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RESEARCH ARTICLE

Correlations between different shrinkage parameters and expansion of paste and mortar containing limestone fines

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ABSTRACT: Shrinkage is definitely a crucial parameter for long-term sustainability of cement paste, mortar and concrete structures. This paper examines the correlation between different shrinkage parameters of paste and mortar with different percentage of limestone fines (LF). Furthermore, the correlation between each shrinkage parameter and compressive strength, and between expansion and compressive strength are also investigated. In the experimental program, cement was substituted with different percentages of LF (0, 5, 10, 15 and 20% by mass). For paste and mortar mixtures, the water to binder ratio (w/b) was 0.45 and the sand to binder ratio (s/b) was 2. Results indicated that there is a positive linear relationship between length change and the percentage weight change. Similarly, there was a positive correlation between expansion and compressive strength for pastes and mortars. However, there was a negative correlation occurring between both shrinkage parameters and compressive strength. As shrinkage increased, the compressive strength dropped.
Keywords: Correlation, paste, mortar, shrinkage, expansion

1. INTRODUCTION

Nowadays, the long-term serviceability of concrete buildings is threatened by the evolution of cracks. The main cause of these cracks is length changes of concrete due to shrinkage, which are inevitable and can be assigned to several reasons over the short and long-term of concrete life. The main types of shrinkage responsible for these cracks are autogenous shrinkage, drying shrinkage, and expansion. Autogenous shrinkage is an important phenomenon. İt is stated as the macroscopic reduction in the external diameter of cement particles with no transfer of moisture in or out of the matrix. It depends on w/c ratio, whereas the lower w/c ratio contributes to higher autogenous shrinkage [1]. On the other hand, drying shrinkage results due to the non-uniform moisture distribution in the matrix. The reduction of water content in the matrix is mainly due to the surrounding environmental conditions. Concerning expansion, it is defined as the length extension of specimens cured in water. Based on previous experimental studies, the inclusion of supplementary cementitious materials has a great influence on concrete shrinkage [2-10]. One of these materials is limestone. It consists of calcium carbonate and is used in many concrete applications. Limestone fines (LF) play an intrinsic role in the cement hydration process.

During the hydration reaction, the cement, LF, and water react to form hydrate products. This reaction causes an overall reduction of volume in the matrix known as chemical shrinkage. The total reduced volume is related to the hydration products having a smaller volume than the reactants and is made up of two components [11, 12]: a) internal volume change through the formation of capillary voids, b) external volume changes due to self-desiccation (Autogenous Shrinkage). Before initial setting, the chemical and autogenous shrinkage are approximately equal to one another. After initial setting the autogenous shrinkage is no longer directly related to the chemical shrinkage, and is a

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result of self-desiccation. Regarding drying shrinkage, it takes place after the harden of matrix.

2. MATERIALS AND METHOD

2.1 Materials

In the framework of this study, Type I Portland cement PA-L 42.5 N was used with a specific gravity, Blaine surface area and density of 3.15, 399.8 m^2/kg and 1440 kg/m^3 respectively. LF was incorporated with a density, Blaine surface area and specific gravity of 2700 kg/m^3, 394 m^2/kg, 2.74 respectively. LF had a fine particle size less than 300 μm. The siliceous sand used in this experiment had a fineness modulus of 2.8.

2.2 Mix proportions

Ten different mixes were prepared in this program: five paste mixes and five mortar mixes where a portion of cement was substituted with LF. Cement was replaced by LF with the following percentages by weight: 0, 5, 10, 15 and 20. The water to binder ratio (w/b) and sand to binder ratio (s/b) are 0.45 and 2 respectively. The details of mixes are listed in Table 1.

Table 1: Details of paste and mortar mixes.

	Quantity (kg/m^3)			
Paste/mortar code	**Cement**	**LF**	**Sand**	**Water**
P0	1303	0	-	586
P5	1237	66	-	586
P10	1177	126	-	586
P15	1123	180	-	586
P20	1074	229	-	586
M0	657	0	1314	296
M5	625	32	1314	296
M10	595	62	1314	296
M15	569	88	1314	296
M20	544	113	1314	296

2.3 Sample preparation and testing

Prism samples measuring 25x25x300 mm^3 were cast in steel molds for the two types of shrinkage (autogenous and drying) as well as for expansion. After 24 h, the samples were demolded, weighted and ready for testing. Two demec points at 200 mm on two sides of the samples were fixed for taking the readings. The measurement of shrinkage and expansion specimens was recorded by a dial gauge as shown in Figure 1. The length and weight change of the samples were measured every 2 days up to 90 days and were calculated using Equation (1) and Equation (2) respectively:

$$LC = \frac{L_0 - L_i}{200} \times 10^6 \quad (1)$$

Where LC is the length change (με); L_0 is the initial length recorded by the dial gauge (mm) and Li is the length recorded by dial gauge at different days (mm).

$$WC = \frac{W_0 - W_i}{W_0} \times 100\% \quad (2)$$

Where WC is the percentage weight change; W_0 is the initial weight of specimen (g) and W_i is the weight of specimen at different days (g).

Autogenous shrinkage and expansion tests were conducted according to ASTM C192 [13], while for drying shrinkage test, it was performed according to ASTM C157 [14]. Shrinkage and expansion specimens are shown in Figure 2. The samples related to autogenous shrinkage were sealed with plastic bags to avoid any external environmental conditions. For drying shrinkage, the samples were placed in a room with constant temperature (25˚C) and relative humidity of 50±3%. For expansion specimens, they were immerged in water at a constant temperature (20˚C). Besides, cubes with a dimensions of 5x5x5 mm^3 were prepared to conduct the compressive strength at 1, 7, 28 and 90 days according to ASTM C109 [15].

Figure 1: Dial gauge.

Figure 2: Drying shrinkage, autogenous shrinkage and expansion samples.

3. RESULTS AND DISCUSSION

3.1 Drying shrinkage

The evolution of drying shrinkage of paste and mortar samples with the addition of LF for a total period of 90 days is presented in Figures 3 and 4 respectively. As revealed from these plots, drying shrinkage increases as LF % increases. As shown in Figure 3, at 90 days, when LF content is 5%, 10%, 15% and 20%, the drying shrinkage of pastes increases by 47.36%, 78.94%, 89.47% and 99.4% respectively compared to the control mix. Same trend is observed for mortar specimens. For example, at 90 days, the percentage increase is 17.64%, 35.29%, 41.17% and 88.24% for 5%, 10%, 15% and 20% LF replacement level respectively (Figure 4). There are two hypotheses, which could explain this fact: 1) the fine pore size of LF contributes in refining the empty pores resulted from the hydration process. This inclusion required extra water to improve paste or mortar workability and simultaneously increases the drying shrinkage [16]; 2) the increase of drying shrinkage magnitude of both specimens indicates the presence of extra water in their pores, which was then evaporated with time. This reduction activates the self-desiccation of internal capillaries and will cause the shrinkage of paste and mortar samples [17].

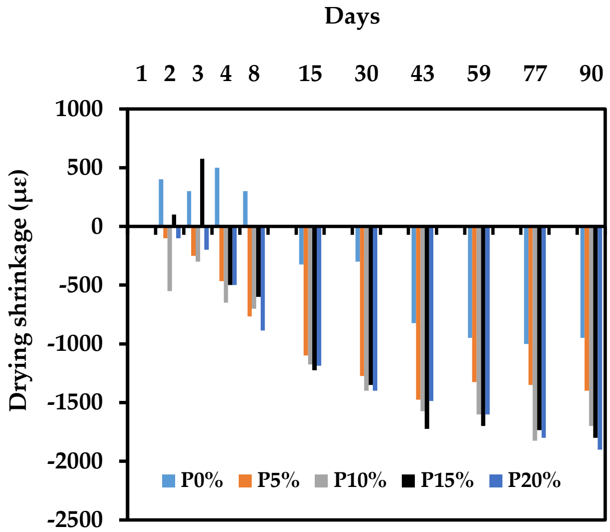

Figure 3: The evolution of drying shrinkage for paste samples during 90 days.

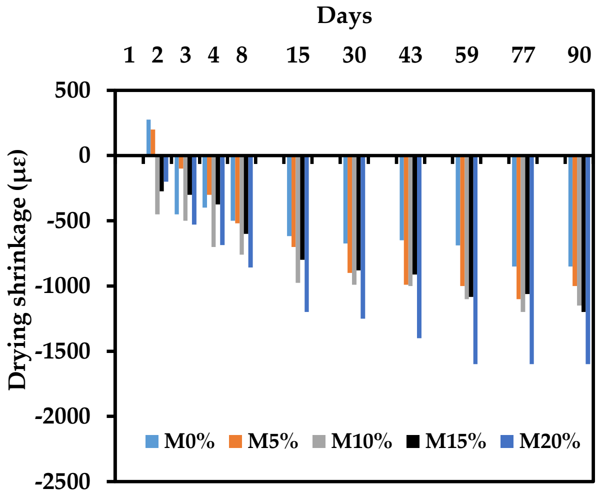

Figure 4: The evolution of drying shrinkage for mortar samples during 90 days.

3.2 Autogenous shrinkage

The results of autogenous shrinkage for pastes and mortars during 90 days with different percentages of LF are presented in Figures 5 and 6 respectively. As shown in both plots, the autogenous shrinkage is affected by the addition of LF. At 90 days, autogenous shrinkage reaches its highest value with the incorporation of 10% LF in paste and mortar samples (1650 με and 1500 με), then shows a sharp drop after this addition. This fact can be elucidated as follow: 1) there should be a sufficient content of water in the larger voids particle inside the cement particles to supply water to the hydration process. As these larger voids stocked with water are depleted, then the cement is involved to pull water from smaller internal pores and capillaries to accomplish the reaction. This could activate the self-desiccation process of the matrix and leads to an increase in the autogenous shrinkage [17]; 2) for replacement above 10% (15 and 20%), the unconfined water from both specimens resulting from the internal curing effect can fill the emptied pores. This leads to a decrease in the degree of self-desiccation as well as reduces the autogenous shrinkage [18].

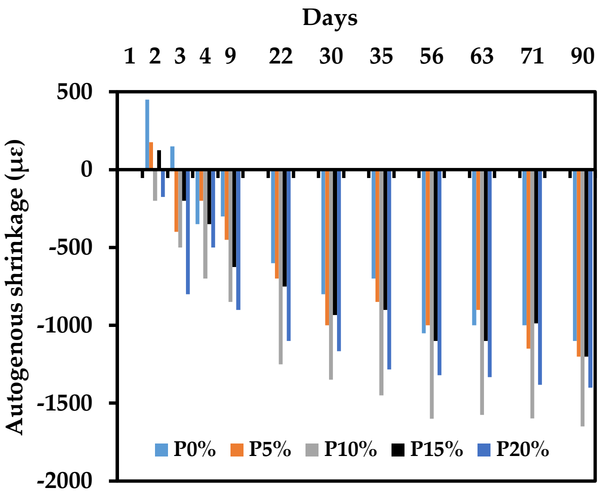

Figure 5: Autogenous shrinkage results for paste specimens during 90 days.

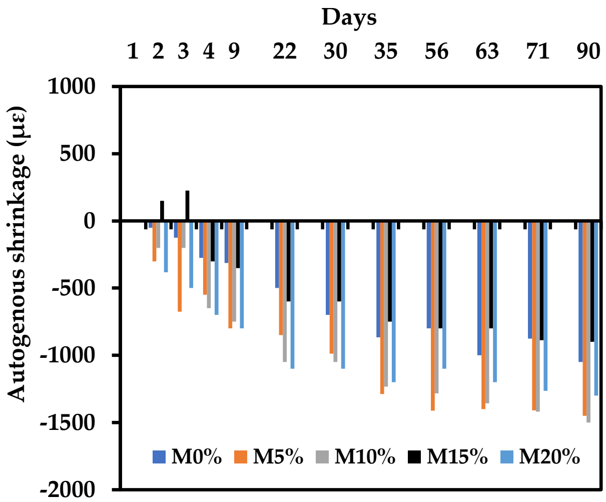

Figure 6: Autogenous shrinkage results for mortar specimens during 90 days.

3.3 Expansion

The development of expansion for paste and mortar specimens with the presence of LF is illustrated in Figures 7 and 8 respectively. The total period of curing is 90 days. Specimens reveal continuous expansion as they are cured in water. As displayed in both plots, the existence of LF contributes to a logical variation in the results. For example, the expansion values for 0% LF in pastes and mortars are 2000 με and 1200 με at 90 days. These values decrease to a minimum value of 1700 με for 10% LF in paste samples and 1000 με for 5% LF in mortar ones. In paste, after this decline, the expansion values increase with the addition of 15 and 20% LF. This could be related to the formation of hydration products at a high LF percentage, which can absorb more water and swell compared to samples with lower LF contents [19]. However, in mortar, the highest increase is achieved for 10% LF replacement followed by a drop. Besides, this could be due to the result of changes in the cement composition phase. The occurrence of LF leads to more formation of CH content in the system. Progressively, the calcium aluminate is switched by carboaluminate which provides a further contribution to the expansion mechanism [20].

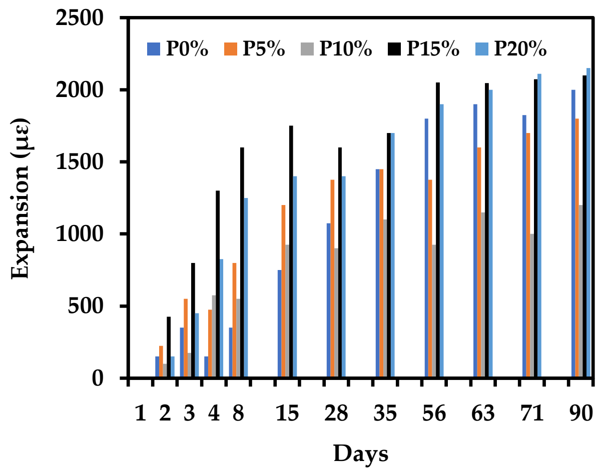

Figure 7: The development of expansion for paste samples during 90 days.

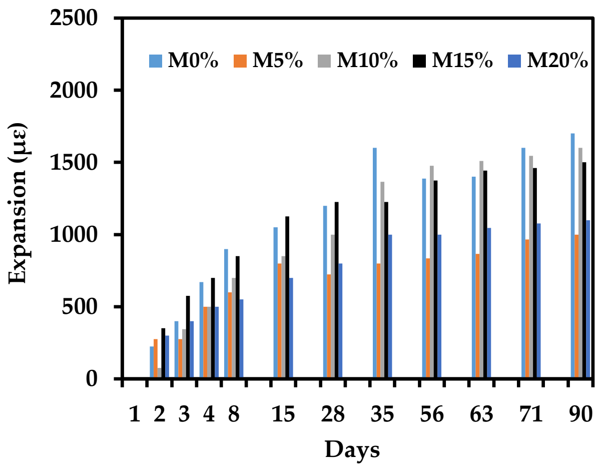

Figure 8: The development of expansion for mortar samples during 90 days.

3.4 Correlation between length change and weight change

The correlations between weight change and length change for drying shrinkage of paste and mortar specimens with different percentage of LF are presented in Figure 9 and Figure 10 respectively. It can be seen that a high correlation exists between them. This finding indicates that the relation is proportional. As length change increases, the weight change will relatively goes up. A high coefficient of determination R^2 occurs for all percentages except for 5% LF in paste samples. In paste, the coefficient of determination ranges from 0.5 to 0.79. However, in mortar samples, R^2 ranges from 0.68 and 0.84. This indicates that the correlation is more obvious and delicate in mortar mixes. This can be related to the high compaction in mortar mixes due to the presence of sand comparing with paste ones [21, 22].

3.5 Correlation between compressive strength and drying shrinkage

Figures 11 and 12 represent the correlation between compressive strength and drying shrinkage for paste and mortar specimens respectively. As observed, there is a negative relationship happening between them with high coefficient of determination R^2 in pastes and mortars ranging from 0.81 to 0.99 and from 0.88 to 0.97 respectively. This means that as drying shrinkage increases, the compressive strength will certainly drop. This fact is logical since drying shrinkage represents the loss of moisture in cement paste, mortar as well as in concrete. This loss in sample moisture produces cracks with time and weakens its power to be subjected for any load and consequently reduces its strength capacity [23, 24]. Besides, it was noted from previous studies [25-28] that drying shrinkage increased as the percentage of LF went up. At 20% LF, the drying shrinkage reached its maximum value in pastes and mortars (1900 and 1600 $\mu\varepsilon$) respectively. Simultaneously, this last finding is interpreted in Table 2, whereas the compressive strength in both paste and mortar specimens achieves a lower value for the addition of 20% LF. This is also elucidating in Figure 10 (for 20% LF) and Figure 11 (For 20% LF), where these plots have the highest slope among the others respectively (49.56 and 86.82).

3.6 Correlation between compressive strength and autogenous shrinkage

The correlation between compressive strength and autogenous shrinkage for both paste and mortar samples is reported in Figures 12 and 13 respectively. Same as drying shrinkage, there is a negative linear relationship with high coefficient of determination R^2 in pastes and mortars ($0.9< R^2 <0.99$). This indicates that both parameters are not proportional to each other. This revealed that as autogenous shrinkage increases, the compressive strength will certainly drop. This correlation clarifies the results obtained from previous studies. As reported by Khatib et al, [25, 26], the autogenous shrinkage continued to increase until achieving the highest value at 10% replacement level of LF then started to drop after that (at 15 and 20% LF) in pastes and mortars. In fact, according to the internal curing impact, the free water occurring in samples with 15 and 20 % LF fills the emptied pores and consequently reduces the degree of self-desiccation which is directly related to autogenous shrinkage [25, 26]. This last finding is obviously noticed in Table 2. The compressive strength increases kind of after the incorporation of 10% LF which reveals that the inclusion of 15 and 20% LF contributed in reducing the autogenous shrinkage and concurrently increasing the compressive strength.

3.7 Correlation between compressive strength and expansion

Figures 14 and 15 display the correlation between compressive strength and expansion in paste and mortar samples respectively. As shown, there is a positive correlation between them represented by a positive linear line with high coefficient of determination R^2 in pastes and mortars ($0.8<R^2<0.99$). This correlation means that as expansion increases, the compressive strength will positively go up. This is mainly explained by the fact that sample in water is more prone to curing. As the sample is more cured in water, the cement hydration process continues and enhances the compressive strength. As previously informed by Khatib et al [25], the swelling in bars rises more for high LF substitutions (15 and 20% LF) with an increase in curing time. This can be related to the fact that the hydration products (mono-carbonate and monocarboaluminate) that are formed at high LF replacements (>10%) are being able to suck more water than samples with lower LF replacements [19, 29]. This is well illustrated in Table 2, where the highest compressive strength is achieved for 15% replacement level in pastes and mortars.

Table 2: Compressive strength results for paste and mortar samples.

Paste/Mortar code	Compressive strength (MPa)			
	1 day	7 days	28 days	90 days
P0	17.7	51.6	60.72	76.4
P5	13.8	33.5	49.2	55.3
P10	13.85	39.6	50.65	56.3
P15	18	54.7	66.5	83.4
P20	16.6	38.8	47.3	50.2
M0	5.8	15	17.8	25
M5	7	15.7	23.13	26.1
M10	5.6	16.4	22.15	24.9
M15	13	17.71	28.4	30.4
M20	5.8	15	17.8	25

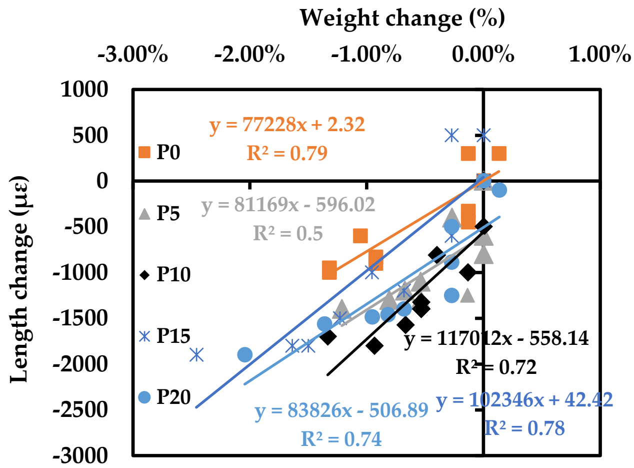

Figure 9: Weight change vs length change for pastes containing different percentages of LF.

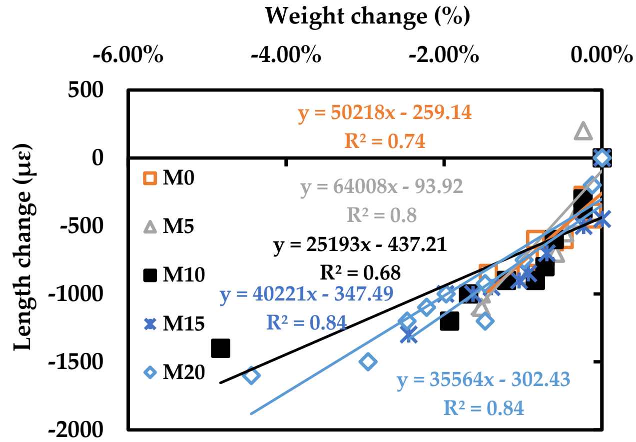

Figure 10: Weight change vs length change for mortars containing different percentages of LF.

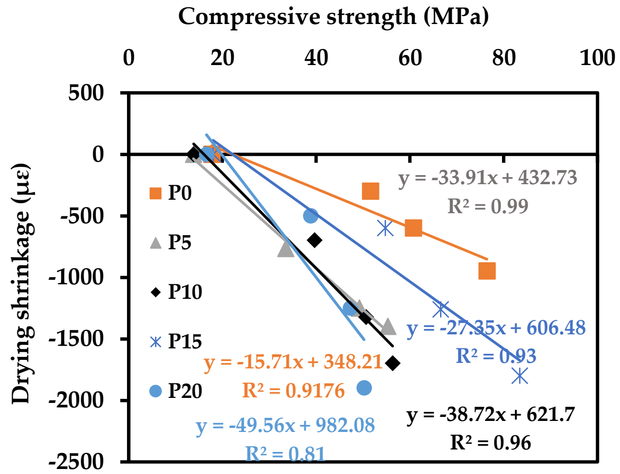

Figure 11: Correlation between compressive strength and drying shrinkage for pastes containing different percentages of LF.

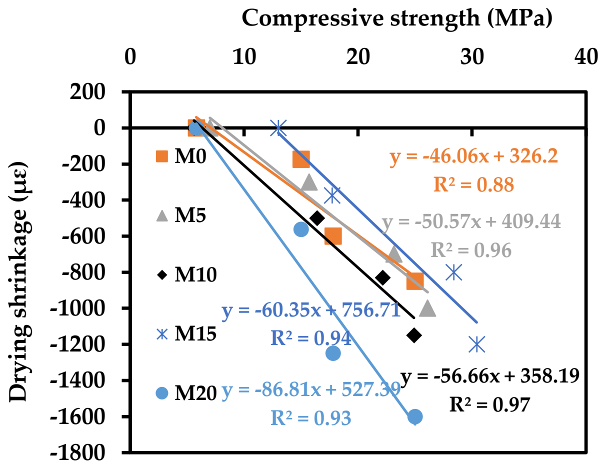

Figure 12: Correlation between compressive strength and drying shrinkage for mortars containing different percentages of LF.

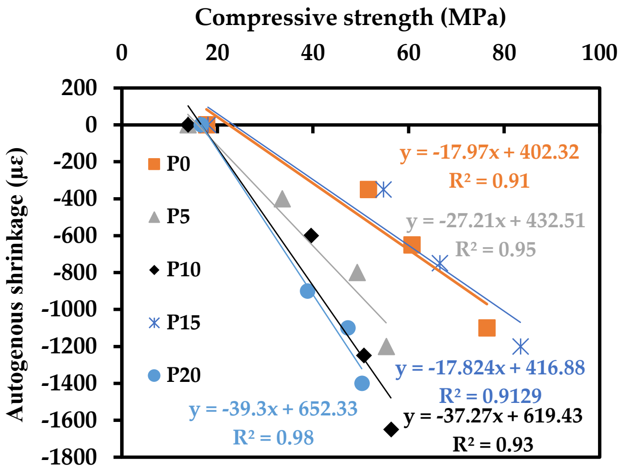

Figure 13: Correlation between compressive strength and autogenous shrinkage for pastes containing different percentages of LF.

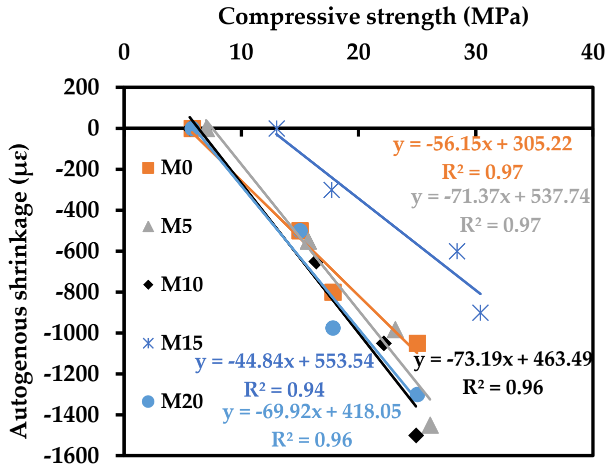

Figure 14: Correlation between compressive strength and autogenous shrinkage for mortars containing different percentages of LF.

4. CONCLUSIONS

From the results obtained from this study, some conclusions can be made:

- The presence of LF have an intrinsic effect on all shrinkage parameters. The addition of 10% LF enhances the autogenous shrinkage of paste and mortar samples. Besides, Drying shrinkage increases as LF content increases. There is a logical variation in expansion values for both specimens (paste and mortar) with the existence of LF. In paste, the addition of more than 10% LF increases the expansion. However, in mortar, the incorporation of LF between 0 and 10% improves the expansion.

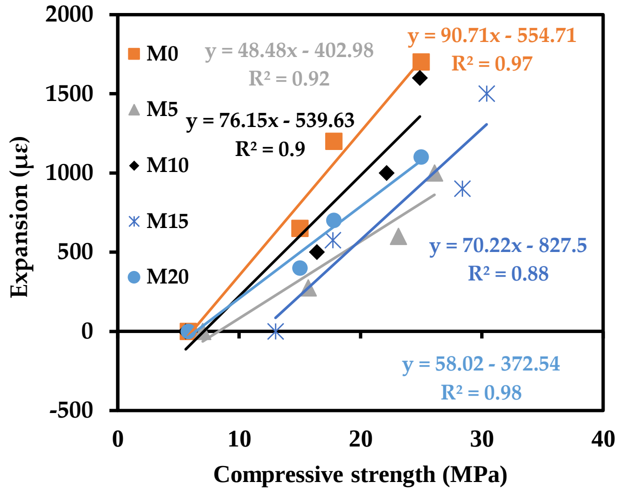

Figure 15: Correlation between compressive strength and expansion for mortars containing different percentages of LF.

- A positive correlation exists between length change and percentage weight change for drying shrinkage of pastes and mortars. This may be due to the fact that as the length change of the sample varies, the percentage weight change will absolutely vary.

- A negative correlation exists between compressive strength and shrinkage parameters (drying and autogenous). This can be attributed by the fact that shrinkage has a negative impact on the compressive strength of pastes and mortars.

- There exists a positive correlation between the compressive strength and expansion for paste and mortar specimens indicating that expansion has a positive effect on compressive strength. As curing time increases, the samples are more cured, leading to an enhancement in compressive strength.

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