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Performance of ready-mixed clay plasters produced with different clay/sand ratios

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ABSTRACT

Recent studies have shown that the usage of earthen building materials such as adobe, rammed earth and clay plaster has increased due to their moisture balancing and breathing characteristics, availability of their raw materials, suitable costs, sustainability and environmentally friendly properties. Although making adobe and clay plaster is quite an old building application, nowadays, more durable clay plasters can be produced on the basis of quality control in the industrial sense. In the literature, there are many studies dealing with adobe and rammed earth materials. However, investigations covering the characteristics of clay plasters are limited. In this study, the performance of ready-mixed clay plasters was examined with regard to the moisture content of the samples during the test, the mixture content of the water and the clay/sand ratios. Compressive strength and shrinkage (volumetric and observational) of the clay plasters were considered as key parameters for the performance analysis. In addition, simple field tests, used for analysis of the composition of earth building materials, were carried out in order to evaluate the effect of the clay/sand ratio on the performance of the clay plasters. As a result, an increase in the initial water content of the mixture and/or the moisture content of the samples during the test had a negative effect on the compressive strength. Furthermore, the optimum clay/sand ratio was between 0.43 and 0.66 by weight when the shrinkage and compressive strength results were considered all together.

1. Introduction

Nowadays, with the understanding of the importance of the green building concept, there is a constantly increasing demand for ecological construction materials. It is openly recognized, especially in industrialized countries, that the most important reasons for choosing these earthen construction materials are to comply with environmental sensitivity and to provide a comfortable indoor ambience (Deliniere et al., 2014).

Earth construction techniques have been used for over 9000 years. Examples include rammed earth foundations dating from the Assyrian civilization of 5000 BC and remains of houses constructed using mud bricks (adobe) from 8000 to 6000 BC discovered in the regions of Turkestan. Earth, in the form of bricks, walls and plaster building materials, was used in all ancient cultures, not only for homes, but also for public and religious buildings as well (Pumpelly, 1908; Minke, 2006).

Clay plaster is more suitable for use internally, but can be used as an external plaster when strengthened by certain additives to make it more durable for outdoor conditions (Hamard et al., 2013). Clay plaster can be applied to a variety of wall surfaces (wood, brick, straw bale, rammed earth, adobe, concrete, etc.) and can provide insulation from heat, sound, moisture, odor and noise. Clay plaster balances and regulates indoor moisture thanks to their high absorption capability. In addition, the usage of clay plaster raises the standard of living by providing a more hygienic and optimal humidity and by keeping the place warm in winter and cool in summer. Clay plaster, with all of these properties, creates a healthier and more comfortable living environment (Minke, 2006; Pacheco-Torgal and Jalali, 2012; Liuzzi et al., 2013; Deliniere et al., 2014). Although traditional methods of clay plaster production are sufficient for country-style buildings, the formulation of modern clay plaster requires some modifications, depending on different regional conditions (Hamard et al., 2013). There is no standard for the characterization of ready-mixed clay plaster except in Germany (DIN 18.947, 2013). The German standard is mostly based on conventional cement- and lime-based plaster standards. Moreover, publications dealing with the characterization of ready-mixed clay plasters are very limited in the literature (Deliniere et al., 2014).

Taylor et al. (2006) investigated the effects of the drying time and water content of clay plaster on compressive strength. They found that compressive strength increased with the increasing clay content, although rigidity was not affected. However, increasing the water content during the test decreased both the strength and the rigidity. Additionally, it was found that clay plaster containing clay had higher strength (Taylor et al., 2006). Hamard et al. (2013) reported that an

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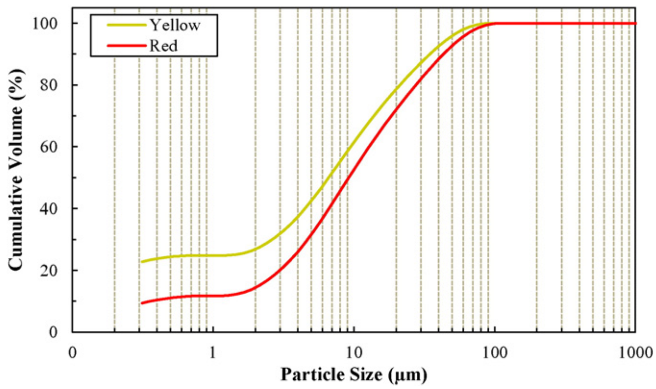

Fig. 1. Particle size distribution of clays.

increase in the proportion of clay in the mixture increased flexural strength in spite of the fact that the interface bonding between the plaster and the wall was weakened (Hamard et al., 2013). Deliniere et al. (2014) found that the real shrinkage observed in the field was different from that measured in tests because of the support which prevented contraction in its immediate vicinity and altered the drying process. Furthermore, it was noted that performing flexural strength could be related to the shrinkage test results, an observation which provides important information about the cracking of plaster (Deliniere et al., 2014). Maddison et al. (2009) examined the humidity buffer capacity of clay–sand plasters filled with fiber-wool from plants frequently encountered in the area where the study was conducted. The water absorption and desorption of the prepared natural fiber-reinforced clay plasters were examined in a climatic chamber. Results showed that natural fibers such as common cattail (*Typha latifolia*) fiber-wool exhibited a positive effect on the absorption and desorption of water (Maddison et al., 2009). Liuzzi et al. (2013) studied the hygro-thermal behavior and relative humidity buffering of lime-stabilized clay composites. Internal clay plaster in a Mediterranean climate provided better air quality and energy saving compared to the alternatives (Liuzzi et al., 2013). In two different studies, Ashour and Wu (2010) and Ashour et al. (2011) investigated the shrinkage of clay plaster with natural fibers and the equilibrium moisture content of clay plaster with natural reinforcement fibers. According to their results, shrinkage cracks increased with increasing clay content but decreased with increasing fiber content. In addition, they found that, in order to enhance the performance of clay plaster, it should be cured at low temperatures and contain a high fiber content (Ashour and Wu, 2010; Ashour et al., 2011). Darling et al. (2012) researched the effects of clay plaster on indoor air quality assessed using chemical and sensory measurements. The effects of clay plasters on troposphere ozone, which adversely affects human health, were investigated. The harmful ozone was decreased in the room plastered with clay (Darling et al., 2012).

Table 1
Chemical composition of yellow and red clays.

Compounds	(%)	
	Yellow	Red
SiO_2	63.678	60.556
Al_2O_3	16.969	19.161
Fe_2O_3	6.507	7.718
K_2O	2.420	2.746
TiO_2	1.144	1.162
MgO	1.022	0.792
CaO	0.566	0.352
Na_2O	0.366	0.340
MnO	0.127	0.173
L.O.I. (800 °C)	7.20	7.00

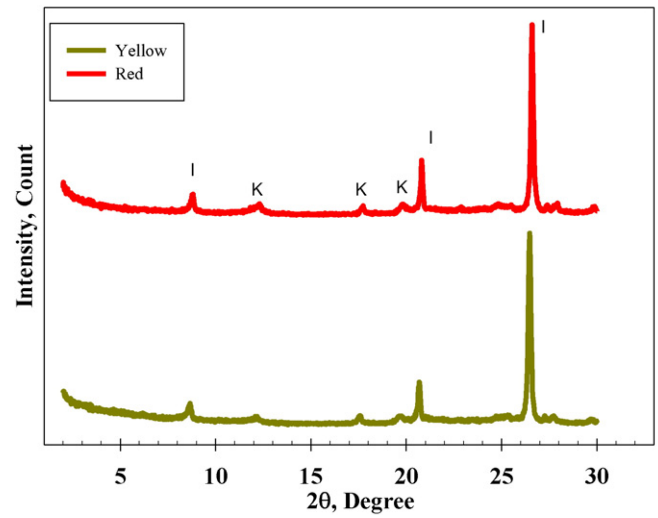

Fig. 2. X-ray diffraction patterns of the clays (K: kaolinite, I: illite).

In this study, the performance of ready-mixed clay plaster produced with different clay/sand ratios was analyzed with regard to ease of application, surface condition (observational cracking analysis) after application, compressive strength and volumetric shrinkage.

2. Materials and methods

2.1. Clay

The two different clay clays finer than 2 mm used in this study were taken from the Düzce/Turkey region. The clays were labeled yellow and red, according to their colors, and had a specific gravity of 2.55 and 2.7, respectively. The particle size distribution of the clays is shown in Fig. 1.

When the particle size distribution of the two clays was examined (Fig. 1), the yellow clay had a finer grain size (less than 2 μm) than the red clay. In addition, the yellow clay had a higher clay content (27%), while the red one contained less clay (15%).

In order to determine the chemical composition of the clays, XRF analyses were performed and the results are presented in Table 1.

The XRF test results showed that the yellow and red clays were chemically composed of a high amount of SiO_2, and low amounts of aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3) and other compounds. The main component of the yellow clay was SiO_2 and the ratio of SiO2/Al_2O_3 (S/A) was 3.75 by weight. Furthermore, a higher amount of potassium oxide (K_2O) than sodium oxide (Na_2O) showed that it was rich in K+ ions resulting from the ion exchange mechanism. On the other hand, the main component of the red clay was SiO_2 and the S/A ratio was 3.16. The red clay contained less SiO_2 and more aluminum and iron than the yellow clay. Additionally, the loss in ignition value indicated that both clays had lower carbonaceous and higher mineral contents. The color differences of the two clays resulted from the iron compounds in their composition.

The clay types were determined by X-ray diffraction (XRD) and the mineralogical analyses of the clays are shown in Fig. 2.

Fig. 3. Listing of specimen codes.