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EFFECT OF DIFFERENT CURING CONDITIONS ON THE COMPRESSIVE AND FLEXURAL PROPERTIES OF PLASTER OF PARIS

Zhenjun Shan, Ian Porter, Jan Nemcik and Qiuqiu Qiao

ABSTRACT: Gypsum plaster is often used when modelling rock and rock structures. As such, it is important that the mechanical properties of the plaster models are known and are consistent. In this study, uniaxial compressive tests (UCS) and 3-point bending tests were conducted to investigate the effect of different curing conditions on the compressive and flexural properties of Plaster of Paris specimens. The variations in curing condition consisted of curing time (1 day, 3 days, 5 days, 1 week, 2 weeks, 3 weeks, 4 weeks, 8 and 12 weeks) and curing environment (room temperature and in a 45°C oven). It was found that the plaster placed in the oven possessed greater overall uniaxial compressive strength than its room condition counterpart, and both groups experienced an increase in UCS over time, reached a maximum but then weakened with further cure time. In a similar finding the plaster cured in the oven had greater flexural strength than the plaster cured under room conditions.

INTRODUCTION

Plaster of Paris is manufactured by heating gypsum to about 150°C:

$$2CaSO_4 \cdot 2H_2O \xrightarrow{\text{Heat}} 2CaSO_4 \cdot \tfrac{1}{2}H_2O + 3H_2O$$

When the dry plaster powder is mixed with water, hydration of the calcium sulphate hemihydrate occurs (Çolak, 2006):

$$2CaSO_4 \cdot \tfrac{1}{2}H_2O + 3H_2O \longrightarrow 2CaSO_4 \cdot 2H_2O$$

Dry cured plaster behaves in a linear elastic manner. A number of researchers have investigated the properties of plaster. Coquard and Boistelle (1994) found that drying and wetting significantly affects the mechanical strength of plaster. Specifically, a 50% decrease in the mechanical strength will occur if the cured plaster absorbs 2% water, but will regain the strength if the water evaporates. A possible reason for this phenomenon is that water contributes to a reduction in the interfacial free energy of the gypsum crystals. It was confirmed in the study of Taylor, Vardy and MacDougall (2006) that moisture content also has an adverse influence on the strength of earthen plasters.

Plaster, which is a polycrystalline material made of intricate gypsum needles, is often used as a rock mechanics modelling material in rock mechanics (Coquard and Boistelle, 1994), thus, it is important to understand the factors that affect the mechanical properties of the plaster. One particular problem is determining how long plaster models should cure for before testing and under what environment should the plaster be cured. This study is an attempt to evaluate the influence of different curing times and environments on the compressive and flexural properties of cured plaster specimens.

UNIAXIAL COMPRESSIVE TEST

Samples preparation and test procedure

Water and a plaster powder were mixed with a weight ratio of 1 : 3.5 respectively. After it became homogeneous the mixture was cast into a cylindrical mould 54 mm in diameter and 120 mm in height. The samples were divided into two groups; while one group was placed in a room environment with the

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relative humidity recorded the other one was placed in a 45°C oven. The samples were then cured for various lengths of time, 1 day, 3 days, 5 days, 1 week, 2 weeks, 3 weeks, 4 weeks, 8 and 12 weeks.

After cure uniaxial compressive tests were conducted in accordance with the International Society for Rock Mechanics (ISRM) 'Suggested Method for Determining the Uniaxial Compressive of Rock Materials'. As the top end of the plaster cylinder may not be perfectly flat all the samples were cut to 109 mm in height and then polished using a lapping machine to make sure the ends were flat and parallel as per the standard. Figure 1 shows the final dimensions of the sample. The test set-up is shown in Figure 2.

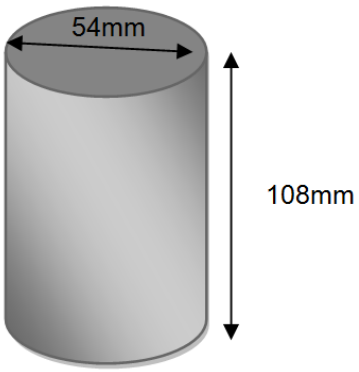

Figure 1 - Final dimensions of the sample

Figure 2 - Uniaxial compressive test set-up

Test results

Statistics on the detailed uniaxial compressive test results are recorded elsewhere, the averages of the test results at each curing time and environment are illustrated in Figure 3. As expected the oven cured plaster samples exhibited a more rapid increase in strength than the corresponding room cured samples, but possibly not so intuitive was that the peak strength of the oven cured samples was greater than the room cured samples at 75.5 MPa and 62.4 MPa respectively. It is evident that the oven cured samples underwent a rapid increase in UCS in the first three days from 38.8 MPa to 63.2 MPa, rapid strengthening stage, but there was not much change in the UCS of the room cured samples, slow strengthening stage. The UCS of both the room and oven samples reached a peak after two weeks, the oven having undergone slow strengthening from day 3 to week 2, while the room samples underwent rapid strengthening from week 1 to week 2.

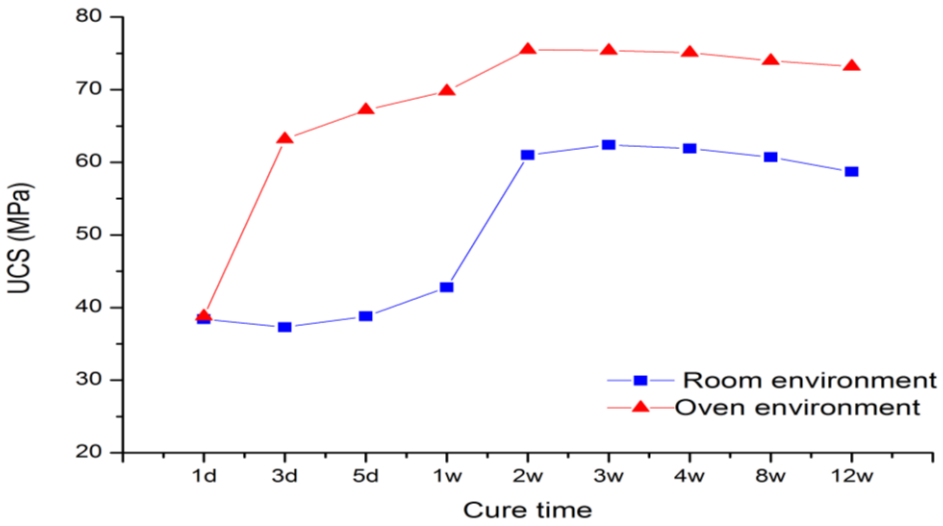

Figure 3 - Unixial compressive test results. Note: 1d=1 day, 2w=2 weeks.

After week 2 all samples remained stable during the period from week two to somewhere between weeks four and eight, but then experienced a slight decrease, a weakening stage. This suggests that

samples should not be used for modelling after around six weeks of curing. No matter what the curing conditions all samples exhibited brittle failure in compression.

THREE-POINT BENDING TEST

Samples preparation and test procedure

As before plaster and water were mixed with a weight ratio of 3.5 : 1 and rectangular blocks of 160 mm × 40 mm × 40 mm were cast, Figure 4. One group of samples was placed in a 45°C oven and the another was placed in the room environment for the predetermined curing times. An Instron servo-hydraulic system was employed to conduct the experiments. The plaster blocks were supported by two rollers located 20 mm from the edge of each sample and a vertical load was applied at a rate of 0.1 mm/min rate to the centre of the sample as shown in Figure 5. Load versus displacement behaviour of the plaster was recorded during the test.

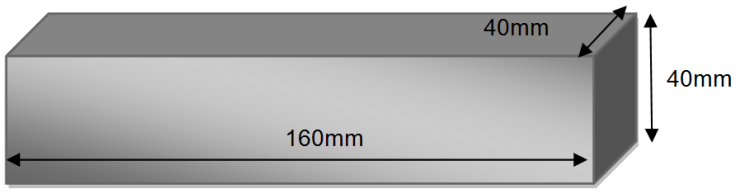

Figure 4 - Geometry of the sample for a three-point bending test

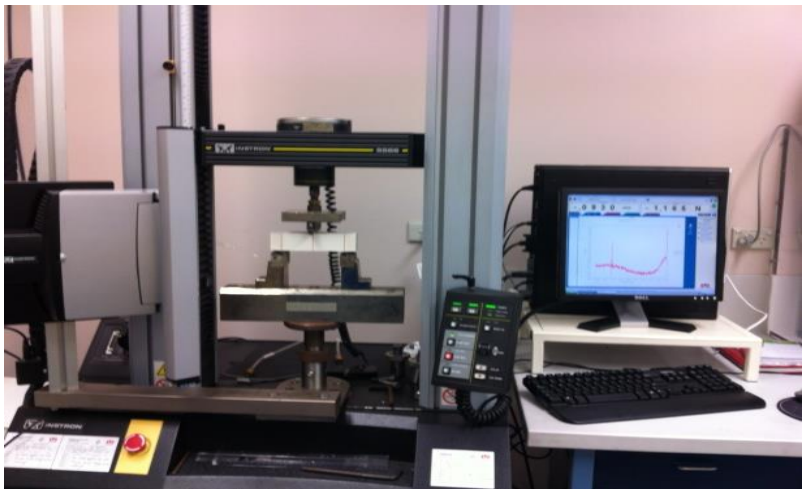

Figure 5 - Three-point bending test set-up

Test results

Figure 6 illustrates a typical load verse displacement curve of a three-point bending test on plaster. Initially, the displacement driven load increased very gently. When the displacement reached 2.8 mm, the load increased dramatically. This was probably caused by insufficient roller contact at the top plaster surface that occurred during the initial setup. The effective load versus displacement line, as shown in Figure 6, is proposed to describe the deformability of the plaster. The slope of this line is calculated from Equation (1):

$$k = \frac{l_p - l_{50}}{d_p - d_{50}} \quad (1)$$

Where k is the slope, l_p is the peak load and d_p is the corresponding displacement, l_{50} is 50% of the peak load and d_{50} is the displacement at l_{50}. The displacement offset d_0 is defined as the point where the effective load versus displacement line intersects the displacement axis, representing the displacement needed to activate the load carrying capacity of the plaster block. The effective displacement equals the difference between d_p and d_0.

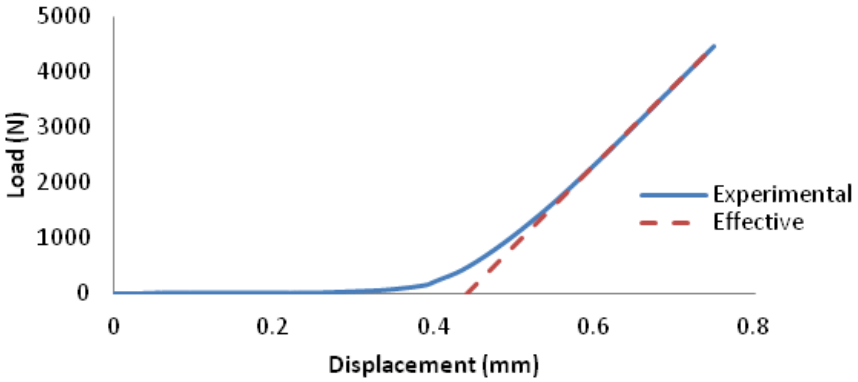

Figure 6 - Typical load versus displacement curve of three-point bending test of plaster

The flexural strength of the plaster (σ_f) was calculated using Equation (2):

$$\sigma_f = \frac{3fl}{2bh^2} \quad (2)$$

where: f = load at failure, l = span length, b = sample width, h = sample thickness.

The average results of the three-point bending tests are shown in Figures 7 and 8. Generally, the displacement at failure of the plaster increased as its flexural strength rose. Plasters cured in the oven had greater flexural strength and displacement at failure than their room cured samples, the peak flexural strength of the oven group was 15.6 MPa with a corresponding displacement at failure of 0.39 mm while the room cured samples were 11.9 MPa and 0.30 mm respectively.

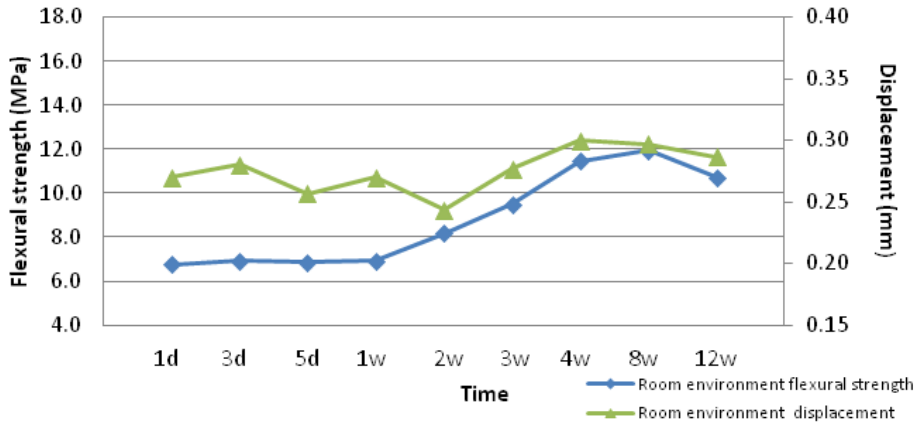

Figure 7 - Flexural properties of room cured plasters

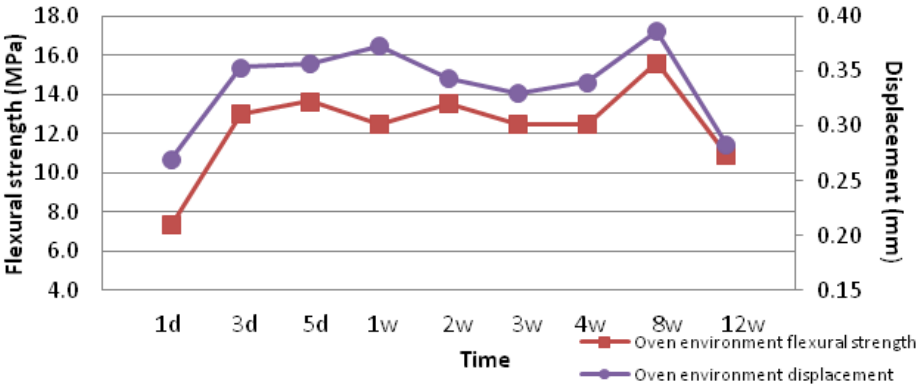

Figure 8 - Flexural properties of oven cured plasters

For the oven group, the flexural strength of the plaster increased significantly from day one at 7.4 MPa to day three at 13.0 MPa, from then till week four it held at around 13 MPa. The peak flexural strength came up in week eight with a value of 15.6 MPa, and after that the plaster experienced a significant decrease in flexural strength. For the room cured plasters, the flexural strength kept stable at about 6.9 MPa during the first week and then started to grow, reaching a peak at 11.9 MPa in week eight. As before the plaster became weaker from then on. It is important to note that although different curing times and environments affected the flexural properties of the plaster, as with the compression test, the material still experienced brittle failure.

As with the compression test samples, the change of flexural strength of the plasters can be divided into different stages, Figure 9. Unlike the compression samples four stages, the room cured samples exhibited only three stages; a stable stage, a slow strengthening stage and a weakening stage. The stable stage occurred in the first week of curing, then followed a slow strengthening stage which lasted to the eighth week and, from the eighth on, the weakening stage. For the oven cured samples, as with the compression samples, there were four stages: a fast strengthening stage for the first three days, a stable stage which lasted to week four, a slow strengthening stage in the following four weeks and finally a weakening stage.

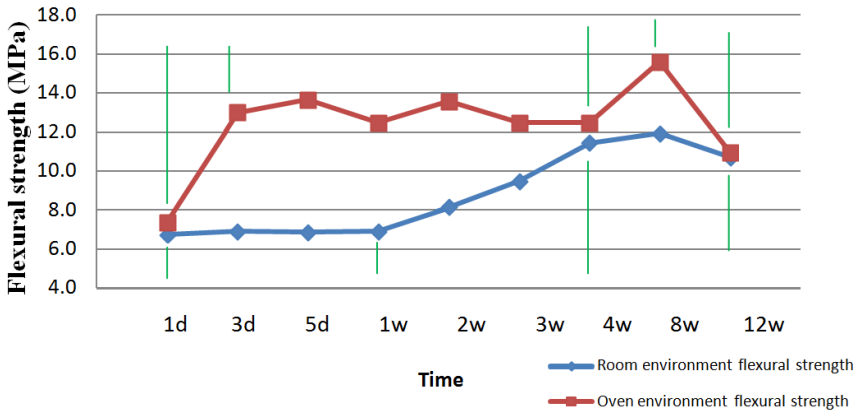

Figure 9 - Flexural strength at various stages of curing

DISCUSSION

It is common knowledge that higher curing temperatures result in faster curing times for Plaster of Paris, providing that temperatures are not so high as to cause calcination. In this study an oven temperature of 45°C was used to cure one set of samples, while another set was cured at room temperature. The tests indicate that while it took two weeks for the room temperature cured samples to achieve a significant increase in mechanical resistance the oven cured samples increased dramatically in both UCS and flexural strength in the first three days. In addition, results from the laboratory tests demonstrate that plaster samples stored (extended curing) in the 45°C oven had a greater peak strength, both in compression and flexure, than those stored under room conditions. The peak UCS of the oven samples was 75 MPa, which was about 20% greater than that of room samples, and the peak flexural strengths of the two groups were around 16 MPa and 12 MPa respectively. This suggests that higher temperature contributes positively to the hydration reaction, resulting in a 20% increase in both compressive and flexural strength.

No matter under which of the above conditions the plaster was stored it initially increased in UCS and flexural strength over a limited time, but then experienced a decrease owing to degradation of the cured sample over extended time periods. Specifically, the UCS of the plasters started to reduce slightly after week four, from 75.4 MPa to 73.2 MPa for the oven group and 61.9 MPa to 58.7 MPa for the room group. The two groups of samples decreased by 4.6 MPa and 1.2 MPa in flexural strength respectively from week eight to week twelve. The reason for this degradation in strength may be as suggested by Palha *et al.* (2012), who, when reporting various researchers (Henriques, 1992; Pühringer, 1983; Arnold and Zehnder 1987; Goudie and Viles 1997), stated that water movement in gypsum plaster may transport soluble salts which can crystallize and damage the mechanical resistance. Thus it is important that curing conditions are optimised.

The curing times to reach the stable stage of the mechanical properties of plaster samples are different with respect to different curing conditions. It is important to make sure the plaster samples are in the stable stage when they are employed as a rock simulation material, otherwise sub-optimum results may be obtained.

CONCLUSIONS

Multiple tests were performed for each cured state to investigate the change of UCS and flexural properties of Plaster of Paris samples as a function of curing time and environment. It can be concluded that:

- Higher temperature makes the plaster cure quicker and produces stronger samples in both compression and flexure;
- The plaster increased in UCS and flexural strength over time to a limit, and then experienced a degradation of strength after around 6 to 8 weeks;
- When plaster is utilized to simulate rock materials it is important to make sure they are tested in the stable stage.

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