Utilization of Soil Stabilization with Cement and Copper Slag as Subgrade Materials in Road Embankment Construction

Jaber Shahiri[1], Mojtaba Ghasemi[2,*]

Received: 29. 08. 2016   Accepted: 02. 05. 2017

Abstract

In this study, unconfined compression tests have been conducted to investigate the impacts of copper slag on mechanical characteristics for stabilized cement and un-stabilized soil. Dozens of specimens were prepared at four percentages of cement (i.e. 0%, 2%, 4% and 6%) and five percentages of copper slag (i.e. 0%, 5%, 10%, 15% and 20%) by weight of dry soil. The samples compacted into a cylindrical specimen and processed for the curing periods of 28, 60 and 90 days. The test results indicated that the inclusion of copper slag had a significant effect on the unconfined compressive strength (UCS). For cement stabilized specimens, the improvement impacts of the copper slag on the UCS was more tangible than un-stabilized ones. Furthermore, an increase in the UCS was most apparent in the 2% cemented specimen wherein the UCS increased more than 78% as the copper slag increased up to 20%. Moreover, it was evident that the more amount of copper slag increased, the more optimum moisture content (OMD) declined and additionally maximum dry density (MDD) of soil was on the rise, while the results of the increase in cement was quite the reverse. Moreover, an artificial neural network (ANN) model has been developed using eight input parameters including: copper slag content, cement content, water content, dry density, liquid limit, plastic limit, PH and curing age. An ANN network, composed of 10 neurons in a hidden layer, was considered as the appropriate architecture for predicting the elastic modulus of mixtures, and an excellent conformity was acquired between the observed test data and the predicted ones. The results was proven that the proposed model can be efficiently applied to predict the elastic modulus of stabilized soils.

Keywords: Copper slag; cement stabilization; unconfined compressive strength; elastic modulus; artificial neural network.

Corresponding author Email: m.ghasemi@kgut.ac.ir

1. M.Sc. Student, Department of Civil and Survey Engineering, Graduate University of Advanced Technology, Kerman, Iran

2. Assistant Professor, Department of Civil and Survey Engineering, Graduate University of Advanced Technology, Kerman, Iran

1. Introduction

A large number of executive plans such as construction of irrigation and drainage networks, roads, and earth dams might face the shortage of appropriate earth materials; therefore, the currently existing materials should be improved and reinforced. A method for soil improvement is soil stabilization, through which the use of weak soil at the site becomes possible and feasible, and the transportation of materials from a far as well as extravagant costs is an inevitable issue. Such an advantage becomes very important and economically effective in the regions where the existing materials are soils such as loess, sand or fat clay. Lime, cement, rice husk ash, pozzolans, microsilica, aluminum sulfate and fly ash are some of the most common additives. Michael showed that the percentage of lime required for boosting the properties of the fine-grained soils ranges from 3% to 8%. Additionally, his research established the basis of a handful discussions and investigations on the lime mortar in the following years [Mitchell, 1981].

Cebeci et al. investigated the effect of temperature and moisture on the strength and shrinkage of cement and cement-lime mortars with different lime percentages. Their research showed an inverse relationship between the strength of cement mortar and increase of temperature; however, for the mortars containing cement-limestone, increase of temperature would lead to the increase of strength, which was due to the impact of lime on cement mortar [Cebeci, Al-Noury and Mirza, 1989].

Cement improves the behavioral properties of argillaceous fine-grained soil such as inflation, shear strength, water absorption capability and Atterberg limit [Bell, 1988]. Due to the constraints of using cement, adding cement to soil might lead to unfavorable effects on stabilized soil properties. These destructive reactions include carbonation, effects of sulfates, impacts of organic materials and effects of sulfides and sodium chloride. If soil contains sulfate ions or if stabilized soil is exposed to the sulfated water, the presence of cement not only would not plummet the stabilized layer inflation, but will also increase inflation and decline strength [Sherwood, 1993]. Such a phenomenon occurs as a result of the chemical reactions between the minerals of clay, cement, and sulfate, forming the Ettringite and Tamasite minerals, which are strictly inflated by water absorption [Nicholson, Kashyap and Fujii, 1994, Bell, 1988].

Bell demonstrated that adding a small amount of cement up to 2% would improve the soil properties and a higher amount of cement would cause some major changes in these properties. Any sort of cement might be applied for soil stabilization, but ordinary Portland cement was the most frequently used type [Bell, 2005].

However, the traditional stabilizers like cement are under discussion, not only for their negative environmental effects during manufacture but also for their cost. Due to the high costs of road construction, studies must be focused on proper designing and selection of appropriate materials which, in addition to being cost-effective, can boost the efficiency and lifespan of roads. Quality of pavement foundation layers is critical for achieving excellent pavement performance. Stiffness and strength of soil are considered as an essential and relevant engineering and mechanical properties in both design and construction of earthworks, while soil density and water content are the necessary physical measurements during the construction process [Salehi Hikouei, Hasani and Shirkhani Kelagari, 2016].

The amount of material being available for constructing roads and buildings is limited and contractors must pay transportation costs to fetch quality materials from quarries for their projects. Hence, industrial waste materials can be used as a secondary resource to satisfy the need for construction materials [Ziari et al. 2016]. Due to the depletion of natural resources, growing increase of construction activities and road construction, and reducing energy consumption and environmental aspects, researchers are trying to find a suitable alternative for the materials consumed in road construction [Yilmaz et al. 2011, Ayan et al. 2016].

Because of increase in population, urbanization, development activities, and changes in life style, there is an enormous rise in the generation of waste materials, which in turn makes the solid waste management one of the major environmental concerns worldwide [Ahmad and Mahdi, 2015].

Furthermore, in addition to the waste materials resulted from the construction projects, the waste and residual materials from industrial factories and mines have caused an increase in the need for a depot site. Numerous works have been conducted on the use of residual materials for road construction by the organizations related to the environment and roads [Li, 2008, Lee, 2009, Zhao, Leeftinkb and Rotterc, 2010]. In recent studies, use of recycled waste lime, phosphate filler waste, ashes of incinerated municipal solid waste, and waste ceramic materials has been studied as the filler and the obtained results are satisfactory [Katamine, 2006, Hwang, Parkand and Rhee, 2008, Huang, Dong and Burdette, 2009]. The industrial factories' waste materials have been used in concrete blocks, soil stabilization, construction materials, cement production, cement mixtures, and so on. Rossi et al. used the waste coal as the fine granules in the pavement concrete blocks. The results showed that replacing 25-50% of the waste coal with the fine-grained ones would lead to satisfactory results in terms of mechanical strength [Rossi, Ramos and Pagnussat, 2012]. Garcya et al. used waste coal as a part of cement in cement mixture and found that the use of waste coal by 20%, instead of cement, increased 7-day compressive strength, but declined 90-day strength [Garcya, Freasa and Sanchez, 2012]. Inuthia and Nidzam used the waste coal for the stabilization of the foundation and sub-foundation. The obtained results indicated an increase in the 7-, 28- and 90-day compressive strength [Inuthia and Nidzam, 2009]. The industrial metal slag, ore and mine waste are generally suitable for recycling and the use of such mine waste has been reported as an alternative in building construction, road construction and geotechnical applications [Hartlen, Carling and Nagasaka, 1997, Kamon, 1997, Kamon and Katsumi, 1994, Sarsby, 2000, Vazquez et al. 1991, Comans et al. 1991].

ANN modeling approach is a computer methodology that attempts to simulate some important features of the human nervous system; in other words, it is the ability to solve problems by applying the information gained from previous precious experiences to contemporary issues. ANN, as a sort of soft computing tools, has been established as a mapping between a set of input and output numbers [Ghanizadeh and Ahadi, 2015]. ANN are widely used in civil engineering for finding the patterns between the input data and output results [Kolay and Baser, 2014, Mozumder and Laskar, 2015, Shafabakhsh, Jafari and Talebsafa, 2015, Zavrtanik et al. 2016].

The present study aims to investigate the effects of combining cement and copper slag with soil. In addition, a feed-forward back -propagation neural network is proposed to predict elastic modulus, failure strain (ε_f) and UCS of the soils modified with cement and copper slag.

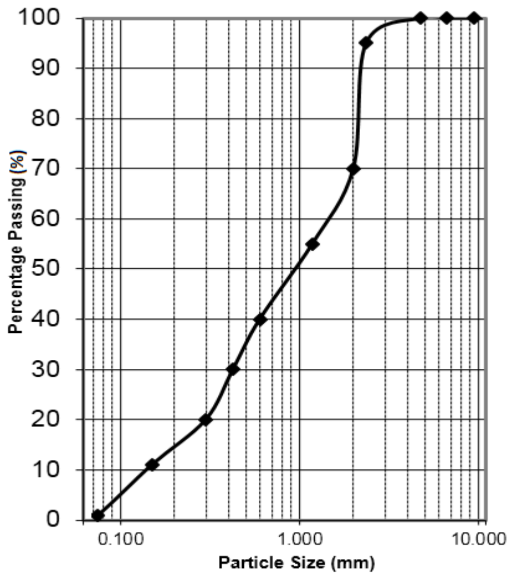
2. Materials and Methods

2.1 Soil and Cement

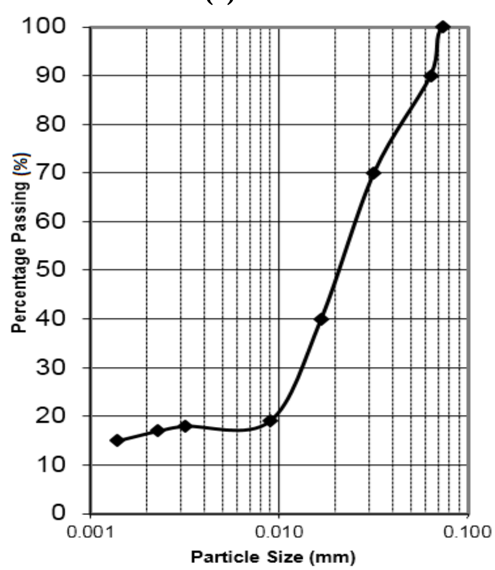
The samples were provided by 20% of clay and 80% of sand by weight. A clay soil from Kerman's mines, which is classified as CL according to the Unified Soil Classification System (USCS), was selected to perform the current experimental work. The particle size distribution curve and the physical properties of the clay and sand are illustrated in Figure 1 and Table 1, respectively. Portland cement (type II) was used for soil stabilization. Table 2 presents the chemical compositions of the employed cement.

2.2 Copper Slag

The copper slag collected from Sarcheshmeh Copper Mine in Kerman. The chemical properties of copper slag are indicated in Table 3. The used copper slag was of black color with density 4.44 gr/cm^3. Figure 2 shows the used copper slag.



(a) sand



(b) clay

Figure 1. Grain size distribution of clay and sand

Table 1. Physical properties of clay

Soil properties	Values
Specific gravity	2.71
Liquid limit	34%
Plastic limit	25%
Plasticity index	9%
USCS classification	CL
OMC	11%
MDD	19.2 kN/m^3

Table 2. Chemical composition of cement

Cement properties	Values
CaO	63.95
SiO_2	21.86
Al_2O_3	4.70
Fe_2O_3	3.51
MgO	2.40
SO_3	2.10
K_2O	0.55

Table 3. Chemical composition of copper slag

Copper slag properties	Values
CaO	5.80
SiO_2	28.83
Al_2O_3	3.71
Fe_2O_3	46.37
Cu	0.54
SO_3	3.26
K_2O	1.15

Figure 2. Copper slag used in sample preparation

2.3 Sample Preparation and Test Procedures

According to requirements of TM-D2166, cylindrical specimen with 50 mm diameter and 100 mm height was determined for unconfined compressive test. Based on pre-test results, the cement contents of 0%, 2%, 4% and 6% and copper slag contents of 0%, 5%, 10%, 15% and 20% by weight of dry soil were selected. For each combination, weight of each material was defined exactly on the basis of OMD and MDD obtained from the standard Proctor compaction test, according to requirements of ASTM D698. The standard Proctor Test is a laboratory geotechnical testing method used to determine the OMD at which soil can reach its MDD. Soil, cement and copper slag were mixed in dry condition properly. Then, water was gradually added into the mixture until a uniform feature was met. The uniformity of distribution has been checked by eye observation.

Weight of each specimen was determined in accordance with given specimen volume and obtained MDD from compaction tests. This weight was divided into three portions and each portion was compacted in 33mm layer in an iron mold. The specimens were cured in a plastic bag to avoid evaporation in a place having a temperature about 20 °C for 28, 60 and 90 days. For each combination, three specimens were examined to assure repeatability of results. UCS tests were carried out on specimens in accordance with ASTM D5102.

3. Results

3.1 Compaction

For soil–cement–copper slag combinations, standard Proctor compaction test was carried out and the results are given in Figures 3 and 4. It is observed that by increasing cement content, MDD decreases and OMC increases. This test also shows that inclusion of copper slag leads to reduction of OMC and increase of MDD.

3.2 Unconfined Compression Tests

To study the effects of curing time, cement, and copper slag, UCS test was performed on the specimens. Figure 5 provides the UCS results of treated specimens with maximum percentages of cement and copper slag after 90 days of curing versus axial strain. Figure 6 is also shows the UCS versus curing time. Figures 7 to 10 provide the UCS results of treated specimens with 0, 2, 4 and 6 percentages of cement at 28, 60 and 90 days of curing versus copper slag percentages.

According to the Figures 5 to 10, the strength of the specimens increased drastically with the rising the cement content. Moreover, the addition of copper slag was found to have a significant effect on the improvement in strength of soil. The increase in UCS may vividly be observed on the basis of the high angle of an internal friction for the copper slag. Furthermore, when the cement content was constant, the relationship between strength versus copper slag contents is approximately linear. So being that, the strength of the specimens increased with the increase of the curing age.

Elastic modulus for a soil is usually the secant modulus from zero deviator of normal stress to a deviator stress equal to one-half of the peak deviator stress. ε_f is also defined as failure strain corresponding to maximum UCS. Elastic modulus and ε_f of each specimen is provided in Tables 4-6

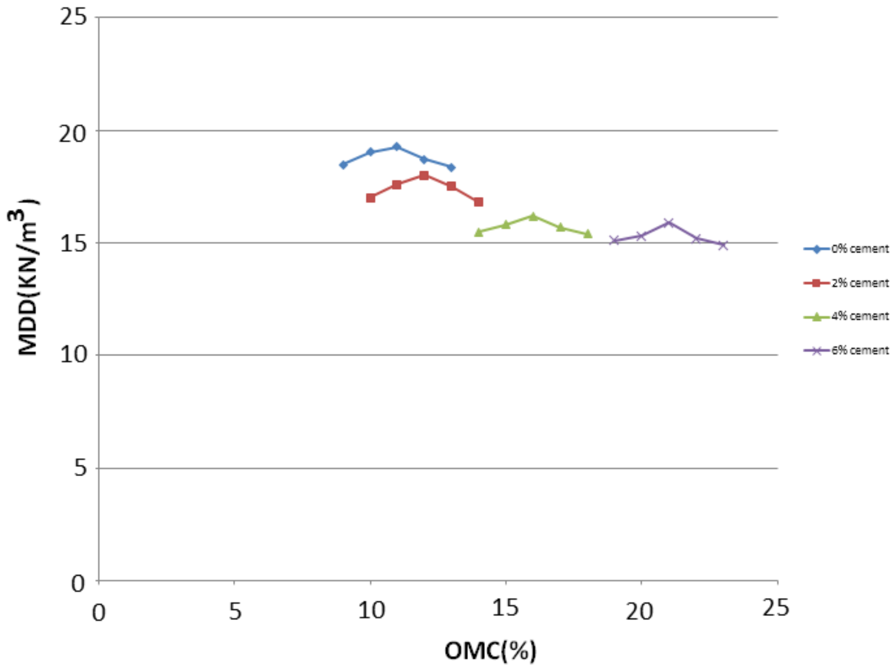


Figure 3. Relationship between MDD, OMC, and cement stabilized clay specimens from Proctor compaction test

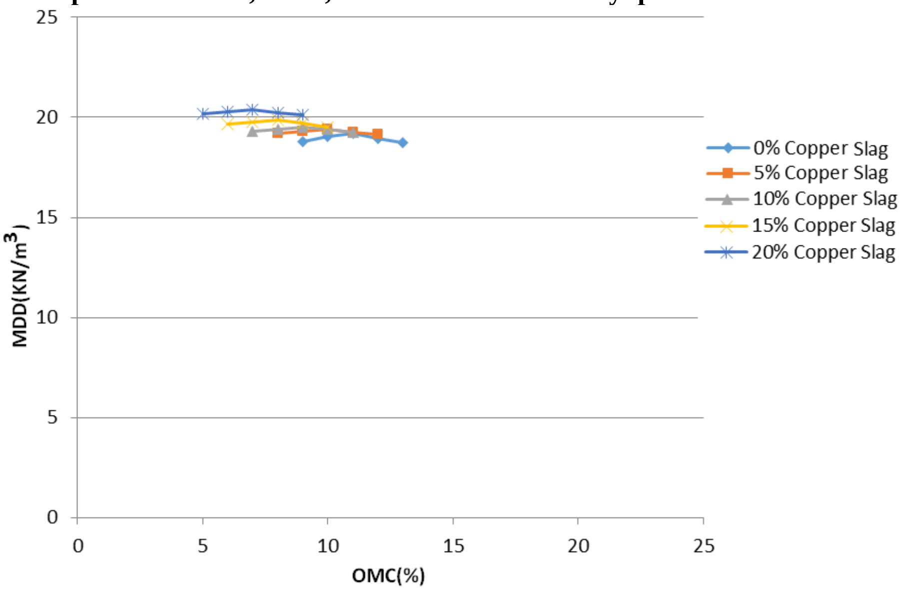


Figure 4. Relationship between MDD, OMC, and copper slag stabilized clay specimens from Proctor compaction test

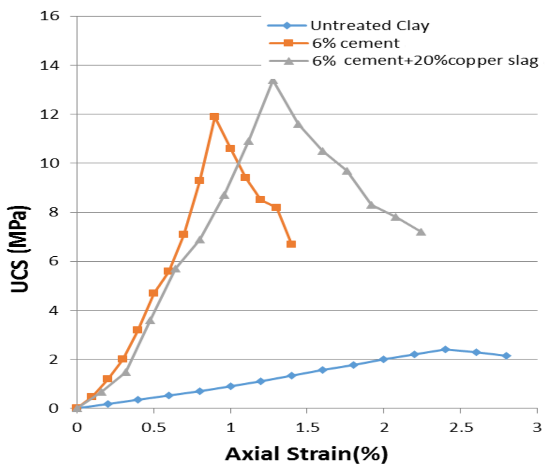


Figure 5. UCS value vs. axial strain after 90 days of curing

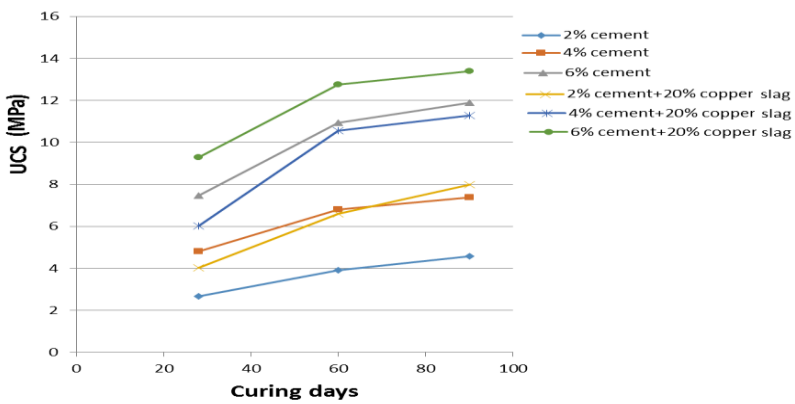


Figure 6. UCS value vs. curing time

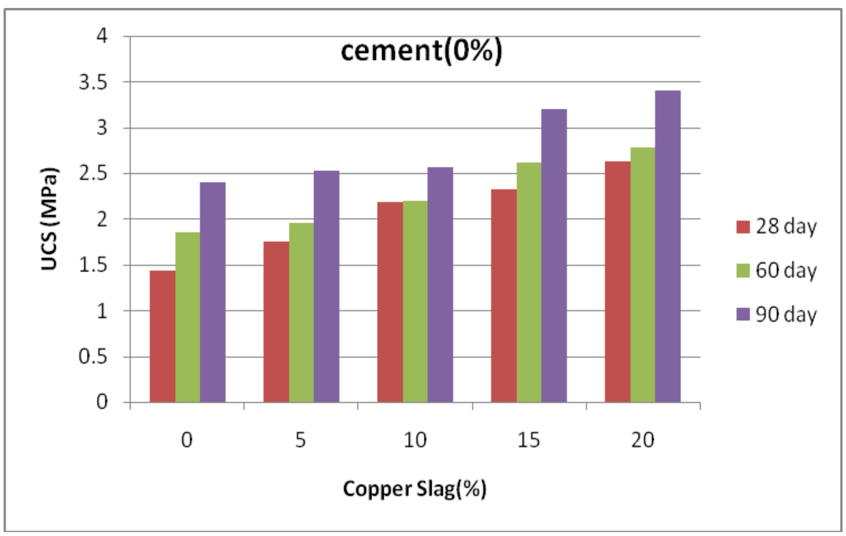


Figure 7. UCS value vs. percentage of copper slag (cement = 0%)

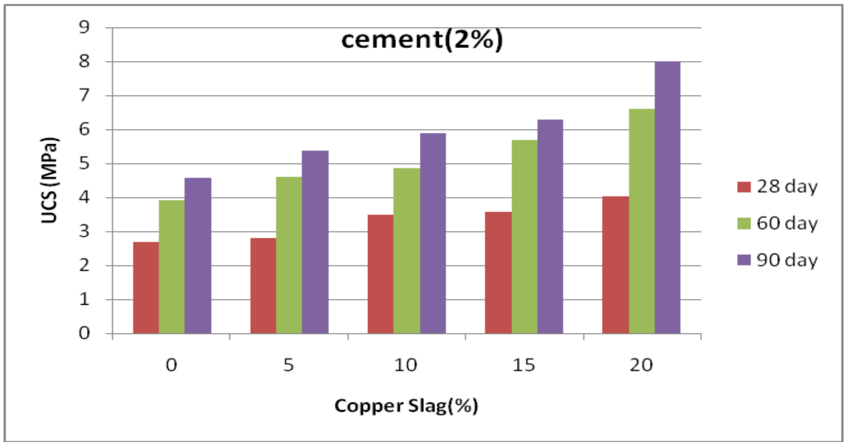


Figure 8. UCS value vs. percentage of copper slag (cement = 2%)

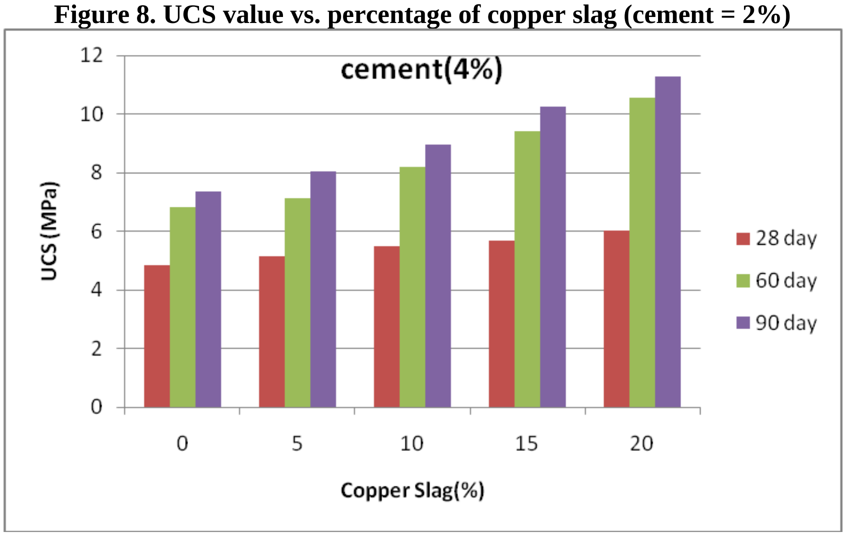


Figure 9. UCS value vs. percentage of copper slag (cement = 4%)

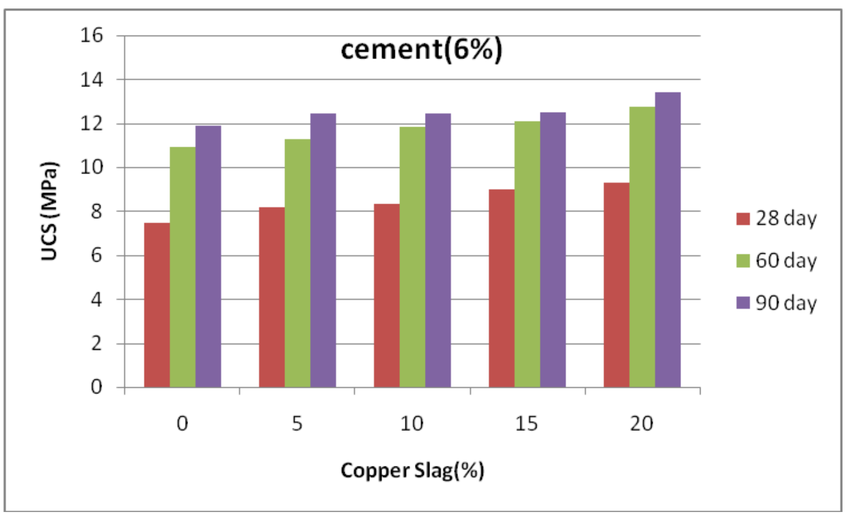


Figure 10. UCS value vs. percentage of copper slag (cement = 6%)

Table 4. Geotechnical properties of the untreated and treated specimens after 28 curing days

Criteria / Soil type	Untreated soil	Cement treated soil			20% Copper Slag and Cement treated soil		
		2% Cement	4% Cement	6% Cement	2% Cement	4% Cement	6% Cement
UCS (MPa)	1.44	2.68	4.82	7.48	4.03	6.02	9.29
ε_f (%)	1.27	1.14	1.11	1.04	1.33	1.25	1.19
Elastic modulus (MPa)	87	112	149	170	144	164	189

Table 5. Geotechnical properties of the untreated and treated specimens after 60 curing days.

Criteria / Soil type	Untreated soil	Cement treated soil			20% Copper Slag and Cement treated soil		
		2% Cement	4% Cement	6% Cement	2% Cement	4% Cement	6% Cement
UCS (MPa)	1.85	3.89	6.81	10.92	6.61	10.57	12.76
ε_f (%)	1.69	1.15	1.06	1.01	1.29	1.25	1.11
Elastic modulus (MPa)	128	263	325	345	301	343	347

Table 6. Geotechnical properties of the untreated and treated specimens after 90 curing days.

Criteria / Soil type	Untreated soil	Cement treated soil			20% Copper Slag and Cement treated soil		
		2% Cement	4% Cement	6% Cement	2% Cement	4% Cement	6% Cement
UCS (MPa)	2.4	4.58	7.37	11.9	8	11.7	13.4
ε_f (%)	1.95	1.75	1.69	1.62	2.10	1.94	1.82
Elastic modulus (MPa)	133	274	337	362	313	357	375

4. Discussion

4.1 Compaction

It can be seemed that the high specific gravity of the copper slag results in an increase of MDD. By mixing the copper slag content, the proportion of sand sized particles increased leading to fewer dependency towards water, thus a reduced OMC is observed. These mentioned effects are combined in cement–copper slag–soil mixture too, but in the range of selected contents of materials, cement content has more hugely effective impressions on compaction parameters in comparison with copper slag content.

4.2 UCS

The UCS value of the un-stabilized soil obtained at 2.4 MPa. Based on the UCS results, by increasing the cement content from 2 to 6%, UCS values of stabilized soil with cement increased from 11.9 MPa for 90 curing days. Then the UCS value of the stabilized soil with 6% cement after 90 curing days was at 4.96 times higher than that of the untreated soil. In the other hand by increasing the copper slag content from 5 to 20%, UCS values of stabilized soil with copper slag increased from 3.4 MPa for 90 curing days. Then the UCS value of the stabilized soil with 20% copper slag after 90 curing days was at 1.42 times higher than that of the untreated soil. Therefore, adding cement has more significant effects than copper slag on increasing UCS.

The average increase in the UCS due to increase in copper slag from 0 to 20% are illustrated in Figure 11. It can vividly be said that the greatest impact of increase in copper slag is when the two percent cement employed for the soil stabilization.

4.3 Elastic Modulus

Among the specimens with cement only and with oth cement and copper slag, the stabilized specimens with both 6% cement and 20% copper slag after 90 curing days had the highest values of elastic modulus at 375 MPa, which was at 2.82 times more than that of the un-stabilized soil, which mad up 133 MPa. Expectedly, elastic modulus increased by increasing the cement content, copper slag content and curing days. From the Tables 4 to 6, it can be concluded that the effects of adding cement was more than the effects of curing time, and the effects of curing time was more than the effects of adding copper slag.

4.4 ε_f

From the results, it can be seen that the ε_f decreased by increasing the contents of cement from 2% to 6%. This trend represents that adding cement increases the brittleness of the specimens. It is unlike adding that by increasing the curing time, the failure strains of the specimens decreased. This trend was due to curing and decreasing water content of the specimens. Furthermore, adding copper slag led to increase the failure strains.

4.5 ANN Modeling And Sensitivity Analysis

An ANN model was developed using 8 input parameters including copper slag content, cement content, water content, dry density, liquid limit, plastic limit, PH and curing age. An ANN with 10 neurons in the hidden layer was considered as the appropriate architecture for predicting elastic modulus, ε_f and UCS of stablized soils, as illustrated in Figure 12. Excellent conformity was observed between the predicted and test data. The result indicated that the proposed model can be applied to predicting elastic modulus, ε_f and UCS of the soils modified with cement and copper slag.

The relative ranking of different target variables of ANN is shown in Table 7. It may be observed in Table 7 that ANN ranked elastic modulus as the most predictable target.

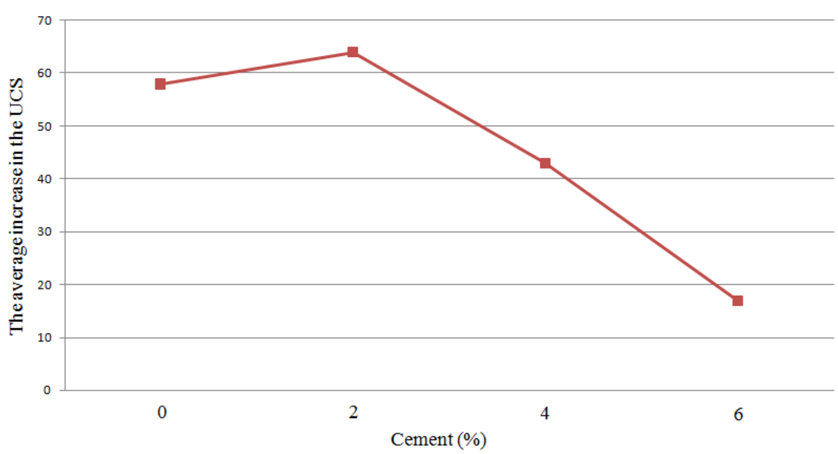


Figure 11. The average increase in the UCS value vs. percentage of cement

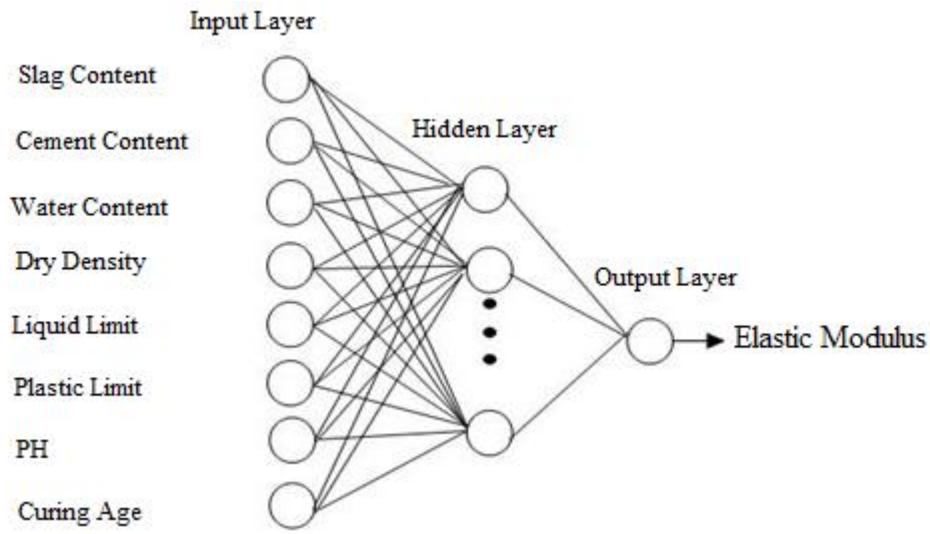


Figure 12. The ANN architecture used as a prediction model for elastic modulus

Table 7. Most predictable target

Target	elastic modulus	ε_f	UCS
R	0.995	0.905	0.967
Relative ranking	1	3	2

Table 8. Results of sensitivity analysis

Eliminated input	Slag content	Cement content	Water content	Dry density	Liquid limit	Plastic limit	PH	Curing age
R	0.846	0.950	0.511	0.897	0.966	0.961	0.633	0.931
Relative ranking	3	6	1	4	8	7	2	5

Sensitivity analysis was employed to understand the effect and to quantify the importance of different input modified soil parameters on the predicted elastic modulus of the specimens. Eight different ANN models developed as one of the inputs were eliminated in each of them. The effect of eliminating each input on reducing the accuracy of the model indicates its importance. The importance and relative ranking of different input variables of ANN are shown in Table 8. It may be observed in Table 8 that sensitivity analysis ranked water content as the most important parameter and liquid limit and plastic limit as the least important ones.

5. Conclusion

The effects of copper slag on the improvement of cement stabilized and unstabilized soil were conceptually investigated by unconfined compression tests and results were discussed in the current laboratory work. The chief conclusions of experiments have been summarized as follows:

1. Copper slag has the potential to improve the mechanical properties of soil. The best UCS belongs to specimens with 6% cement content and it increases by inclusion of 20% copper slag.

2. Adding copper slag to the soil led to the reduction of the OMD and increase of the MDD, which was completely opposite to the behavior of the cement.
3. Increasing the time for completing the pozzolonic reaction is the leading factor of an increase in the soil strength so that the strength would become almost twice from 28 to 90 days.
4. In different construction projects, in addition of improving soil properties, using the copper slag would permit engineers to take a step in order to protect and preserve the environment, decrease the construction costs through saving material expenses and decline the demand for the primary natural resources.
5. The ANN model was able to predict the elastic modulus of stabilized soil with copper slag content, cement content, water content, dry density, liquid limit, plastic limit, PH and curing age as input parameters.

6. References

- Ahmad, M. and Mahdi, F. (2015) "Characterization of bitumen mixed with plastic waste", International Journal of Transportation Engineering, Vol. 3, No. 2, pp. 85-99

- Ayan, V., Khavandi, A., Omer, J. R. and Limbachiya, M. C. (2016) "Toughness performance of recycled aggregates for use in road pavement", International Journal of Transportation Engineering, Vol. 3, No. 3, pp. 171-179

- Bell, F. G. (1988) "Stabilization and treatment of clay soils with lime, part 1, Basic principles" Ground Engineering, Vol. 21, No. 1, pp. 10-15

- Bell, F. G. (2005) "Engineering treatment of soils", Published by Taylor & Francis e-Library.

- Cebeci, O., Al-Noury, S. and Mirza, W. (1989) "Strength and drying shrinkage of masonary mortars in various temperature-humidity environments", Cement and Concrete Research, Vol. 19, No. 1, pp. 53-62

- Comans, R. N.J., Van det Sloot, H. A., Hoede, D. and Bonouvrie, P. A. (1991) "Chemical Processes at a redox/pH interface arising fromthe use of steel slag in the aquatic environment, Waste materials in construction", Proceedings of the International Conference on Environmental Implications of Construction with Waste Materials, Maastricht, The Netherlands, pp. 243-254

- Garcya, R., Freasa, M., Sanchez de Rojas, M. I., Juan Valdés, A. and Medina, C. (2012) "Effect of activated coalmining wastes on the properties of blended cement", Cement Concrete Compositions, Vol. 34, pp. 678-683

- Ghanizadeh, A. and Ahadi, M. (2015) "Application of artificial neural networks for analysis of flexible pavements under static loading of standard axle", International Journal of Transportation Engineering, Vol. 3., No. 1, pp. 31- 43

- Hartlen, J., Carling, M. and Nagasaka, Y. (1997) "Recycling or reuse of waste materials in geotechnical applications", Proceedings ofthe second International Congress on Environmental Geotechnics, Osaka, Japan, pp. 1493-1513

- Huang, B.S., Dong, Q. and Burdette, E.G. (2009) "Laboratory evaluation of incorporating waste ceramicmaterials into Portland cement and asphaltic concrete", Construction and Building Materials, Vol. 23, No. 12, pp. 3451-3456

- Hwang, S.D., Park, H.M. and Rhee, S.K. (2008) "A study on engineering characteristics of asphalt concreteusing filler with recycled waste lime", Waste Management. Vol. 28, No. 1, pp. 191-200

- Inuthia, J.M. and Nidzam, R.M. (2009) "Effect of slag and siliceous additions on the performance of stabilized coal waste backfill", World of Coal Ash Conference (WOCA), Lexington, Kentucky, USA.

- Kamon, M. and Katsumi, T. (1994) "Civil Engineering use of industrial waste in Japan", Proceedings of the International Symposiumon Developments in Geotechnical Engineering, Bangkok, Thailand, pp. 265-278

- Kamon, M. (1997) "Geotechnical utilization of industrial wastes", Proceedings of the second International Congress onEnvironmental Geotechnics, Osaka, Japan, pp. 1293-1309

- Katamine, N. M. (2006) "Phosphate waste in mixtures to improve their deformation", Journal of Transportation Engineering, Vol. 126, pp. 382-391

- Kolay, E. and Baser, T. (2014) "Estimating of the dry unit weight of compacted soils using general linear model and multi-layer perceptron neural networks", Applied Soft Computing, Vol. 18., No. 1, pp. 223–231

- Lee, S.T. (2009) "Influence of recycled fine aggregates on the resistance of mortars to magnesium sulfateattack", Waste Management, Vol. 29, No. 8, pp. 2385-2391

- Li, X.P. (2008) "Recycling and reuse of waste concrete in China, Part I: Material behavior of recycled aggregateconcrete", Resources, Conservation and Recycling, Vol. 53, No. 1, pp. 36-44

- Mitchell, J.K. (1981) "Soil improvement state-of-the-art", Department of Civil Engineering, University of California.

- Mozumder, R. and Laskar, A. (2015) "Prediction of unconfined compressive strength of geopolymer stabilized clayey soil using artificial neural network", Computers and Geotechnics, Vol. 69, No. 10, pp. 291–300

- Nicholson, P. G., Kashyap, V. and Fujii, C. F. (1994) "Lime and fly ash admixture improvement of tropical Hawaiian soils", Resources, Conservation and Recycling, Vol. 1440, pp. 71-78

- Rossi dos Santos, C., Cassiano, R. S., Juarez, R.A.F. and Daniel, P. (2012) "Use of coal waste as fine aggregates in concrete blocks for paving", 10th International Conference on Concrete Block

Paving, Shanghai, Peoples Republic of China.

- Safa, M. and Makarchian, M. (2013) "Effect of stabilizition lime and GGBS on the soft clay",7th Confrence of Civil engineering , Iran, Zahedan.
- Salehi Hikouei, I., Hasani, A. and Shirkhani Kelagari, Z. (2016) "Evaluation of PFWD and DCP as quality control tools for sub-grade of GW and SW soils", International Journal of Transportation Engineering, Vol. 3., No. 3, pp. 189-194
- Sarsby, R. (2000) "Environmental geotechnics", Thomas Telford Ltd., London, UK.
- Shafabakhsh, G. H., Jafari Ani, O. and Talebsafa, M. (2015) "Artificial neural network modeling (ANN) for predicting rutting performance of nano-modified hot-mix asphalt mixtures containing steel slag aggregates", Construction and Building Materials, Vol. 85 , pp. 136–143
- Sherwood, P.T. (1993) "Soil stabilization with cement and lime-state of the art review", HNSO Publication.
- Vazquez, E., Roca, A., Lopez-soler, A., Fernandez-Turiel, J. L., Querol, X. and Felipo, M. T. (1991) "Physico-chemical and mineralogy characterization of mining wastes used in construction, waste materials in construction", Proceedings of the International Conference on Environmental Implications of Construction with Waste Materials, Maastricht, The Netherlands, pp. 215-223
- Yilmaz, M. Baha Vural Kok and Necati Kuloğlu (2011) "Effects of using asphaltite as filler on mechanical properties of hot mix asphalt", Construction and Building Materials, Vol. 25, pp. 4279-4286
- Zavrtanik, N., Prosen, J., Tušar, M. and Turk, G. (2016) "The use of artificial neural networks for modeling air void content in aggregate mixture", Automation in Construction, Vol. 63, pp. 155–161
- Zhao, W., Leeftinkb, R. B. and Rotterc, V. S. (2010) "Evaluation of the economic feasibility for the recycling of construction and demolition waste in China: The case of Chongqing", Resources, Conservation and Recycling., Vol. 54, No. 6, pp. 377-389
- Ziari, H., Moniri, A., Ayazi, M. and Nakhaei, M. (2016) "Investigation of Rutting Performance of WMA Mixtures Containing Copper Slag", International Journal of Transportation Engineering, Vol. 3, No. 3, pp. 22