Int. J. of GEOMATE, Dec. 2011, Vol. 1, No. 2 (Sl. No. 2), pp. 130-135
Geotec., Const. Mat. and Env., ISSN:2186-2982(P), 2186-2990(O), Japan

Behavior of Collapsible Loessic Soil After Interparticle Cementation

Arrúa P., Aiassa G.; Eberhardt M. and Alercia Biga C.
GIGEF - FRC, Universidad Tecnológica Nacional, Córdoba, Argentina

ABSTRACT: The water content, shape and roughness of soil particles are related to the strength and stiffness of loessic soil samples under remolded conditions. When soil sample are under undisturbed condition, the cementation level between particles by the presence of water-soluble carbonates, govern the soil macroscopic behavior. Soil stiffness depends on the rigidity of the link. To control the mechanical collapsible behavior usually compaction and stabilization are made by Geotechnical Company with cementations agents. This work presents the hydration process of cement without mixing water and how geotechnical index and other parameter are modified. Those variables influence the resistance have been evaluated using unconfined compression tests. Results showed that resistance depend on the initial water content of hydration. Optimal conditions for generation cementing bridges are established.

Keywords: Micrograph, Hydration, Strength, Unconfined compression

1. INTRODUCTION

In the construction of geotechnical structures, the improvement of soil properties is very common in Argentine [1]-[4]. There are many literature related using cement for improving engineering properties of soils[5]-[8]. The compacted soil and soil mixtures must be done using local soil. So soil mechanical behavior and soil mixing design have direct correlation. The Córdoba city is located in the geographical center of Argentina. Loess soils are usually found in arid or semiarid climates and their physical and chemical characteristics depend on their geological origin [9]. In nature the loess has an open structure, low unit weight, highly dependent on external conditions. The purpose of the addition of cementing agents is to stabilize the silty loess due to lack of technical qualities for application in construction works. Environmental conditions such as temperature and humidity significantly influence the strength characteristics of soil-cement mixtures [10]. The amount of cements incorporated, is generally related to the strength and stiffness assigned to the material at the stage of design, however this definition may be inadequate if the environmental conditions during the stage of hydration are not considered in the final strength of material [11], [12]. This paper presents the chemical composition, principal geotechnical properties, particles size and relation between different kinds of loess in Argentine. A scanning electron microscope (SEM) has been used to establish the chemical composition of local cement. Different samples have been built to study the behavior of loess-cement mixtures. To quantify the stress strain relation, unconfined compression test have been conducted. Time of curing, temperature of curing, initial water and cement contents, are variable and govern soil mechanical behavior. The results allow establishing relationship between roughness and sphericity of the particles. It also identifies the link between them. The results showed that the stress-strain curved and initial modulus modified with variation of cement content.

2. MATERIALS

2.1 Loessic soil

Loess is non stratified aeolian deposit, and probably most abundant Quaternary deposit on land [13]. It consists of silt with some small fraction of clay, sand and carbonate. The deposits are up 30 m in thickness in the Missouri and Rhine Rives Valleys, more than 180 m thick in Tajikistan, 330 m thick in northern China [14] and 2-80 m thick in Argentine. The most important deposit in Latin America is located in central area of Argentine.

These kinds of soils have been deposited during the Upper Pleistocene and Holocene and cover much of the province of Córdoba. Reference [15] has been described how, light yellow or brown in color, some times with a reddish or grey tinge. Usually, most researchers agree that the material originates from the Andes Mountains, with volcanic mineralogy agents. Recent contributions on the knowledge of the origin and evolution of the loess are presented in [9] and [16]. Locally, the soil has got mineral content from Small Hills of Córdoba Province. Grain-size distribution includes fine sand (1%-10%), silt (50%-80%) and clay (2%-15%) that have been deposited by wind action in areas of low energy. Fig. 1 presents typical grain size distribution. The chemical compositions of loess are mainly SiO_2, Al_2O_3, Fe_2O_2 y CaO.

Chemical compositions of the soils from different regions of Argentina are shown in Table I. Note that close similarity exists between those loess, except for the percentages of CaO (which reflect the influence of locally degradation of Cordoba Small Hills). However the chemical composition is remarkably uniform, suggesting a common regional source. In natural conditions the water content ranges from 12.7% to 23.0%, the dry unit weight (kN/m^3) is 12.5 to 13.5, Specific gravity is 2.66 to 2.67, Atterberg limits are: liquid limit 23% – 30% and plasticity index 4.2% – 4.9%. Dynamic Cone Penetration Index [mm/blow] is 18–24, for Mohr-Coulomb failure criterion the friction angle in triaxial test (CD) is 27º – 30º, and cohesion [kN/m^2] in triaxial test (UU) is 15 – 40. Poisson modulus rages from 0.3 to 0.35, and elasticity modulus from unconfined compression test (MN/m^2) is 1.5–8. From oedometer test, the secant modulus for 100kPa in MN/m^2 is 2.0 – 7.0. Usually yield pressure in oedometer test (a: vertical direction; b: horizontal direction) is (a) 60kPa – 280kPa, (b) 100kPa – 180kPa.

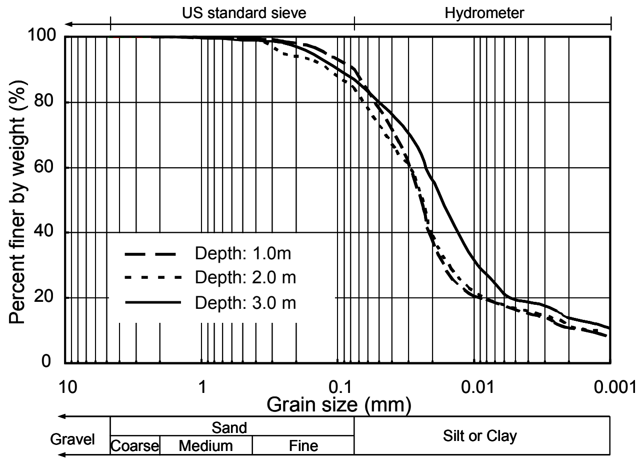


Fig. 1. Gradation result for loess soil

2.2 Cement

The chemical composition of Normal Portland Cement CP40 and particle morphology have been determined by a LEO 1450 VP Energy Dispersive Spectroscopy analysis (EDS) and Scanning Electron Microscope (SEM). The results shows that ordinary cement manufactured in Malagueño-Córdoba content of SiO_2: 15.42%, Al_2O_3: 4.60%, Fe_2O_2: 3.35%, CaO: 65,71%, MgO: 2.79%, K_2O: 1.97%, Na_2O: 0.59%, SO_3: 5.10%, TiO_3: 0.47%. The most important difference with soil are content of SiO_2 and CaO.

2.3 Soil cement mixtures

The mixtures were designed to evaluate the performance in Unconfined Compression (UC). A review of literature about the testing of laboratory samples of soil-cement indicates that test results are highly dependent on sample preparation. This work includes variations in cement content, time of curing, temperature of curing, initial water content and compaction level.

The cement contents (C.c.) used, expressed as a percentage of the dry soil weight, were: 2.5%, 5.0%, 7.5%, 10% and 15%. The soil was dried in an oven at 105 ºC for 24 hours, was sieved and recovering the material passing sieve #40. Water was added in the proportions established at each case as mixing water. The samples were generated by compaction in the mold at constant dry unit weights (approx. 14 kN/m^3). The manufacture of the samples was performed in three equal layers scarification between them. Were classified and arranged in different curing conditions. Variable temperatures were taken from -20°C to 120°C.

Table 1: Oxides soil components

SiO_2	Al_2O_3	TiO_3	Fe_2O_2	CaO	MgO	K_2O	Na_2O	H_2O	Reference
58.35	16.64	---	6.69	8.98	2.75	2.82	2.11	---	Soil used in this work. Cordoba City
67.22	14.35	---	6.81	5.16	2.13	2.93	1.41	---	Córdoba City [17]
59.20	13.60	---	4.30	6.50	1.10	2.20	3.10	---	Provincia de Córdoba [18]
59.86	17.40	---	4.80	3.08	1.17	1.70	1.97	6.04	Baradero, La Plata [13]
62.70	15.00	---	6.00	2.80	1.90	1.88	1.40	4.32	Miramar. Buenos Aires [13]
57.16	17.28	---	5.43	2.83	1.67	3.68	8.35	---	Buenos Aires [15]
66.01	16.22	0.88	5.30	2.85	1.62	1.90	1.97	3.14	La Pampa [19]
59.00	17.00	---	5.87	3.05	2.55	1.56	1.38	5.80	Valles Preandinos subtropicales; Provincia de Tucumán [20]
---	14.00	0.80	4.60	0.09	1.50	3.00	1.90	---	Llanura Chaco Oriental [21]

3 SHAPE AND COMPOSITION OF PARTICLE

The shape and connection between particles are an inherent soil characteristic that play a major role in macroscopic mechanical properties. The morphology describes at large scale the level platy or sphericity, and texture in smaller scales reflect the surface roughness.

In this work, the chart from [22] is used to compare individual grains for visual estimation of roundness and sphericity. The chart from [23] is used for shape characterization. The particle morphology, roughness and roundness have been determined by a LEO 1450 VP Scanning Electron Microscope (SEM) and the components of loess soil with an Energy Dispersive Spectroscopy analysis (EDS).

The microscopic morphology of loess were shown in Fig. 2. It could be seen from these SEM results that the surface of loess material are subrounded and rounded with 0.7 sphericity coefficient and a 0.5 to 0.7 roundness coefficient. The particle size distribution is homogenous. The silt particles are the biggest and the smaller size are clay particles. Fig. 2 shows a zoomed zone for analysis in Fig. 3. The cement presence affects the structure inherent of soil, because small particles stick to larger particles in stable connections. SEM photos of loess, cement, soil cement mixture at C.c: 2.5% and 15% are also shown in Figs. 3. Fig. 3(a) shows that particle size taken in consideration for comparison with mixtures, It has size of upper limit of silty soil (~< 75µm and ~< 45µm). It can be seen that particle has angular and subangular shape with some small silty particles. Also appears some clays particles. The Fig. 3(b) presents Portland cement particles. It shows that predominant grain sizes are smaller than silt and with size between ≈1μm to ≈10 μm. It could be seen from these SEM that sphericity coefficient is 0.3 to 0.5 and roundness coefficient is 0.3-0.5. From SEM photo, it is found that the particles of cement are smaller than loessic soil.

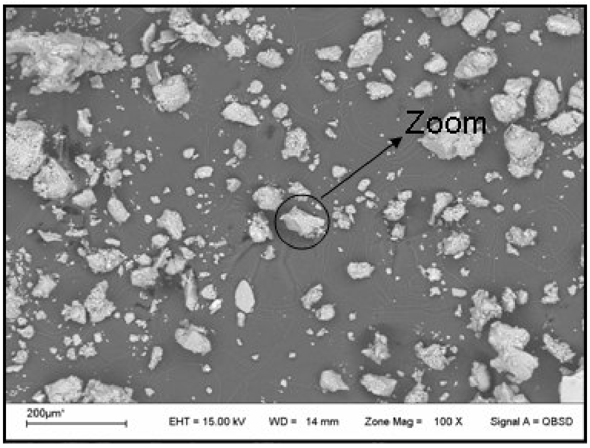
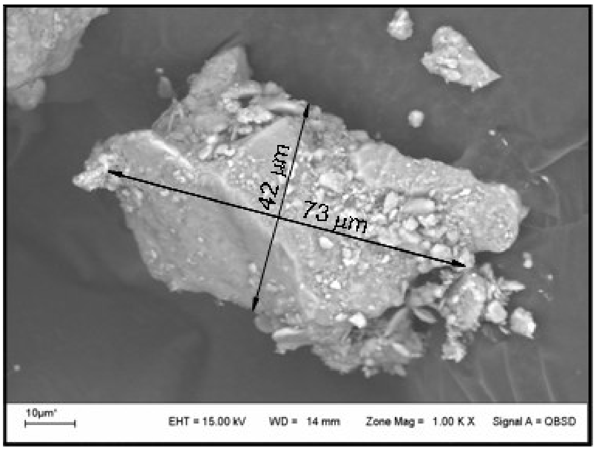
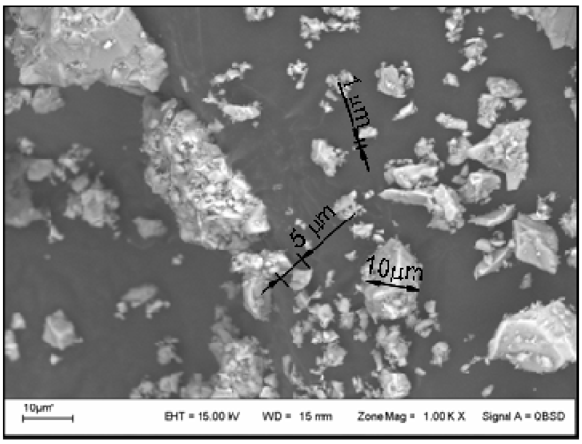


Fig. 2. SEM morphology of loess



(a)



(b)

Fig. 3. SEM photos. (a) Natural loess soil (b) Normal Portland cement

As shown in Fig. 4 mixture after 21 cementation days with cement content of 2.5% do not shows relevant difference with Fig. 3(a). When the cement content is low, stick on the cement particles some of silty soil, forming clusters that fail to establish links with others silt.

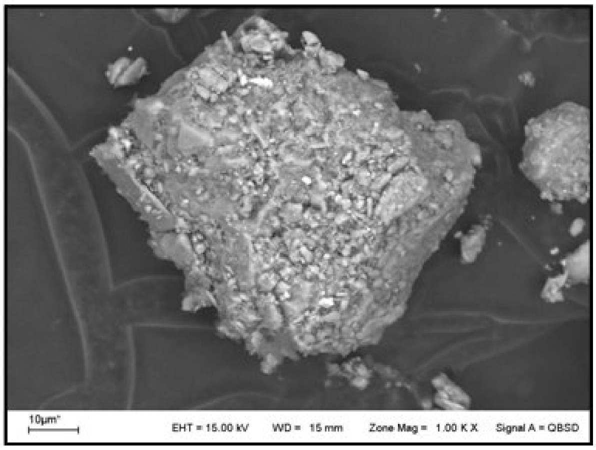


Fig. 4. SEM photo of mixture C.c.: 2.5%

There are cementation between smaller particles and big silt particles, but we do not find cementation between big silty particles. The low cement content may be responsible for the links absence.

Fig.5 shows the SEM for a cement content of 15%. When the cement content is high (15 % of C.c.) was able to establish stable cementation and links between different silt particles. This phenomenon may be responsible for increased stiffness and strength of mixtures samples. The ellipses areas indicate links between silt and hydrations products.

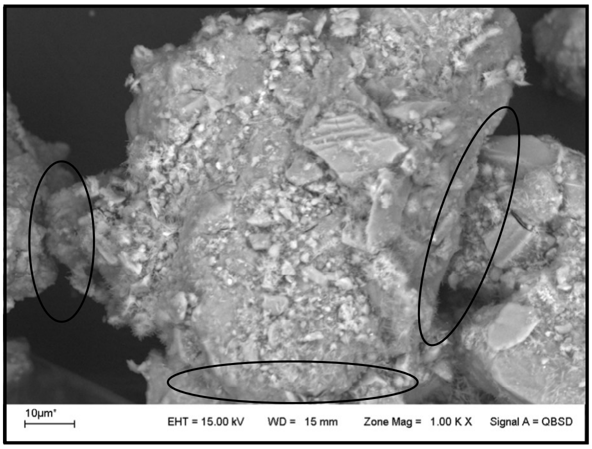


Fig. 5. SEM photo of mixture C.c.: 15%

Analysis of Energy Dispersive Spectroscopy is presented in a schema three dimensional (Fig. 6). It shows the mineral level present in cement, loessic soil and a mixture of soil cement with C.c: 15%.

The figure shows that the content of Si decreases with increasing of cement content (C.c), while calcium (Ca) decreases with decreasing of cement content. The content of Ca is 35.50%, 12.91% and 5.34% for cement, mixture soil-cement (15% of Cc), and loess respectively. The content of Si are 5.46%, 18.63% and 22.78% for cement, mixture soil-cement (15% of Cc), and loess respectively.

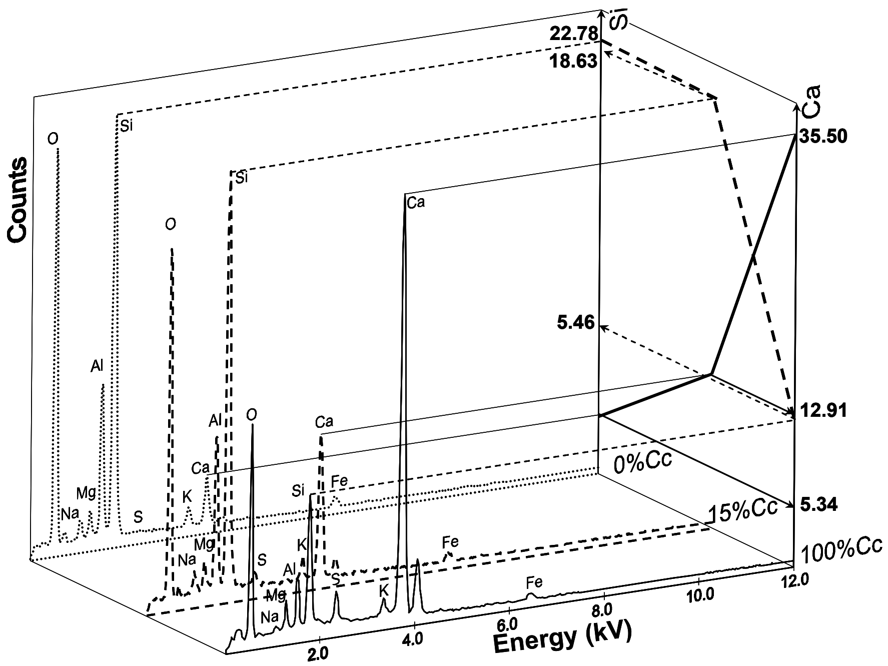


Fig. 6. Energy Dispersive Spectroscopy test (EDS). Variation of Si and Ca

4 MECHANICAL TEST

For unconfined compression tests (UC) a mechanical press was used, instrumented with a load cell with a capacity of 50kN and a digital comparator for recording displacements with a precision of 0.001 mm, to a constant deformation rate of 2.4 mm/min. UC tests is used to evaluate the stress–strain characteristics and the stiffness properties of the Soil-Cement-Mixture (SCM).

Fig. 7 shows the typical failure of specimens with C.c: 15% and natural loess soil (C.c: 0%). The addition of cement, causes an increase stress and strength. SCM samples have a typical inclined failure plane (α_f) for defining cohesion and friction angle in Mohr-Coulomb failure criterion. In loess samples without cement addition (C.c: 0%) there is an increase of sectional side due to material ductility. The failure stress is considered as maximum stress reached before softening in stress-strain curve. It does not take into account the level of deformation reached.

The results obtained from 5 UC tests with unit weight of: 14 kN/m^3, time of curing: 14 days, temperature of curing of: 20 ºC, and initial water content: 21 % is shown in Fig. 8. The tendency on stress-strain curves show that the initial modulus increases with increasing of cement content. The tendencies are not linear and deformation reaches 2.5%. Cement content of 2.5% has a unconfined compressive strength of 270 kPa, but a cement content of 15% can increase resistance to 9628 kPa. Cementation, cohesion and suction level, modify cohesive parameter from Mohr-Coulomb failure criterion. (Fig.9), it grows to 1564 kPa for C.c: 15%, 1463 kPa for C.c.: 10%, 987 kPa for C.c: 7.5%, 208 kPa for C.c: 5.0%, 71.95 kPa for C.c: 2.5%. For each C.c specified in paragraph 2.3, has been modified water content. This allows establishing its influence in the development of resistance. The specimens were built to 14 kN/m^3 dry unit weight.

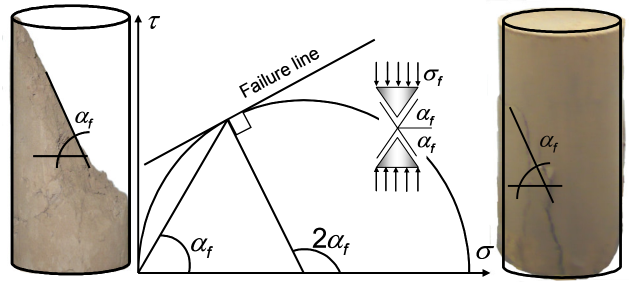


Fig.7. Typical failure. (a) Soil-cement (C.c.: 15%) (b) Theoretical behavior model (c) Natural loess soil

Fig. 9 shows the maximum compressive strength of concrete mixtures and the initial water content. Samples built with Cc: 2.5%, presents a maximum resistance to wi = 19%, for Cc: 5.0% at wi = 23%, Cc: 7.5% at wi = 19%, Cc: 10.0% at wi = 21 %, and Cc: wi = 15% to 23%. The results show that the peaks of resistance are obtained for water contents between 19% and 23%, average 21%. Outside this interval, the unconfined compressive strength decreases significantly. This behavior can be associated with deficiency or excess in available water in the soil matrix during the hydration process.

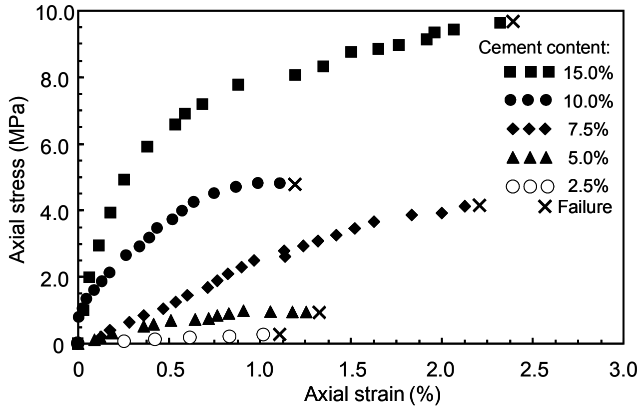


Fig.8. Stress-strain curves unconfined compression test

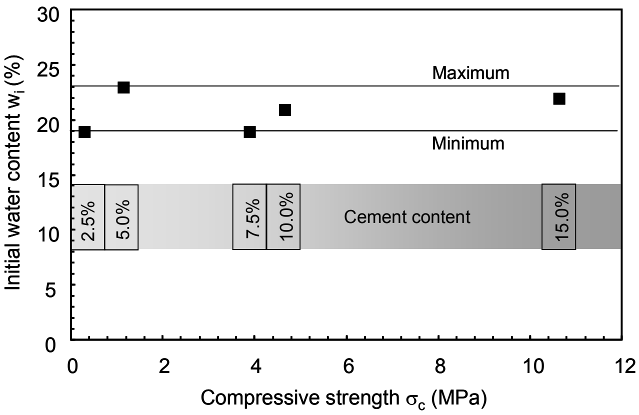


Fig. 9. Maximum compressive strength for different initial water content

A cement content of 9% has been defined to study the curing time influence and curing temperature influence. Fig. 10 presents the relationship between unconfined compressive strength and curing time, with 21% initial water content and 20 °C curing temperature.

At early ages less than 15 days, developed the most important percentage of resistance, which reaches 3.5 MPa. In semilogarithmic scale, the relationship between curing time and the resistance is linear.

After 15 days, there is a strength improvement less than 20% of the maximum strength.

Fig. 11 presents results that relate to the curing temperature and unconfined compressive strength. The samples were stored during the curing period in different environmental conditions. The samples were cured in an oven, refrigerator and laboratory environment. Temperature was controlled.

For temperatures below 0 °C, the maximum strength reached is 2.0 MPa. The optimum is between 20 ºC and 30 ºC. The results showed that unconfined compressive strength decrease (40%), for temperature extreme conditions (100 ºC).

Decreased resistance to low and high temperatures may occur by inhibition of water available for hydration during freezing effect or vaporization effect respectively.

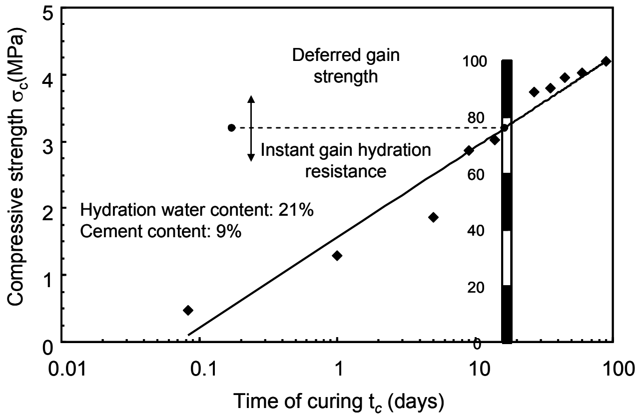


Fig. 10. Compressive strength and time or curing

This phenomenon prevents the hardening material generation and the cement links between particles. The lowest resistance obtained for tests, is presented for low temperatures. Possibly because of increased volume of water during freezing, and decrease in water available for hydration.

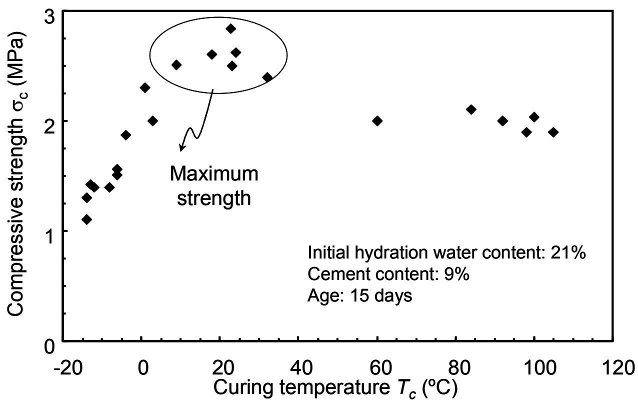


Fig. 11. Compressive strength vs. temperature of curing

5 CONCLUSION

This paper has presented a study on loess material and normal Portland cement and revised the importance of interparticle bridges and their influence on the mechanical performance of the material. Water content, unit weight, cements content, time of curing and temperatures of curing have been studied. The principal results are as follows:

- The unconfined compression shows a maximum independent of cement content when initial water content range is 19% to 21% (hydration water).
- The temperature range that triggers the hydration of cement and improves the unconfined compressive strength ranges from 20 ºC to 30 °C.
- Extreme temperatures (high or low) will reduce strength of samples of 60%.
- 80% of unconfined compression strength is achieved

during the first 15 days of hydration.

- Mixtures with Cc: 7.5% or higher have appropriate physical and mechanical properties for use in various civil infrastructures. Highlights the possibility of making bricks for building houses.

6 ACKNOWLEDGMENT

This work was partially funded by the National University Technological, Regional Córdoba Faculty (Argentina), the National Agency of Scientific and Technological Promotion of Argentina and Ministry of Science Technology (Government of Córdoba). The authors thank the staff of GIGEF.

7 REFERENCES

[1] Arrúa, P; Aiassa, G. Eberhardt, M. and Alercia, I. 2011. Estabilización de suelos loessicos mediante la incorporación de un aglomerante mineral. 14th Pan-American Conference on Soil Mechanics and Geotechnical Engineering. Toronto, Ontario, Canadá 2 - 6 October 2011 (to be published).

[2] Eberhardt, M.; Arrúa, P.; Aiassa, G. y Terzariol, R. 2011. Optimización de las obras de cierre para el control de inundaciones en el noreste pampeano. Revista de Geología Aplicada a la Ingeniería y el Ambiente. ISSN: 1851-7838. Junio 2011 Nº26. pp. 29-36.

[3] Aiassa, G. y Arrúa, P. 2007. Diseño de mezclas de suelo compactado para la construcción de terraplenes. Revista EIA. ISSN:1794-1237. Vol. 7 pp. 51-69.

[4] Aiassa, G.; Arrúa, P. and Eberhardt, M. 2011. Geotechnical and hydrogeological considerations for landfill site selection in the Argentina loess region. International Journal of Earth Sciences and Engineering. ISSN: 0974-5904. Vol. 4, No 1, pp.1-12.

[5] Lachemi M., Hossain, K., Shehata, M., Thaha W. 2008. Controlled low strength materials incorporating cement kiln dust from various sources. Cement & Concrete Composites 30, pp. 381–392.

[6] Piattoni Q., Quagliarini E., Lenci S. 2011. Experimental analysis and modelling of the mechanical behaviour of earthen bricks. Construction and Building Materials 25, pp.2067–2075

[7] Bahar R., Benazzoug M., Kenai S. 2004. Performance of compacted cement-stabilised soil. Cement & Concrete Composites 26: pp. 811–820.

[8] Li Chen, Deng-Fong Lin. 2009. Stabilization treatment of soft subgrade soil by sewage sludge ash and cement. Journal of Hazardous Materials 162: 321–327.

[9] Zárate, M.A. 2003. Loess of southern South America. Quaternary Science Reviews. PERGAMON. 22: 1987-2006.

[10] Shan B., Wang C., Dong Q., Tang L., Zhang G., and Wei J., 2010. Experimental study on improving collapsible loess with cement. Global Geology, 13 (2) pp. 79-84.

[11] Altun S., Sezer A., Erol A., 2009. The effects of additives and curing conditions on the mechanical behavior of a silty soil. Cold Regions Science and Technology 56, pp.135–140.

[12] Ying Xia Yu, Yu Feng Jiao, Bin Liang, Wei Zhang. 2011. Experimental Research on the Mechanical Properties of Compacted Cement Soil in Collapsible Loess Area and Engineering Application. J. of Advanced Materials Research. Volumes 250 – 253, pp. 421-424.

[13] Sayago J., Collantes M., Karlson A., Sanabria J. 2001. Genesis and distribution of the Late Pleistocene and Holocene loess of Argentina: a regional approximation. Quaternary International, 76/77: 247-257.

[14] Mitchell, J.K. and Soga, K. 2005. Fundamentals of Soil Behavior, 3rd ed. Jhohn Wiley & Sons, Hoboken, New Jersey, USA

[15] Teruggi M. 1957. The Nature and Origin of Argentine Loess. Journal of Sedimentary Petrology 27 (3): 322-332.

[16] Bidegain J., Rico Y., Bartel A., Chaparro M. and Jurado S. 2009. Magnetic parameters reflecting pedogenesis in Pleistocene loess deposits of Argentina. Quaternary International, Vol 209, pp. 175-186.

[17] Arrúa, P.; Aiassa, G. and Eberhardt, M. 2011. Loessic soil stabilized with cement for civil engineering applications. International Journal of Earth Sciences and Engineering. ISSN: 0974-5904 (to be published)

[18] Ricci J. 1966. El loess de Río Tercero y el probable origen de los mallines (Córdoba). Terceras Jornadas Geológicas Argentinas, Bahía Blanca.

[19] Arens, P. 1969. Algunos paisaje geoquimicos de la región pamepeana, Reunión Argentina de la Ciencia del Suelo, Santa Fe, Argentina, Actas V.

[20] Camino, M., 1988. Estratigrafía y evolución paleoambiental durante el Cuaternario del Valle de La Sala. Unpublished Thesis, Facultad de C. Naturales, Universidad de Tucumán, Tucumán, Argentina.

[21] Morras, H., 1996. Composición y evolución de la fracción limo grueso de suelos del Chaco meridional argentino. Congreso Geológico Argentino, Actas XIII Vol. IV: 263-265.

[22] Krumbein W., and Sloss L. 1963. Stratigraphy and Sedimentation, 2nd ed. W.H. Freeman, San Francisco.

[23] Powers M. 1953. A new roundness scale for the sedimentary particles. Journal of Sedimentary Petrology, Vol. 23, pp.117-119.

International Journal of GEOMATE, Dec. 2011, Vol. 1, No.2 (Sl. No. 2)
MS No. 2d received Aug.30, 2011, and reviewed under GEOMATE publication policies.

Corresponding Author: Arrúa P.