COMPRESSIVE TESTING AND ANALYSIS OF A TYPICAL STRAW WALL PLASTER

Stephen Vardy, Ph.D. Candidate, Department of Civil Engineering, Queen's University, Kingston, Ontario, Canada

Timothy Tipping, Research Assistant, Department of Civil Engineering, Queen's University, Kingston, Ontario, Canada
Colin MacDougall, Assistant Professor, Department of Civil Engineering, Queen's University, Kingston, Ontario, Canada

Abstract:

The use of plastered straw bale walls for residential construction has found increasing popularity in Canada and the United States in recent years. Straw bales provide excellent insulation and a sustainable building material, while the plaster skins carry the majority of the loading on the wall. Therefore, it is essential to have an understanding of the structural properties of plaster. This paper presents the results of cube compression tests conducted on a lime-cement plaster typically used in straw bale wall construction. It was found that similar to concrete, the compressive strength of plaster increases with an increase in curing time and a decrease in water-cementitious materials ratio. It was also determined that a relationship exist between slump and strength for plasters and that slump tests can be used as plaster strength quality control on construction sites.

Introduction and Background:

Due to the recent surge in popularity of straw bale construction there is an increasing need for research pertaining to the structural performance of plastered straw walls (Lerner et al. 2000). Typical straw wall construction creates a sandwich panel where the straw provides a connection between exterior and interior load-bearing plaster skins (Magwood and Mack 2000). The plaster is a mixture of sand, lime, cement and water. Data is available to show how mix proportions can effect strengths of concretes and lime plasters (Kosmatka et al. 2002, Allen et al. 2003), but there is a deficiency in the literature when it comes to understanding the effects that mix proportions may have on lime-cement plasters. Information regarding the effect that water content has on plaster properties is of the upmost importance for construction as the amount of water added to a mix can vary significantly from site-to-site.

Approach / Experimental:

The proportions of sand, lime and cement in the plaster mix were determined based on a typical plastering scheme for straw bale walls. The final mix had proportions of 4.5 : 1.25 : 0.25 of sand lime and cement respectively and was used consistently throughout all of the experiments. The amount of water in the mix was varied for the experiments to achieve water–cementitious materials (w/cm) ratios ranging from 1.0774 to 1.2774. These values represented the approximate limits of the workable range for the proportions of dry materials used.

After the mix was prepared, a slump test was conducted in accordance with ASTM C 143 (1997). Next, three 50 mm cubes were made in accordance with ASTM C 109 (1998). The cubes were kept moist for seven days before the molds were removed and the cubes were allowed to continue curing in dry conditions. This was done to simulate the curing conditions that may be expected on a straw bale construction site. The rate of loading was approximately 5 mm/min as the cubes have a very low compressive strength. The ultimate load was recorded and the compressive strength was calculated for each cube.

Results and Discussion:

Tests were conducted on plasters with various w/cm ratios. The slump and compressive cube strength values are given in Table 1.

Table 1: Slump and Compressive Cube Tests

Test Information			Slump (mm)	Compressive Strength (MPa)			
#	w/cm Ratio	Curing Time		Cube 1	Cube 2	Cube 3	Avg.
1	1.0774	28d	45	1.00	0.88	0.92	0.93
2	1.1274	28d	51	0.96	0.76	1.00	0.91
3	1.1774	7d	58	0.72	0.76	0.76	0.75
4	1.1774	14d	58	0.96	0.96	0.84	0.92
5	1.1774	28d	58	1.20	1.20	1.20	1.20
6	1.2274	28d	84	0.80	0.72	0.72	0.75
7	1.2774	28d	98	0.64	0.76	0.68	0.69
8	1.0774	28d	45	1.64	1.80	1.72	1.72

The compressive strength for the cubes initially tested with w/cm ratios of 1.0774 and 1.1274 was significantly lower than expected, due to poor consolidation of the plaster in the mold. The data for these cubes will be omitted from further discussion. Test 1 was repeated in Test 8 and sensible results were obtained when proper compaction was ensured.

The proportion of water in a concrete mix can greatly affect the strength of the mix (Kosmatka et al. 2002). Figure 1 compares the cube strength of the plasters found for a number of different w/cm ratios. Also included in Figure 1 is a plot of the relationship between w/cm ratio and strength for a typical concrete mix (Kosmatka et al 2002).

Figure 1 indicates that as the water content is increased, the strength of the plaster decreases significantly. Over the range of water contents tested the strength was found to vary between 0.69 MPa and 1.72 MPa. It is evident that the relationship between strength and w/cm for these low-strengths plasters is very similar to those seen for structural concrete. Similar results have been reported for Hydraulic Lime Mortar (Allen et al. 2003).

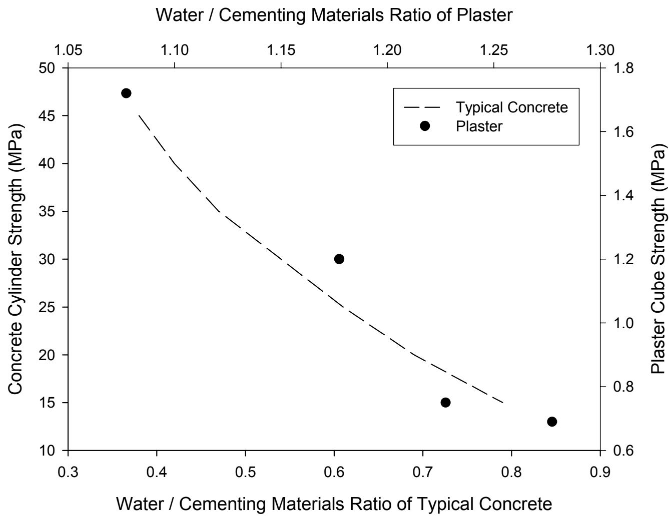

Figure 1: Relationship between strength and water-cement ratio for plaster and concrete.

Figure 2 shows the relationship between the slump and strength of the plasters tested. The results suggest that slump can be related to plaster strength. This would provide a simple and practical quality control test that straw-bale builders can perform in the field. The relationship between slump and strength could be established by experimentation before construction for any given set of dry proportions. This would enable the builder to ensure the plaster is of adequate strength based on slump measurements taken on-site.

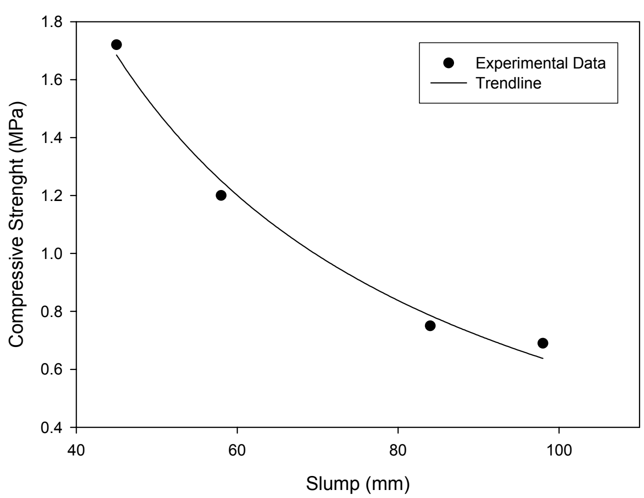

Figure 2: Relationship between strength and slump.

Figure 3 shows the increase in plaster strength over time compared to a typical concrete mix (Kosmatka et al. 2002). Both plots were normalized with their respective 28 day compressive strengths. The results indicate that the plaster reaches its 28 day strength at a rate similar to a typical concrete mix.

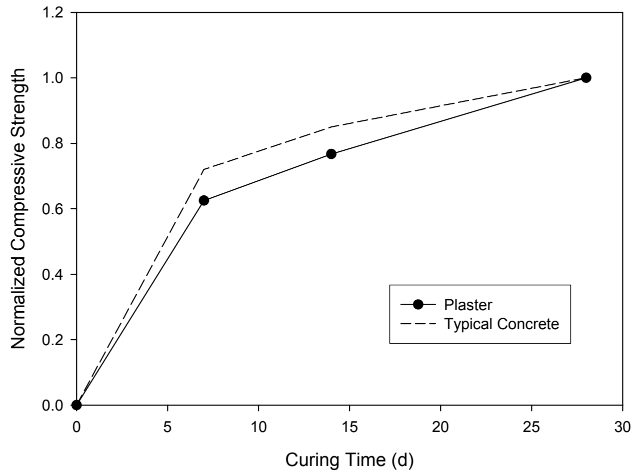

Figure 3: Time Dependent Nature of Plaster

Summary and Conclusions:

Mix proportions affect the strength of lime-cement plasters in much the same way that mix proportioning affects the strength of structural concretes or lime plasters. As the curing time increases, the strength of the plaster increases. As the proportion of water in the mix is decreased, the strength of the lime-cement plaster increases and the slump decreases. The relationship between slump and strength could provide a practical quality control test, since the slump on-site can be compared to experimental results to determine the actual strength of the plaster being applied to the structure.

References:

Allen, G., Allen, J., Elton, N., Farey, M., Holmes, S., Livesey, P., Radonjic, M. (2003) "*Hydraulic Lime Mortar: for Stone, Brick and Block Masonry*" Donhead Publishing, Dorset, England

ASTM C 109 (1998). "Standard test method for compressive strength of hydraulic cement mortars (using 2-in or [50-mm] cube specimines)." Annual book of ASTM Standards, Section 4 – Construction, Volume 04.01 – Cement; Lime; Gypsum, West Conshohocken, Pa

ASTM C 143 (1997). "Standard test method for slump of hydraulic-cement concrete." Annual book of ASTM Standards, Section 4 – Construction, Volume 04.02 – Concrete and Aggregates, West Conshohocken, Pa

Kosmatka, S.H., Kerkhoff, B., Panarese, W.C., MacLeod, N.F., McGrath, R.J. (2002) "*Design and Control of Concrete Mixtures, 7th Ed.*" Cement Association of Canada, Ottawa, Ontario

Lerner, K., Donahue, K. (2003) "Structural Testing of Plasters for Straw Bale Construction." Ecological Building Network, http://www.sustainable.doe.gov/codes/azstraw.shtml

Magwood, C., and Mack, P. (2000). *Straw Bale Building: How to plan, design & build with straw.* New Society Publishers, Gabriola Island, B.C.