.7±1
Cement 27%	0.37	13.3±1.5	12.8±1	13±1	7.8±0.5
	0.4	13±1	11.3±1	12±0.5	11.8±1
	0.43	12.5±1	10.3±1	11.2±1	11.7±0.5
	0.46	11.6±0.5	8.5±1	11.8±1	10.2±1
Cement 30%	0.33	13.4±1.5	13.3±0.5	13.3±0.3	12.2±1.5
	0.36	12.7±1.5	11.5±0.5	12.3±1	12±1
	0.38	13.2±0.5	11.3±1	13.7±1	11±1
	0.41	12.8±1	9.2±0.3	13.1±1.5	9.5±1.5
Without Seaweed powder (GracilariaSp.) cement 21%	0.48	7.5±0.5	7.9±0.3	7.5±1	6.8±0.5

** Calcium hydroxide, 28 days at normal climate, 28 days in saturated Calcium hydroxide solution at 50 °C, 34 days in normal climate. Normal climate =23°C, 50% relative humidity.

Table 06. Adhesion strength (N/mm2) of formulation 1, bars 40. 40. 160 mm

	W/C ratio	**28 days in normal climate (N/mm^2)**	**21 days in normal climate, 7 days in water (N/mm^2)**	**90 days normal climate* (N/mm^2)**	**28 days at normal climate* (N/mm^2)**
Cement 21%	0.48	1.33±0.05	0.83±0.02	1.41±0.07	1.89±0.16
	0.52	1.35±0.05	0.94±0.16	1.4±0.06	1.67±0.16

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	0.56	1.37±0.6	1.05±0.02	1.37±0.05	1.7±0.16
	0.6	1.35±0.5	0.96±0.16	1.37±0.05	1.75±0.06
Cement 24%	0.41	1.38±0.1	0.97±0.5	1.64±0.06	1.79±0.16
	0.45	1.52±0.09	0.97±0.16	1.58±0.06	1.95±0.06
	0.49	1.44±0.09	0.96±0.16	1.43±0.06	1.73±0.06
	0.52	1.46±0.05	1.1±0.05	1.46±0.07	1.75±0.16
Cement 27%	0.37	1.53±0.05	1.38±0.16	1.71±0.06	1.77±0.16
	0.4	1.61±0.15	1.07±0.16	1.72±0.06	1.66±0.06
	0.43	1.55±0.08	0.93±0.09	1.68±0.05	1.65±0.16
	0.46	1.58±0.5	0.87±0.09	1.58±0.06	1.68±0.06
Cement 30%	0.33	1.74±0.35	1.48±0.5	2.1±0.05	1.72±0.16
	0.36	1.73±0.16	1.44±0.02	1.92±0.05	1.82±0.16
	0.38	1.53±0.16	1.14±0.16	1.73±0.06	1.58±0.06
	0.41	1.59±.15	1.05±0.16	1.69±0.06	2.14±0.16
Without Seaweed powder (GracilariaSp.) cement 21%	0.48	0.51±0.05	0.31±0.19	0.38±0.1	Destroyed

** Calcium hydroxide, 28 days at normal climate, 28 days in saturated Calcium hydroxide solution at 50 °C, 34 days in normal climate. Normal climate =23°C, 50% relative humidity.

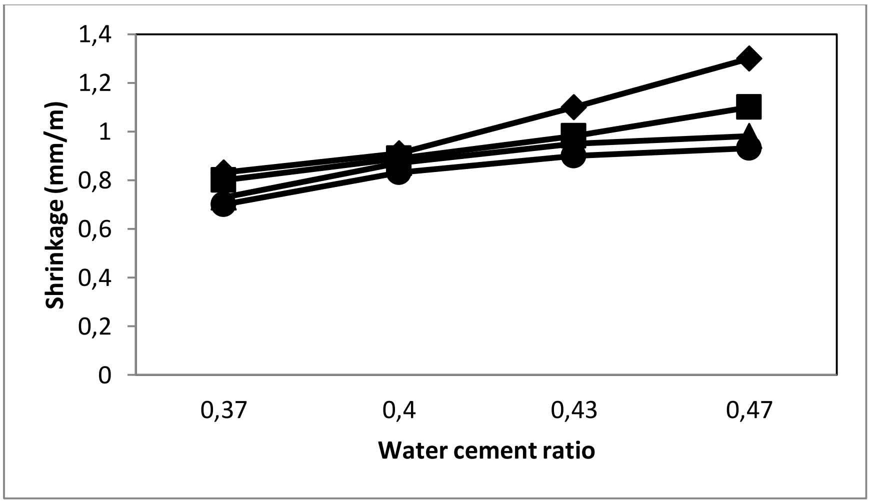

Figure 05. Shrinkage of preparation 1 at 56 days of normal climate, where ♦- 30% cement, ■-27% cement, ▲- 24% cement and ●- 21% cement.

7. Conclusions

The effect of water cement proportion and cement concentration on the features of polymer-modified mortars (applied for concrete repair works) had the same effect for unmodified mortars. Compressive strength was reduced with higher water cement proportion, and the cement concentration was of negligible effect. Shrinkage and water absorption were enhanced with the higher water cement proportion and cement level. The flexural strength of unmodified samples at water-cement ratios of 0.41–0.61 was almost independent of water cement proportion and cement level. The flexural strength of the polymer-modified samples was increased than the unmodified samples. The flexural strength of the modified samples at the higher water-cement proportion was reduced slightly after 28 and 90 days storing in an ideal climate. On the other hand, after underwater storage of the modified samples, there was a considerable decrease in the flexural strength with higher water-cement proportions. The effect of the

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cement concentration on the flexural strength of the mortars was not of first order. The adhesion strength of the polymer-modified sample was much greater in comparison to that of the unmodified sample; there was only a minor influence of the water-cement proportion, and an increasing cement concentration increased the adhesion. The outcome of this work fits exactly into the concept of the composite compound, as the polymer-modified samples showed. Both binders acted in collaboration: cement being the inorganic binder was accountable for mechanical solidity regarding compressive strength and the seaweed powder being the organic one was performing as a reinforcement and was responsible for inner tensile strength and outer adhesion-bond strength. As both binders were working simultaneously, the new polymer-modified mortars may reach to the industrial revolution that unmodified mortars cannot.

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