Monitoring the effect of age and drying on the fracture behavior of earth concrete

Hassan Fardoun[1], Jacqueline Saliba[1], Nadia Saiyouri[1]

[1] *Université de Bordeaux, UMR 5295, Institut de Mécanique et d'Ingénierie (I2M), CNRS, Esplanade des Arts et Métiers, **33405 Talence, France.***

RESUME This work aims to assess the effect of different curing conditions on the fracture behavior of earth concrete mixtures made with natural sand (NS), recycled sand (RS) and different percentage of clay at the age of 14, 28 and 90 days. Compressive tests were monitored in parallel with the acoustic emission (AE) and the digital image correlation (DIC) techniques. The results show an increase in the compressive strength with age for specimens conserved at 90% of relative humidity (RH). The compressive strength increases also for specimens conserved at a RH of 50% which may be due to suction effect; however a decrease in the compressive have been observed at the age of 90 days at this RH with RS mixtures. Moreover, the fracture energy decreases with the age of earth concrete mixtures indicating a more brittle behavior. The AE and DIC techniques were able to reflect this brittleness.

Mots-clefs : earth concrete, drying, acoustic emission, age effect, curing conditions

I. INTRODUCTION

Earth concrete is an ecological material that poses advantages in terms of cost, energy consumption and moisture buffering. Research on such material is carried out lately to better understand its behavior. The compressive strength, fracture characteristics and failure behavior are undoubtedly major features of earth concrete.

The effect of aging on compressive strength of earth materials at different curing conditions is a research interest. The development of strength with time is governed by the percentage of cement, initial amount of water, earth material's content and accordingly the voids in the mixture (Ma et al., 2016). Nevertheless, as a result of drying, compressive strength may increase due to suction effect or decrease due to shrinkage induced cracking (Ngo et al., 2020; Fardoun et al., 2021). In addition, the assessment of fracture parameters as fracture energy on concrete materials does not reveal explicit increase or decrease tendency (Fardoun et al., 2020).

The aim of this work is to assess the age and drying effects on the fracture behavior of earth concrete made with natural sand (NS) and recycled sand (RS) with different percentages of clay. Moreover, the failure behavior is monitored by the AE and DIC techniques that have shown their effectiveness in assessing damage and fracture (Saliba and Mezhoud, 2019).

II. MATERIALS AND EXPERIMENTAL PROCEDURE

A. Materials

The work considers the mix with 30% of clay (by mass) and 70% of NS as a reference mixture (NS30/70). On the other hand, three other mixes of 20/80, 30/70 and 40/60 were prepared with 100% of RS. 80% pre-saturation of RS is considered to all mixes avoiding the dry state that would exhibit a slump loss with time and the saturated state that would show a decrease in strength due to water flow outside RS. Kaolinite clay of liquid limit and plastic limit of 52.84% and 32.81%

respectively is used. RS reported a water absorption value of 14.6%. Cement (CEM 1, 52.5 N PM-CP2/ NF EN197-1) was added to be able to remove the formwork board at early age and for strength and durability purposes. Though a value of 9% cement of the dry solid mass may be considered high, it is still adopted so far particularly for strength development (Arrigoni et al., 2018). The superplasticizer Tempo 10 is used as a water reducing admixture. Dry components were first introduced into a blender and mixed for 5 min in order to obtain a homogeneous mixture. Then, water was progressively added to ensure a slump value between 7 and 10 cm for all the mixes.

B. Experimental procedure

10x10x10 cm^3 cubes were casted and demolded after 3 days to be conserved at a RH of 90% and 50% and a room temperature of 20°C. Compressive tests were carried out on specimens after 14, 28 and 90 days of casting using an electro-mechanical machine with a 100 KN capacity. The speed was changed at approximately 80% and 40% of the maximal strength in the post peak region to reduce experiment time. Its adopted values are 0.5 mm/min, 1.5 mm/min and 4.5 mm/min. Furthermore, the displacement was determined by adding a marker at each loading plate recording the change in distance upon loading.

The compression tests were monitored in parallel with the AE technique. The AEWIN acquisition system with a data analysis and storage system was used. 8 R15 piezoelectric sensors were placed on two opposite sides of the specimens using a thin layer of silicone to ensure a good coupling and allow the capture of signals. The detected signals were amplified with a 40 dB differential amplifier. The detection threshold was set at 33 dB to avoid the influence of any background noise. The 8 sensors and the way they are positioned allow to cover the whole surface and to localize damage in 3D with better precision. Regarding the two placed cameras (one at each surface), their resolution was of 2452x2056 pixels.

III. RESULTS AND DISCUSSIONS

A. Fracture parameters

Figure 1 (a) shows the evolution of the compressive strength of each mixture at the age of 14, 28 and 90 days at RH=50% and RH=90%. All the mixtures exhibited an increase in the compressive strength with the age and as the curing conditions changes from 90% to 50%. This increase in strength indicates that the suction effect is dominant. Indeed, the soil gains strength by cohesion and friction. As water content decreases, suction increases due to the increasing in capillary forces –a main source of cohesion. Accordingly, clay particles got closer and more in direct contact. The latter, in its turn, enhances friction contributing to strength development. The clay content basically justifies the less remarkable increase in strength in RS20/80 mixture as a result of drying compared to the other RS mixtures. In the same way, apparently RS40/60 shows higher rate increase due to drying as it poses 40% of clay.

At a curing age of 90 days, NS30/70 still poses an increase in strength indicating the continuous domination of suction effect. However, RS mixtures exhibited lower strength at 90 days in comparison to that obtained after 28 days of drying. This reflects the vulnerability of RS to drying, the less domination of suction effect at later ages in RS mixtures and the more formation of shrinkage induced cracking with time as they got dried.

Figure 1 (b) shows the development of fracture energy with age at different curing condition. The fracture energy was calculated as the area under the load-displacement curve.

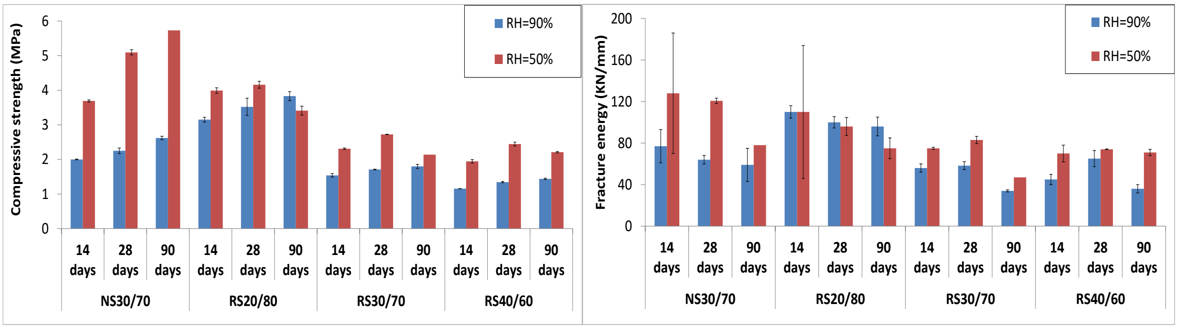

FIGURE 1. **Development of (a) compressive strength and (b) fracture energy at different ages and curing conditions**

The fracture energy decreases with the percentage of clay for mixtures made with RS. In addition, the fracture energy decreases with age for all earth concrete mixtures at different curing conditions except for the RS20/80 mixture. This decrease indicates that earth concrete has a more brittle behavior with age. However, the rate of this decrease is less remarkable with RS mixtures and as the rate of clay increases. This may indicate that, as a result of drying, kaolinite clay mixtures behave in a less brittle way than sandy ones.

B. AE analysis and image processing

The correlations between the stress and the cumulated number of AE hits and amplitude of NS30/70 mixture –similar behavior in other mixtures- at different curing ages are presented in figure 2. The AE activity shows different phases during the fracture process. The first stage can be associated to friction at the contact with metallic plate. The second phase can be associated to the diffused damage with low AE hits amplitude. The increase of the rate of AE activity in phase 3 indicates the propagation of macrocracks that generates energetic AE hits. Finally, the fourth phase indicates the stable propagation of cracks.

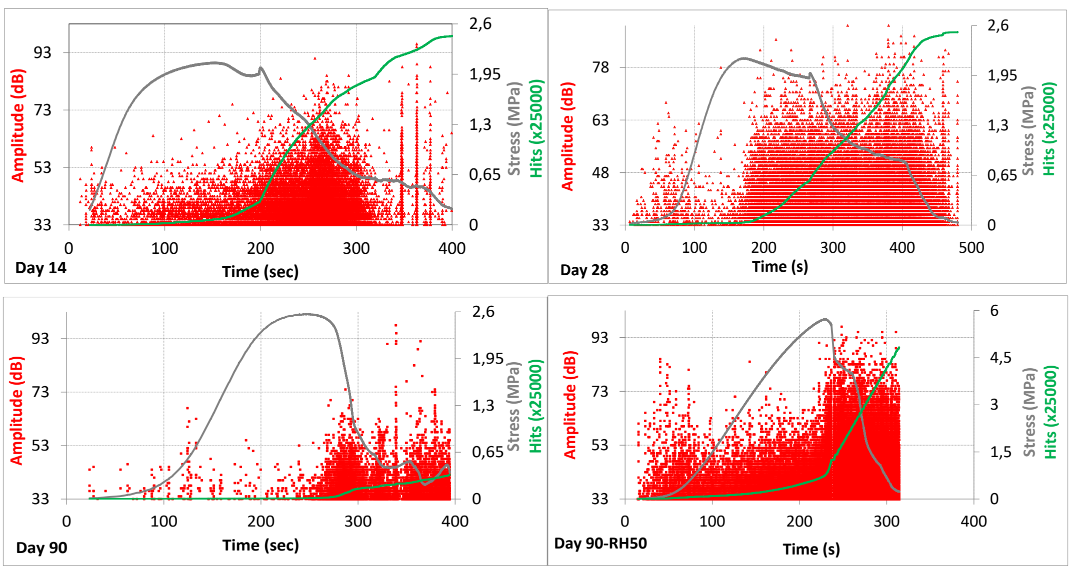

FIGURE 2. **Correlation between stress, cumulated number of AE hits and amplitude of NS30/70 at RH=90% (a) 14 days, (b) 28 days and (c) 90 days and at RH=50% (d) 90 days**

The comparison of the AE activity at the age of 14 and 28 with respect to 90 days shows a significant decrease in the cumulated number of AE hits. The number of AE hits decreases during the second phase with age indicating less damage rate before the peak due to the increase of strength. In addition, it increases suddenly after the peak indicating a delay in cracking and a brittle failure of earth concrete specimens. The comparison of the AE activity of earth concrete specimens conserved at RH=50% and RH=90% at the age of 90 days shows a higher number of AE hits at RH=50%. In addition, the important AE activity at RH=50% before the peak indicates a premature damage of specimens subjected to drying due to shrinkage induced cracking which generates damage at low loading levels. In addition, the AE energy and amplitude of AE hits is higher at RH=50%. Figure 3 shows the cameras' photos taken for NS30/70 at the age of 14, 28 and 90 days at the peak and 50% of maximum stress in the post-peak (PP) region. It can be noticed that the macrocrack is more localized with age at peak. The macrocrack at 90 days was localized all through the specimen from top to bottom indicating a brittle behavior.

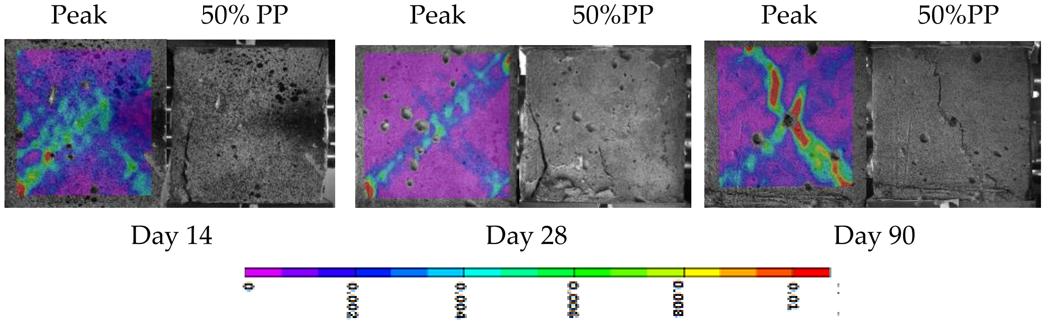

FIGURE 3. Images' treatment at peak and 50% of peak stress in the post peak region at the age of 14, 28 and 90 of NS30/70

IV. CONCLUSIONS

The fracture behavior of earth concrete mixtures made with NS, RS and different percentage of clay has been studied considering age and drying. The results show an increase in the compressive strength with age and drying due suction effect. However a decrease in the fracture energy has been observed indicating a more brittle behavior. The AE technique was able to reflect this brittleness by displaying different AE activity during the fracture process. Additional analysis will be realized in the future at the microstructure level for a better understanding of the fracture behavior.

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