Laboratory Study of the Effects of Industrial Wastes and Recycled Materials on Strength and Stress-Strain behaviour of Lime Concrete

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Abstract.

In this study, the effects of recycled materials such as fly ash, wood ash, magnesium slag, and cement and polyamide fibers on the strength and stress-strain behaviour of lime concrete have been investigated. Based on the review studies and the tests performed on materials, the optimum mix designs for lime concrete have also been identified. The optimum amount of water and clay for preparing lime concrete samples were considered at 24% and 23%, respectively. Samples with the optimum amount of clay, lime, water, and coarse-grained soil and recycled additives were prepared. The amounts of additives used in different samples were selected as 4% magnesium slag, 4% wood ash, 4% fly ash, 4% cement and 1% polyamide fibers. The amount of lime in the samples was selected in a way that the total percentage of additives and lime was 8%. After curing the samples for 28 days, the uniaxial compressive strength tests were carried out. The results showed that the highest strength was obtained from the lime-fly ash concrete, and the best ductility behaviour was achieved for that concrete made of lime and polyamide fibers.

Keywords: lime concrete, recycled materials, fly ash, wood ash, magnesium slag, cement, polyamide fiber.

1. Introduction

One of the first research studies in the field of lime-stabilized soils is a research carried out in 1981 to improve the properties of fine-grained soils. The results of this study indicated that the percentage of lime required to improve the properties of fine-grained soils is between 3% and 8% (Mitchell, 1981). In 1989, the effect of temperature and humidity on the strength and shrinkage of cement mortars and lime-cement mortars with different percentages of lime were studied by the researchers. According to the results of this study, the strength of cement mortar is inversely related with increasing temperature while in mortars containing lime cement, increasing temperature led an increase in strength. This is due to the addition of lime and its effect on cement mortar. In addition, increasing the temperature caused an increase in the initial shrinkage of the mortar and a reduction in final shrinkage (Cebeci et al., 1989). Osinubi and Nwaiwu investigated the effect of delay in compaction of lime mortar by determining the maximum relative specific gravity and optimum moisture, California Bearing Ratio (CBR) and Uniaxial test. It was reported that increasing the percentage of lime reduced the effect of compaction delay on uniaxial strength (Osinubi & Nwaiwu, 2006). In a study by Hanley and Pavia, optimum moisture of lime mortars of European standard was determined and corrected according to British Standard (BS). As a result, the amount of optimum moisture of the European standard construction lime mortar was somewhat modified. For Experiments performed in this research we can refer to a combination of uniaxial tests, flow table tests, one-point bending test (Hanley & Pavía, 2008). Stefanidou and Papayianni investigated the effect of aggregate amount and aggregate size on the characteristics of lime concrete. In this research different mixtures were prepared with different lime to aggregate and water to lime ratio. The results showed that the coarse distribution in the mortar lime had no effect on the strength of the mortar, although due to compaction, the capillary pores reduced sufficiently. Moreover, the maximum strength of lime concrete achieved with reducing the ratio of lime to aggregate with a maximum size of zero to 4 mm (Stefanidou & Papayianni, 2005). In 2010, extensive studies were conducted on variables affecting the strength and hardness of lime mortars. The results of this research led to the definition of an equation to determine uniaxial strength and its relationship with the porosity to lime ratio and shear modulus and also the ratio of shear modulus to porosity in lime mortars (Consoli et al., 2010). The effect of different percentages of polypropylene microfiber in lime mortars was studied by researchers in 2010. The results showed an improvement in the ductility of lime mortar as well as an increase in shear strength (Chan & Bindiganavile, 2010). In another study, extensive research was conducted on the properties and structure of dolomite lime mortar. It was reported that with increasing the amount of magnesium in dolomite lime mortars, the phenomenon of shrinkage and the need of the mortar for water and soil reaction to carbonate lime increased and decreased, respectively. While in terms of strength and ductility showed similar property to low-grade carbonate lime (Chever et al., 2010). In the continuation of these studies, the effect of curing speed on the mechanical properties of lime-stabilized soils in 2012 was studied. In this study, lime mortar in two states of 7 days at 41 ° C and 28 days at 23 ° C Celsius was prepared and uniaxial test was performed on it. Finally, 7-day samples at 41 ° C showed more uniaxiality strength than 28-day- old samples at 23 ° C (Toohey et al., 2012). Extensive studies have been performed in recent years. These include research by Polamer et al by using various additives at years 2015 to 2018. The results of these studies showed that the addition of lightweight grains and additives such as perlite not only increase the acoustic and thermal properties of the mortar, but also improve the hard properties which can also be clearly seen in SEM micro structural studies (Palomar et al, 2015; Palomar & Barluenga, 2017; Palomar & Barluenga, 2018).

Moreover, in Iran many studies have been done by researchers on this subject who have achieved significant achievements. In 2010, the effect of using a geogrid layer on the elasticity modulus of samples containing cement and lime mortar was studied. The results showed that the highest modulus of elasticity was obtained with the highest cement / lime ratio, while the percentage of cement is not more than 5%. Using a geogrid layer in a mixture of sand and cement under the constant energy caused decreasing specific gravity of soil (Azadegan & Pourebrahim, 2010). Jahandari (2015) extensively investigated the effects of saturation degrees and humidity, caused by rising groundwater table and capillary phenomenon, on the strength of lime concrete under curing periods of 7, 14, 28, 45, 60 and 90 days in laboratory condition (Jahandari, 2015). In a study conducted by Hassanpour et al., the compressive strength of lime concrete mortar and the optimization of their applicable use were examined (Hassanpour et al., 2016). Jahandari et al. in 2017 reported taht using geogrid layers between lime-stabilized soils achieved led to an increase in ductility and a reduction in brittleness coefficient (Jahandari et al.,2017,b). Jahandari et al. in 2017 in another study investigated the effect of curing time on the behavior of stabilized soils with lime and geogrid and concluded that curing caused increasing the strength of lime-stabilized soils and also, the use of geogrids caused the area below the strain stress diagram increased significantly (Jahandari etal.,2017,b). Saberian et al. in 2017 examined the effect of capillary phenomenon and rising underground water on the mechanical properties of lime concrete with laboratory experiments and mathematical model. The results showed that the capillary phenomenon and rising surface of underground water reduces the strength of lime concrete parameters (Saberian et al., 2017). Jahandari et al., in 2019 studied the effects of degree of saturation, freezing-thaw and curing time on the geotechnical parameters of lime concrete and lime cement. The results showed that with rising groundwater levels and increasing saturation degrees, lime concrete strength greatly reduced. Whereas if lime cement is used instead of lime concrete, rising groundwater and increasing saturation degree has no effect on strength (Jahandari et al., 2019).

Based on literatures review, the lime concrete is widely used and also there is not enough research conducting on the main weakness points of lime concrete. It should also be noted that due to the antiquity of these materials, many strain-stress behaviors of this mortar is unknown and has not been carefully studied. Due to the increasing use of recycled materials in traditional conctruction materials with the purpose of preserving the environment and creating potential in improving the desired properties of products, in this study, industrial wastes and recycled materials were used to stabilize the soil. One of the characteristics that researchers pay very little attention to it, is the study of strain stress behaviors in case of adding recycled materials to lime concrete. In addition, the aim of this study is investigating the potential use of recycled materials in construction materials.

2. Properties of raw materials

The characteristics of water, clay, coarse-grained soil and lime used in this research are similar to the raw materials used in the research studies conducted in refs (Jahandari et al., 2018; Jahandari et al., 2020). Coarse-grained soil used in lime concrete was from Ekhtiarabad Kerman sand mine and fine-grained soil of clay type was sampled from an area located in the city of Kerman from a depth of 1-3 meters. Results of the experiment performed on the soil are presented in Figure 1 and Table 1. According to the results and classification in BS EN 459 - 1: 2010 (EN, B., 2010), lime used in this study is hydrated lime with a high percentage of hydrated elements. In this research, Portland cement type II and magnesium slag were provided from Kerman Cement Factory and Magnesium factory located in Ferdows city, respectively (Amini & Ghasemi, 2019). Furthermore, fly ash was prepared from a factory in Zarand-Kerman and used as a stabilizer. In addition, wood ash was prepared from burning wood. Among the properties of polyamide or nylon fibers used in this research, it can be referred to extraordinary high tensile strength, high melting point, high thermal and fire resistance, as well as suitable solvent resistance and dimensional stability at room and high temperatures. Tap water was used for moulding the samples and distilled water for characterization tests (Sadeghian et al., 2020; Shabjareh et al., 2014; Ameri et al., 2015; Afshar et al., 2020; Kazemi et al., 2020,a; Kazemi et al., 2020, b; Saberian et al., 2018; Toghroli et al., 2020; Rasekh et al., 2020; Vali et al., 2019; Rezania et al., 2020).

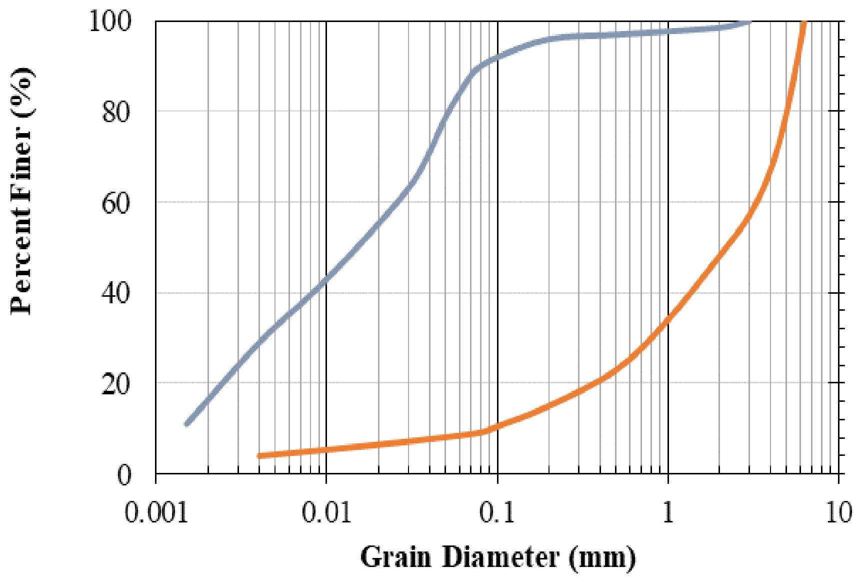

Figure 1: Particle size analysis of the used clay and sand (Jahandari et al., 2019).

Table 1: Properties of the studied soils (Jahandari et al., 2019; Amini & Ghasemi, 2019; Sadeghian et al., 2020)

Properties	Results	Reference
Type of fine-grained soil	CL	ASTM 2487-11 (2011)
Mineral of clay	Kaolinite	Das (2008)
Activity degree of clay	0.47	Das (2008)
Effective size of clay (D_{10})	0.0015	ASTM D422-63 (2002)
Uniformity coefficient (C_u) of clay	18	ASTM D422-63 (2002)
Coefficient of curvature (C_C) of clay	0.4	ASTM D422-63 (2002)
Liquid limit of clay	33%	ASTM D423-66 (1972)
Plastic limit of clay	25%	ASTM D424-54 (1982)
Plasticity index of clay	8%	Das (2008)
Specific gravity of clay	2.46	ASTM D854-10 (2010)
Maximum specific weight of dry clay	18.74kN/m^3	AASHTO T180 (2010)
Optimum moisture of clay	15%	AASHTO T180 (2010)
Type of coarse-grained soil	SW-SM	ASTM 2487-11 (2011)
Effective size (D_{10}) of SW-SM	0.1	ASTM D422-63 (2002)
Uniformity coefficient (C_u) of SW-SM	34	ASTM D422-63 (2002)
Coefficient of curvature (C_C) of SW-SM	1.88	ASTM D422-63 (2002)
Liquid limit of SW-SM	27%	ASTM D423-66 (1972)
Plastic limit of SW-SM	14%	ASTM D424-54 (1982)
Plastic index of SW-SM	13%	Das (2008)

2. Sample preparation, curing, and UCS tests

Materials used in this research are clay, lime, water, fly ash, wood ash, and magnesium slag and polyamide fibers. In this regard, 4 samples were made for each additive for testing, which is described below. To construct the samples tap water was used to better simulate the samples with the real environment.

Based on the results of research conducted by Jahandari et al (Jahandari & Toufigh, 2018; Jahandari et al., 2020), in the present study the amount of clay is 23% of the dry weight of sand and the optimal moisture content of about 24% of the total material weight was selected. Furthermore, the amount of lime were considered 4% of dry weight of clay and sand in samples reinforced with cement, wood ash, fly ash and magnesium slag. Howevere, the amount of lime in samples including fibers was 7%. The amount of fly ash, wood ash, cement and magnesium slag were the 4% dry weight of clay and sand, while the amount of fibers was considered about 1% dry weight of clay.

To make lime concrete, first, clay and coarse-grained soil of Ekhtiarabad mine were mixed well. After complete combining lime in water and making lime slurry, this slurry was added to the soil along with the additive and all the materials well mixed for about 5 minutes. Then concrete was poured into the mold. Samples were taken out of the mold after three days and were placed inside plastic freezers for processing. After casting and demolding the lime concrete samples, they were cured for 28 days in laboratory conditions at the average temperature 20 ºC and the average natural humidity of 27%. Then the Uniaxial Compressive Strength (UCS) tests were then conducted on the samples.

In standard ASTM D 5102 (ASTM D, 2020) guidelines for uniaxial tests on lime concrete is provided. Based on this standard, the amount of axial strain should not be more than 5% of the sample height and also the loading speed should be between 0.5 to 2 mm on minutes. The loading speed of the device was set and controlled equal to 1 mm / min. It is worth noting that the uniaxial experiment was performed by a three-axis machine without lateral pressure and fluid as well as the membrane around the samples. Samples after curing were placed inside the uniaxial test set up. Uniaxial test was performed after the necessary control for loading to the sample center and loading speed. After the experiments, the strain-stress curves are plotted and the final uniaxial strength of the samples as well as the strain corresponding axis was performed.

3. Results and discussions

Results of uniaxial tests on samples of lime concrete-magnesium slag, lime concrete -wind ash, lime concrete- wood ash, lime concrete- cement and lime concrete- fiber are presented in the figure 2 to 4.

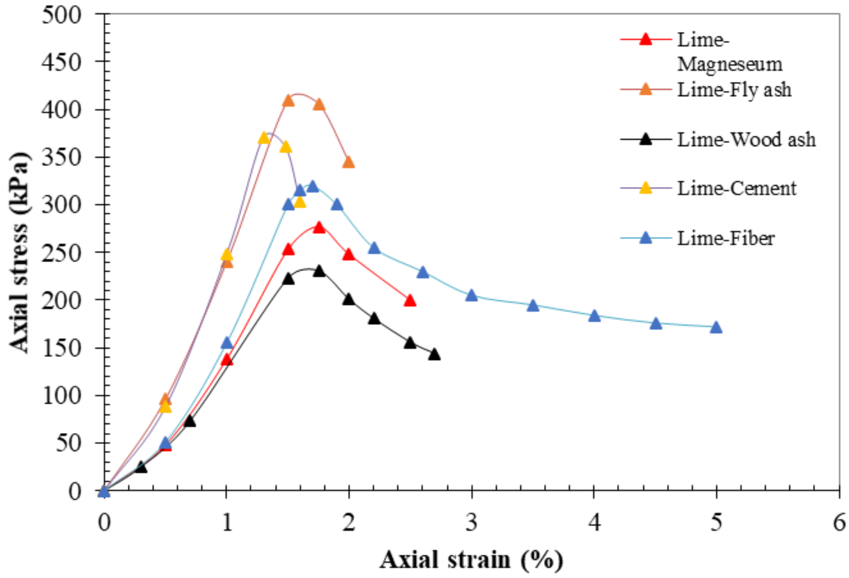

Figure 2: Comparison of strain-stress behaviors of lime concrete containing different additives

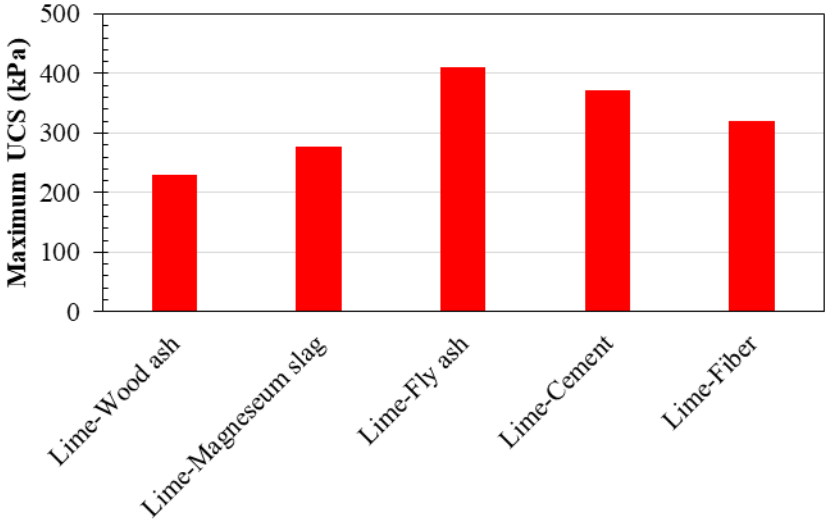

Figure 3: Maximum compressive strength of lime concrete containing different materials

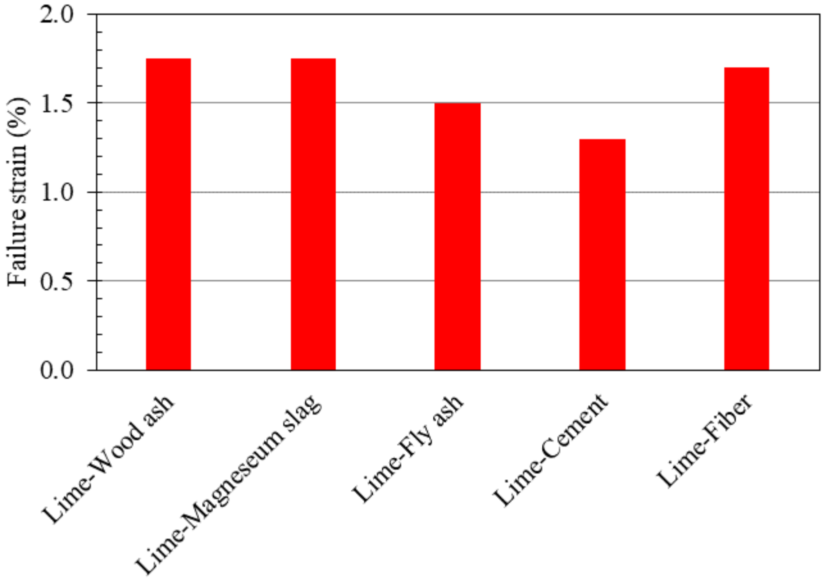

Figure 4: Failure strain of lime concrete containing various additives

Based on tests performed on raw materials and uniaxial tests, the following results were achieved:

According to the characteristics of coarse-grained soil (Figure 1), it can be seen that Ekhtiarabad sand mine in Kerman city is well-graded and therefore, it is suitable for use in lime concrete projects.

Comparison of stress-strain diagrams of lime concrete shows that the lime-fly ash concrete has the highest amount of compressive strength (UCS) which is 410 kPa. This is because lime (as a source of calcium) in the mixture works as an alkali activator and activates fly ash; therefore, the compressive strength increases. However, the lowest amount of compressive strength is related to lime-wood ash concrete which is 231 kPa. Compressive strength of lime-cement concrete, lime-magnesium slag concrete and fiber-reinforced lime concrete are 371, 277 and 320 kPa, respectively. Therefore, the main result is that the addition of fly ash to the lime concrete significantly increases the compressive strength as demonstrated in Figures 2 and 3.

Based on Figure 4, lime concrete containing magnesium slag and wood ash have the highest failure strain at the maximum UCS (1.75%) and the lowest amount of failure strain is related to lime concrete containing cement, which is 1.3%. Therefore, lime-cement concrete shows a more brittle behavior.

According to Figure 2, lime concrete containing fibers show different strain-stress behavior than other additives. The final failure strain is up to about 5%. This results demonstrates that the use of fibers is very effective in improving the plastic behavior and increasing the ductility of lime concrete.

4. Conclusion

In this research study, the effects of some common recycled materials and additives, such as fly ash, wood ash, magnesium slag, cement, and polyamide fibers, on the strength and stress-strain behavior of lime concrete have been investigated. The following main conclusions can be drawn from the present study:

1. Fly ash is the most effective additive to increase the compressive strength of lime concrete compared to the other additives such as of wood ash, magnesium slag, cement, and polyamide fibers.

2. Cement is the most effective additive to decrease the ductility of lime concrete compared to the other additives such as of wood ash, magnesium slag, cement, and polyamide fibers.

3. Addition of polyamide fibers has a significant effect on increasing the ductility behavior of lime concrete.

4. Because lime concrete is a none structural concrete and is often used under the foundation of building, a low compressive strength is often sufficient. Therefore, the use of waste and recycled materials in this type of concrete is highly recommended to alleviate the environmental concerns.

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