Recent Trends in Civil Engineering and Built Environment Vol. 3 No. 1 (2022) 1291-1302

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Drying Shrinkage Properties and Crack Development of Mortar Containing Sandy Clay

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DOI: https://doi.org/10.30880/rtcebe.2022.03.01.146
Received 4 July 2021; Accepted 13 December 2021; Available online 15 July 2022

Abstract: The global demand for mortar has prompted the worldwide utilization of fine aggregates. Environmental issues have arisen as a result of the depletion of fine aggregates. In this study sandy clay is used to replace natural fine aggregate to prepare the mortar. The experimental works were focused on the drying shrinkage properties and crack development of mortar with varying proportions of sandy clay. Five types of mortar with 0%, 25%, 50%, 75% and 100% of sandy clay were prepared. A total of 10 prism specimens with the dimensions of 75mm x 75mm x 300mm length subjected to air curing under ambient temperature were prepared to determine the drying shrinkage properties. While, another 10 panel specimens of 300mm x 300mm x 15mm thick were used to study the crack development. 5 panels were kept indoor (cured) and another 5 panels were exposed to the sun and rain (uncured). Both of the drying shrinkage and crack development tests were carried out for 60 days. From the experimental results, mortar containing 75% and 100% sandy clay achieved much higher drying shrinkage. Meanwhile, panels (75% and 100%) under uncured conditions were shown significant crack development. The optimum percentage of sandy clay used in mortar is 25% with acceptable drying shrinkage properties without significant crack for both cured and uncured conditions.

Keywords: Mortar, Sandy Clay, Drying Shrinkage, Crack Development

1. Introduction

Mortar was a product of lime before the 19th century and the lime has been replaced by cement due to the workability and the ease of cement mortar. Cement improves the mechanical properties of mortar including compressive strength, bending strength, durability and so on compared to lime mortar. Mortar employed in construction has been founded on an ancient culture that utilized a basic mixture of cement, fine aggregates and water in an appropriate ratio. Satisfactory workability and durability may be achieved by providing an appropriate amount of cement and fine aggregate, while an appropriate water/cement ratio can ensure suitable plasticity of mortar. Both of these qualities will have a direct impact on the ease with which the mortar can be applied during building activity.

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The increasing global demand for mortar has led to a high global use of fine aggregate. Due to the depletion of fine aggregate, environmental and social concern have arisen. In order to reduce the amount of fine aggregate in mortar, sandy clay is used. Besides that, the fine aggregate used for mortar is specified should be clean and sharp. The precautions taken to ensure the specification will result in additional costs for the contractor. Therefore, a small amount of foreign matter such as sandy clay is used in the mortar instead of fine aggregate [1]. However, sandy clay increases the drying shrinkage of mortar, causing it to shrink to a smaller size, even causing mortar to crack. When the percentage of sandy clay used in mortar increases, the drying shrinkage properties and crack development of mortar increase. Sandy clay induces the pores between the particles in mortar, causing more water to evaporate from mortar, thus increasing the drying shrinkage. Drying shrinkage creates self-balancing stress fields in mortar structures, which can lead to structural cracks [2]. Cracking usually occurs when clay is constrained when it shrinks, which creates a high negative pore pressure in the dry soil [3]. Cracking caused by higher shrinkage increases the risk of corrosive substances penetrating the mortar. The volume of the material is reduced during the drying process, resulting in internal stress. When this stress develops to a level higher than the strength of the mortar, it begins to crack. Cracking accelerates the penetration of corrosive substances into the mortar, causing the mortar to deteriorate [4]. Drying shrinkage properties and crack development are two important issues of mortar containing sandy clay because they may affect the performance of mortar in a structure, even the safety of the structure. A structure constructed by mortar with high drying shrinkage and cracking is considered as unsafe.

Thus, this study aims to determine the drying shrinkage and to investigate the crack development of mortar containing different percentages of sandy clay, which are 0%, 25%, 50%, 75% and 100%. The experiment study is carried out for 60 days. A comparison between cured and uncured panel specimens were established for crack development of mortar containing sandy clay. The optimum percentage of sandy clay used in mortar without significant crack is determined in this study.

2. Materials and Methods

2.1 Materials

The preparation of raw materials is an important step in the design of the mix ratio, and the materials used determine the quality of the mortar. The raw materials used in this study for mortar mixing are:

- Cement
  Composite cement is the main component to produce mortar in this study. Composite cement used in this study is manufactured by Holcim and it is certified by EN 197-1: 2000 - CEM IV/B(V) 32.5 R [5].
- Fine aggregate
  Sufficient fine aggregate is prepared and used for all mortar mixes. This is to ensure the consistency of the material. Fine aggregate used in this study was not sieved and exposed to sunlight to prevent the moisture in fine aggregate influences the water/cement ratio. Fine aggregate used in this study is classified as poorly graded sand according to Unifies Soil Classification System [6].
- Sandy clay
  Sandy clay used in this study is from the same resources to ensure the consistency. Sandy clay used in this study was exposed to sunlight for drying process and crushed into a smaller size to prevent porosity in mortar. Sandy clay used in this study is classified as well graded sand according to Unified Soil Classification System [6].
- Water
  In this study, tap water was employed as the water source. Water is a necessary ingredient in mortar mixing. The water utilized in this study is free of contaminants, and its pH is neutral, ensuring the cement's effective hydration stage.

2.2 Mix design

Mortar mixes in this study consisted of cement, fine aggregate, sandy clay and water. The standard ratio of 1:3, which 1 part of cement and 3 parts of sand by weight can guarantee the quality of the mortar [7]. Thus, a ratio of 1:3 of cement to sand by weight was used in this study. The percentage of 0%, 25%, 59%, 75% and 100% of sandy was used to replace the fine aggregate in mortar. The water/cement ratio in this study was fixed at 0.60. Table 1 shows the materials proportion for mortar mixes used in this study.

Table 1: Materials proportion

Mix	Cement (kg)	Sand (kg)	Sandy Clay (kg)	Water/Cement Ratio	Remarks
M0	4.50	13.5	0	0.60	0% S.C
M25	4.50	10.13	3.38	0.60	25% S.C
M50	4.50	6.75	6.75	0.60	50% S.C
M75	4.50	3.38	10.13	0.60	75% S.C
M100	4.50	0	13.5	0.60	100% S.C

2.3 Preparation of specimens

There were two main tests in this study, namely drying shrinkage and crack development. A total of 5 mortar mixing designs with different percentage of sandy clay (0%, 25%, 50%, 75% and 100%) were used in this study. Each mix design was labelled M0, M25, M50, M75, M100.

2.3.1 Drying shrinkage

Two 75 mm x 75 mm x 300 mm length prisms were used for each mix design to determine the drying shrinkage of hardened mortar in this study. The total number of hardened specimens for drying shrinkage is tabulated in Table 2. Figure 1 shows the prism specimens.

Table 2: Total number of hardened specimens for drying shrinkage

Mix Design	Size (mm x mm x mm)	Number of Specimen
M0	75 x 75 x 300	2
M25	75 x 75 x 300	2
M50	75 x 75 x 300	2
M75	75 x 75 x 300	2
M100	75 x 75 x 300	2
Total Specimens		10

Figure 1: Prism specimens

2.3.2 Crack development

To investigate the crack development of mortar containing sandy clay, each mixed design employed 300 mm square x 15mm thick of panels. This study employed a total of 10 panel specimens, including 5 cured specimens and 5 uncured specimens. The cured specimens were covered by newspaper and sprayed with water for 1 day while the uncured specimens were exposed to the sunlight and rain. The total of the number of panel specimens is shown in Table 3. Figure 2 shows the cured and uncured panel specimens.

Table 3: Total number of panel specimens

Mix Design	Size (mm x mm x mm)	Number of specimens		Total Specimens
		Cured	**Uncured**	
M0	300 x 300 x 15	1	1	2
M25	300 x 300 x 15	1	1	2
M50	300 x 300 x 15	1	1	2
M75	300 x 300 x 15	1	1	2
M100	300 x 300 x 15	1	1	2
Total Specimens		5	5	10

Figure 2: Cured and uncured specimens

2.4 Methods

The drying shrinkage test and crack development test of mortar containing 0%, 25%, 50%, 75% and 100% were performed in this study. The tests were conducted over 60 days. There were 2 prism specimens and 2 panel specimens were used for drying shrinkage test and crack development test, respectively in this study.

2.4.1 Drying shrinkage

The drying shrinkage test in this study was based on the ambient temperature. The procedure for drying shrinkage test was starting from the measurement of the weight and length for all prism specimens. The prism specimens were installed on the drying shrinkage apparatus as shown in Figure 3 after 24 hours casting. The change in length for all specimens were observed and recorded for 60 days. Figure 4 shows the dial gauge used in this study. The accuracy of dial gauge is 1 x 10^{-6} m. The final mass of prism specimens was recorded as well.

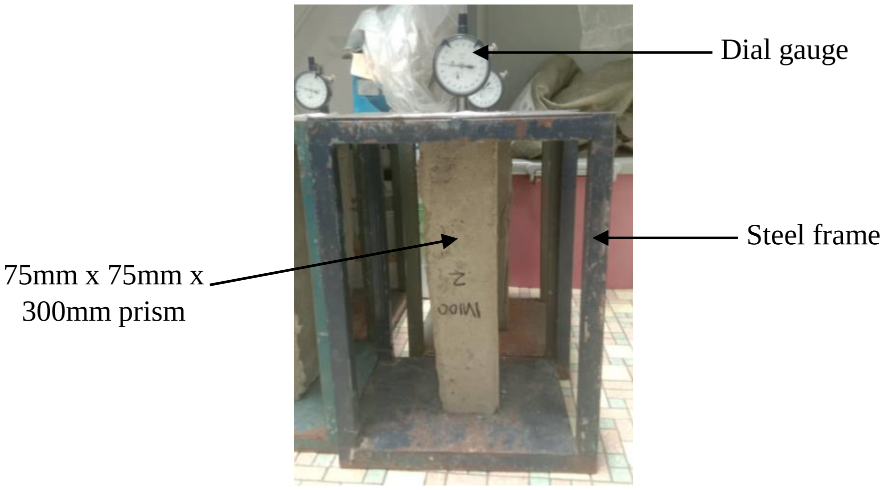

Figure 3: Drying shrinkage apparatus

Figure 4: Dial gauge

2.4.2 Crack development

The panel specimens were divided into cured and uncured specimens for each mortar mix. The crack development of mortar was observed and recorded for 60 days. The crack development of cured and uncured specimens was compared. Figure 5 shows the panel specimens used in this study.

Figure 5: Panel specimens

2.5 Equations

Eq. 1 was used to determine the drying shrinkage of prism specimens. All the units used are in meter.

$$Drying\ Shrinkage, S = \frac{\Delta L}{L_o} \quad Eq. 1$$

Where:
ΔL = Change of the length
L = Length of prism

3. Results and Discussion

3.1 Mass of prism specimen

Since the different percentage of sandy clay used in mortar resulted in different performance of mortar, it is important for the determination of the mass of prism specimens to support the results of drying shrinkage test in this study. All the prism specimens have reduced the mass after 60 days. Table 4 shows the percentage of mass reduction for each mortar mix. Compared with other mixes, M100 had the highest percentage of mass reduction, which is 7.15%. It proves that the percentage of mass reduction increases with the increase of the percentage of sandy clay used in mortar. This is due to the fact that sandy clay increases the porosity of mortar, thus more water is evaporated from mortar through the pores between sandy clay particles. When the loss of water in mortar increases, the percentage of mass reduction increases.

Table 4: Percentage of mass reduction for each mortar mix

Mix	Percentage of mass reduction (%)	Remarks
M0	1.63	0% of S.C
M25	1.89	25% of S.C
M50	4.12	50% of S.C
M75	6.05	75% of S.C
M100	7.15	100% of S.C

3.2 Drying shrinkage

The behaviour of drying shrinkage of prism specimens with different percentages of sandy clay used in mortar over 60 days were shown in Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10. There are 2 specimens to be used for each mortar mixture to obtain an average drying shrinkage. All the prism specimens exhibited similar behaviour, which shrank very quickly until reaching the first 15 days, and had a gradually drying shrinkage until the end of the test date. The comparison of drying shrinkage between each mortar mix over 60 days is indicated in Figure 11. Figure 11 shows that mix M100 has achieved the highest drying shrinkage with the value of 536.45 micro strain while mix M0 has achieved the lowest drying shrinkage with the value of 271.67 micro strain. It proves that the drying shrinkage of mortar increases along the percentage of sandy clay used in mortar. This is due to the cement paste in mortar is not sufficient to fill the pores between the sandy clay parties, thus increasing the porosity of mortar [8]. The presence of sandy clay was causing mortar to become a porous material. Thus, the water is easy to evaporate from the mortar. More water is evaporated through the pores between the sandy clay particles and causing the drying shrinkage of mortar increases.

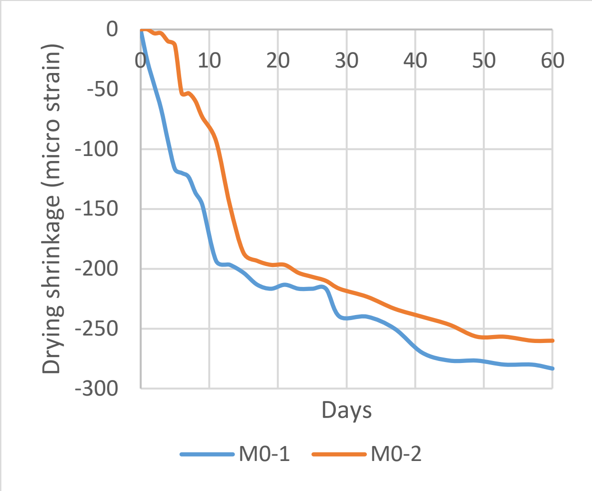

Figure 6: Drying shrinkage of M0 over 60 days

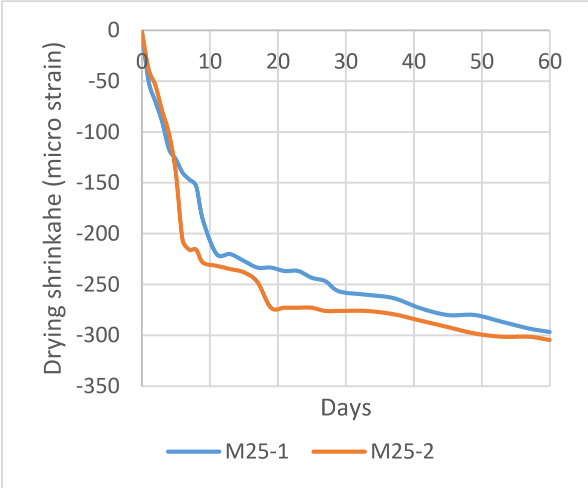

Figure 7: Drying shrinkage of M25 over 60 days

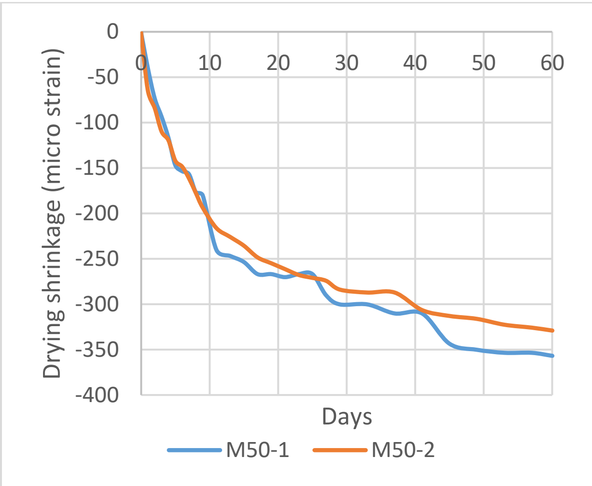

Figure 8: Drying shrinkage of M50 over 60 days

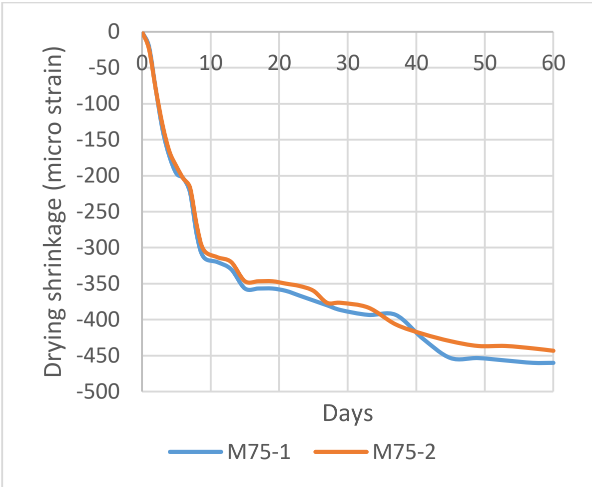

Figure 9: Drying shrinkage of M75 over 60 days

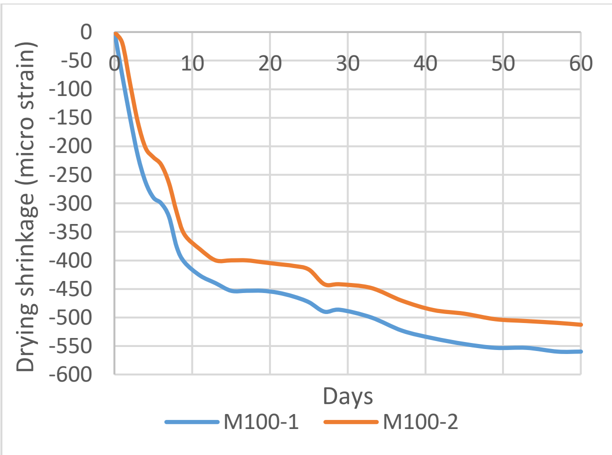

Figure 10: Drying shrinkage of M100 over 60 days

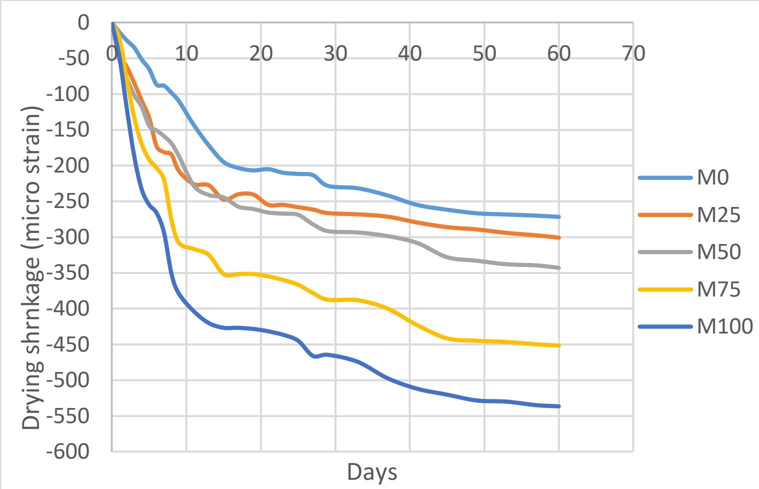

Figure 11: Drying shrinkage of each mortar mix over 60 days

3.3 Crack development

Since the properties of mortar produced under different curing conditions will be different, it is important to compare the crack development between cured and uncured specimens for each mortar mix. Figure 12 and 13 show the cured panel specimens for mix M0, M25, M50, M75 and M100. The cracks did not appear on the surface of all cured specimens over 60 days. This is because drying shrinkage is controlled under curing conditions, allowing capillary pressure and tensile stress to be controlled within allowable limits. The surface of the uncured specimens of mix M0, M25 and M50 showed no cracks as shown in Figure 14, while mix M75 and M100 showed cracks. The crack development of mix M75 and M100 over 60 days can be observed in Figure 15, Figure 16, Figure 17 and Figure 18. The uncured mix M100 has experienced the greatest crack development of mortar, it proves that the percentage of sandy clay used in mortar increased and the crack development increased. Based on the results, 75% and 100% of sandy clay was considered not suitable for replacing the fine aggregate in mortar. Tensile stress generated where there was a restraint of volume change of mortar due to drying shrinkage [9]. The cracks developed when the tensile stress generated exceeded the tensile strength of mortar. As the percentage of sandy clay used in mortar increased, the drying shrinkage of mortar increased, thus the crack development of mortar increased.

M0 M25 M50

Figure 12: Cured specimens of mix M0, M25 and M50


M75 M100

Figure 13: Cured specimens of mix M75 and M100


M0 M25 M50

Figure 14: Uncured specimens of mix M0, M25 and M50


M75 M100

Figure 15: Uncured specimens of mix 75 and M100 after 1 hour

M75 M100

Figure 16: Uncured specimens of mix 75 and M100 at 15th day

M75 M100

Figure 17: Uncured panel specimens for M75 and M100 at 30th day

M75 M100

Figure 18: Uncured panel specimens for M75 and M100 at 60th day

4. Conclusion

This study has determined the drying shrinkage and investigated the crack development of mortar containing sandy clay. The mix M100 has experienced the highest drying shrinkage with the value of 536.45 micro strain. It was observed that the drying shrinkage increases along the percentage of sandy clay used in mortar. This is because the cement paste in the mortar is not enough to fill the pores between the clay particles, which leads to an increase in the porosity of the mortar [8]. The water was easy to evaporate if the mortar became a porous material. The drying shrinkage increased when more water was evaporated through the pores between the hardened microstructure. It also resulted in the increasing percentage of mass reduction of prism specimens as the mix M100 had the highest percentage of mass reduction which was 7.15%. This is due to the sandy clay increasing the drying shrinkage of mortar. The mass of mortar reduces when the water is evaporated which also leads to drying shrinkage, thus the more water evaporated, the lighter the mass of mortar. Furthermore, there was a comparison of crack development between the cured and uncured panel specimens. It was observed that no crack was developed in the cured specimens while cracks appeared on the surface layer of mix M75 and M100 for uncured specimens. Self-equilibrium stress field was produced by the difference in shrinkage between inner layer and surface layer [8]. When the tensile stress created exceeds the tensile strength of mortar, cracks were developed. The curing process limited the drying shrinkage of mortar and thus limited the tensile stress so that it did not exceed the tensile strength in mortar. The uncured specimen of mix M100 has experienced the highest crack development of mortar. In a nutshell, the optimum percentage of sandy clay used in mortar without any significant crack was 25%.

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