UNBONDED CAPPING OF MASONRY PRISMS

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ABSTRACT

Compression testing is often used as a quality control measure in concrete masonry production and construction. Capping is used on masonry prisms to eliminate surface imperfections, produce a plane surface, and provide uniform load distribution. Currently, bonded capping, specifically gypsum and sulfur, are the only methods allowed by US standards. Preparing bonded capping in masonry prisms is time consuming and labor intensive. The use of reusable or unbonded capping could dramatically reduce specimen preparation time and labor while still providing accurate results. In concrete compression testing, unbonded capping methods are already standardized.

This article presents preliminary results of a study that used several unbonded capping materials for compressive strength testing of masonry prisms. Selection of the materials was based on the compressive strength, thickness, Poisson's ratio, and hardness of the material. Hydrocal gypsum cement was the control capping material; the other capping materials were fiberboard, laminated foam, and neoprene. The neoprene was restrained against excessive lateral expansion by a steel confining apparatus.

Compressive strength results of the tests with the fiberboard capping were comparable to the results of the tests with the gypsum capping with only a 5 percent increase in average compressive strength. The repeatability of the fiberboard capping procedure was evidenced by the small coefficient of variation of the results. Compressive strength results of the tests with the neoprene capping also had a small coefficient of variation, 3.18, but the average compressive strength was 13 percent greater than that obtained with the gypsum capping. The increase in average compressive strength was most likely due to the combination of the neoprene hardness and additional confining stresses caused by the steel confining apparatus. The average compressive strength of the prisms with laminated foam capping was 27 smaller than that of prisms with gypsum capping. The variability of the laminated foam capping procedure was the highest of all capping procedures.

KEYWORDS: gypsum capping, soft capping, unbounded capping, neoprene, masonry compression test, masonry prisms

INTRODUCTION

Concrete masonry compressive strength is commonly used as a quality control measure and is typically determined by applying a uniaxial load on masonry prisms. Concrete masonry unit (CMU) have rough and uneven surfaces which result in stress concentrations when axially loaded; capping eliminates these imperfections by producing a plane surface that uniformly distributes the load [1]. ASTM C1552 [2] specifies bonded capping for determining masonry compressive strength but unfortunately, the process of hard capping is time consuming and labor intensive and requires experienced technicians. In concrete compression testing, unbonded or soft capping has become a suitable alternative to hard capping [3-8]. Soft capping has the advantage of reducing specimen preparation time which translates into cost savings [9]. Though soft capping has yet to become a standard practice for determining compressive strength of masonry, its implementation would provide advantages similar to those observed in concrete compression testing [9,10].

Ideally masonry prisms should be tested under pure compression when determining their compressive strength. The capping provides a flat surface that evenly transfers compressive forces from the test machine to the prism. Capping, however, introduces other types of forces on the prism. To obtain true uniaxial compression, the capping and prism must have equal Poisson's ratios and there must be a frictionless platen-prism interface. Due to the impracticality of these requirements, the selection of capping material is based on other criteria which include a minimum compressive strength, thickness, lateral strain compatibility and hardness.

The contact between the capping and prism provides a path to transfer compressive forces. Voids between the capping and prism decrease the effective bearing area and introduce stress concentrations, which decreases the measured compressive strength. It is critical, therefore, that capping materials easily conform to rough surfaces and fill existing voids to provide a uniform load distribution.

Research in concrete compressive testing has shown that in cases where the capacity of a specimen is affected by the capping material, the apparent strength relates to the elastic modulus rather than the strength of the capping [11]. In addition, the rates of lateral deformation under compression, or Poisson's effect, can have significant effect on the measured strength [12]. Interlocking at the capping-prism interface restricts strain deformation of the material with the higher rate of expansion. The differing rate of lateral strain between the two materials induces stresses at the prism ends producing a tri-axial stress state. When the lateral strain of the prism is greater than the lateral strain of the capping, the ends become confined under compressive stresses. There is an increase in axial compressive strength as axial compressive strain decreases, which results in a higher apparent strength [12]. These confining pressures are partially responsible for the mechanism causing the conical failure pattern typically observed in specimens capped with gypsum and sulfur. If the capping strain is greater than the prism strain, the ends are subjected to lateral tensile stresses and the apparent compressive strength is slightly reduced. Soft capping is often composed of materials that undergo larger strain deformations than the prism. This is one reason unbonded methods using soft capping result in slightly lower apparent compressive strength than bonded methods [9]. Soft unbonded capping, however, if properly chosen and correctly used, could have the advantage of reducing confining pressures commonly observed in bonded capping.

LITERATURE REVIEW

Research on concrete testing indicates that the use of confined neoprene capping produces similar compressive strength results as those obtained using sulfur capping [3,6,9,13,14]. Consequently, neoprene capping has been deemed acceptable for determining concrete cylinder compressive strength. Neoprene is durable, reusable and deforms to accommodate imperfections and surface irregularities of the surfaces of the specimens.

The hardness and thickness of the neoprene used for capping are critical. The measured strength and elastic modulus of a specimen correlate directly with the required strength and stiffness of the neoprene. The shore durometer test is a method of determining the resistance to inelastic deformation of rubber, polymers and elastomers. Specimen with higher strength and elastic modulus require a neoprene with higher durometer hardness. However, a neoprene that is too hard is unable to deform to surface imperfections, resulting in points of stress concentrations. Conversely, a neoprene with a low durometer hardness used on higher strength specimens experience excessive wear and damage. The durometer hardness should be chosen according to the expected strength and elastic modulus of the specimen to assure both a good distribution of compressive force and acceptable durability of the neoprene.

Neoprene has a relatively high Poisson’s ratio which introduces significant lateral tensile stress in the specimen, potentially reducing its apparent ultimate strength. In concrete compression testing the neoprene capping is confined with a steel ring to minimize lateral displacements. Steel confinement has been investigated in CMU neoprene capping tests [9,14]. However, the non-circular geometry of masonry prisms induces nonlinear stresses, which increases from the mid-sides to corners of the prisms [11]. Build-up of these stresses around the corners is expected to reduce the measured strength of the prism.

Though not a standard capping material, boards have been used as capping for quality control measure in concrete masonry production and construction. Compression tests have been performed using a wide variety of board materials, including Oriented-Strand-Board (OSB), fiberboard, particleboard and even ceiling tiles. The main advantages of using a board over other unbonded materials are cost and availability. Thus, smaller testing laboratories can perform routine compression tests without having to invest in a more costly capping procedure or devote a significant amount of labor. The use of board capping over hard capping has been shown to reduce the apparent compressive strength by approximately 10 percent. Maurenbrecher [15] and Roberts [16] report compressive strength ratios of 0.99 and 0.92 for two series of soft to hard capped prisms. Other studies using various types of board also show a reduction in the measured compressive strength [12,13]. Board materials are more rigid than neoprene and thus less prone to conform to surface imperfections. Board capping therefore creates points of stress concentration causing early failure. Results from compressive testing using board capping are dependent on variables such as the thickness, wood type, manufacturing process and hardness of the board. The repeatability of results is typically reduced, making board capping difficult to adopt as a standard.

The use of expanded polystyrene (EPS), typically laminated, as capping material has only recently been investigated. EPS is a rigid closed-cell foam commonly used for packaging and thermal insulation in buildings, but, it has numerous other applications. EPS deforms well under compression, potentially making it ideal for filling the voids and imperfections on the surface of the specimen. Also, EPS gains compressive resistance at 10 percent of yield. EPS has many of the same advantages as a board but is less prone to compositional variability.

MATERIALS

This research investigated three unbonded capping materials for compressive strength testing of masonry prisms. Selection was based on compressive strength, thickness, Poisson's ratio and hardness. Gypsum cement was chosen as the control material and was compared to neoprene, fibreboard, and laminated foam.

Masonry prisms were constructed using nominal 200 × 200 × 200 mm (8 × 8 × 8 in.) half blocks, which were manufactured specifically for this research as half blocks with a sash groove rather than full units cut in half (see Figure 1). All block were from a single source. The use of half blocks versus full blocks increases the prism aspect ratio, reducing the effect of platen restraint. Half blocks prisms tests are also easier and more economical to perform. Upon arrival blocks were visually examined for defects before prism assembly; defective blocks were rejected. The concrete masonry units used in this study were manufactured by Oldcastle, complied with ASTM C90 [18] standards and were produced from the same batch using standard fabrication methods. All units were mold-formed and consequently had tapered cells. The tapering creates face shells/webs that vary slightly in dimension from top to bottom.

Figure 1. Half Block with a Sash Groove

Following ASTM C140 [19] six representative units were selected for determination of absorption, in situ moisture content before sample construction, density, and measurement of dimensions. The actual dimensions of a grouted prism were utilized to calculate a bearing area of 37,484 mm^2 (58.1 in^2). The average absorption, density and moisture content of the CMUs were determined accordingly and are presented in Table 1 along with corresponding values from the block data sheet.

Table 1: Properties of Concrete Masonry Units

Average Absorption, %		Average Density, kg/m^3 (lb/ft^3)		Average Moisture Content (%)	
Measured	Data Sheet Value	Measured	Data Sheet Value	Measured	Data Sheet Value
6.6	8.76	2054 (128.21)	1768 (110.39)	43.01	56.51

Commercial grade Quikcrete Mason Mix Type S Mortar was used for all samples. The mix is a dry pre-blended mixture of sand and cement meeting several US standards [20,21,22]. An average mortar flow of 112 mm (4.4 in.) was determined from four measurements. The temperature during mixing was measured as 21ºC (70 ºF). The 28-day compressive strength of the mortar was 19.1 MPa (2,770 psi). Mortar and grout were both prepared in drum mixers.

Mix proportions for the grout are presented in Table 2. A slump of 229 mm (9 in.) was measured following ASTM C172 [23]. The temperature of the grout was monitored using ASTM C1064/C1064M [24] procedures; the recorded temperature was 20ºC (68 ºF). Grout specimens were used to determine the average compressive strength in accordance with ASTM C1019 [25]. The 28-day compressive strength of the grout was 21.7 MPa (3150 psi).

Table 2: Grout Mix Proportions

Material	Weight, grams (lb)	Percent Weight (%)
Sand	872 (1923.5)	49.7
Gravel	369 (813.8)	21.0
Free Water	245 (540.7)	14.0
Portland Cement	268 (591.8)	15.3

Four capping materials were used for compressive strength test comparisons. Gypsum capping, the control group, was made using hydrocal white gypsum cement which has a compressive strength of approximately 34.5 MPa (5 ksi). Bonded capping was prepared according to ASTM C1552 [2], with a thickness less than 3 mm (0.12 in.) Three unbonded capping materials were used. The first material was a 12.7 mm (0.5 in.) EPS laminated with a 3 mm (0.12 in.) plastic acrylic sheet; the second material was a 12.7 mm (0.5 in.) fiberboard. Both products were cut to 200 × 200 mm (8 × 8 in.) dimensions. The third material was a 12.7 mm (0.5 in.) neoprene pad with a durometer-shore A hardness of 50. This hardness was chosen by correlating the typical masonry strength of 17.2 MPa (2500 psi) with that presented by Crouch [9].

The neoprene pad was placed into a welded steel retainer to reduce tensile forces induced by lateral expansion. The steel retainer was comprised of 4 steel bars welded to a plate with 6.4 mm (0.25 in.) welds (see Figure 2). The retainer had a thickness of 38 mm (1.5 in.), inside dimensions slightly less than 200 × 200 mm (7.9 in × 7.9 in.) and outside dimensions slightly less than 210 × 210 mm (18.25 × 8.25 in.). The neoprene pad was cut to slightly less than 200 × 200 mm (7.87 × 7.87 in.) and snugly fitted into the steel retainer.

Figure 2. Top View of Steel Retainer

METHODOLOGY

Forty-four masonry prisms were constructed by experienced masonry professionals. Prisms were set in an opened, moisture-tight bag, large enough to enclose and seal them after construction. Units were laid in stack bond with full mortar beds and were free of surface moisture during construction. The mortar consistency was proportioned by weight. The amount of mortar mixed per batch was determined by the maximum work time before retempering was required. The mortar joints were approximately 10 mm (0.375 in.) and flush cut. Within one day after constructing the prisms, grout was mixed and poured into the prism cells. Prior to grouting all mortar fins and droppings were removed. The gout was consolidated with a low force vibrator. Excess grout was screeded from the surface; prisms were then sealed in the plastic bags and cured for 30 days.

Prism specimens that appeared to have been disturbed or had significant grout shrinkage were discarded prior to capping. Disturbed specimens appeared to have CMUs that were misaligned or had gaps between the mortar and CMU in one or more locations; four prisms were discarded. All prisms surfaces were cleaned prior to capping. Eleven gypsum capped specimens were prepared according to ASTM 1552 [2]. Gypsum-capped prisms were inspected prior to testing to ensure they met standard specifications. The remaining 29 prisms were grouped by capping method: 11 fiberboard, 10 laminated-EPS and 8 neoprene. Prisms were placed into the load bearing apparatus with their respective capping material. All specimens were tested on a Baldwin-Tate-Emery Testing Machine with a load capacity of 1,334 kN (300,000 lb). The loading platens were spherically seated and met dimension requirements of ASTM C1314 [26]. The loading rates were adjusted for each material so that prism failure occurred within approximately 240 seconds. Failed samples were examined and the failure patterns documented. Reusable caps were also examined to assess wear.

RESULTS

Pictures of failed specimens are shown in Figure 3. Prisms experienced most of the failure modes described in ASTM C1314 [26], namely, conical break, cone and shear, cone and split, shear break, and face-shell separation; tension break and semi-conical modes were not observed.

Figure 3. Failed Specimens: Neoprene, Gypsum, EPS, and Fiberboard Capping

The results for all four capping methods are displayed in Table 3; for each capping material the compressive strength obtained for each specimen is listed. Neoprene sample 1 was excluded because the confinement ring welds failed. The remaining neoprene samples were tested with a modified confinement ring that was better constructed to prevent weld fracture. The compressive strength mean value for each capping material as well as the corresponding standard deviation and coefficient of variation are also given. The last row of Table 3 shows the percentage increase or decrease of mean compressive strength mean for each capping material compared with that obtained for the gypsum capping.

The gypsum, foam, fiberboard, and neoprene capping methods produced mean compressive strengths of 21.8, 16.0, 22.9, and 24.7 MPa (3168, 2322, 3328, and 3581 psi), respectively. The mean compressive strength of the fiberboard and neoprene capping groups are, respectively, 5 and 13 percent greater than that of the gypsum capping group while the strength of the foam capping group is 27 percent smaller than that of the gypsum capping group.

Figure 4 shows the box plot for each capping material. The data spread for the foam capping group is slightly greater than that of the control group. The neoprene capping group has the smallest spread followed by the fibreboard group. The neoprene capping group also showed the highest repeatability, i.e., lowest COV, but experienced slightly greater apparent strengths.

Table 3: Prism Compressive Strength Results

Specimen	Compressive Strength							
	Gypsum		Fiberboard		Foam		Neoprene	
	MPa	psi	MPa	psi	MPa	psi	MPa	psi
1	22.7	3292	23.7	3443	14.4	2090	*	
2	24.4	3536	21.9	3172	15.0	2178	24.4	3540
3	23.4	3390	23.7	3440	14.4	2086	23.5	3410
4	25.2	3661	24.3	3531	17.3	2506	25.5	3702
5	20.6	2988	23.1	3353	14.4	2087	24.9	3609
6	19.6	2841	24.5	3559	18.1	2620	25.8	3741
7	21.7	3152	24.2	3515	17.2	2494	24.5	3558
8	20.4	2958	21.6	3132	14.8	2141	24.2	3508
9	21.4	3102	20.2	2927	19.3	2797	-	-
10	20.8	3011	22.5	3259	15.3	2217	-	-
11	20.1	2920	22.6	3283	-	-	-	-
Mean	21.8	3168	22.9	3328	16.0	2322	24.7	3581
Std Dev	1.85	268	1.35	196	1.79	260	0.79	114
C.V. (%)	8.45	8.45	5.90	5.90	11.19	11.19	3.18	3.18
Mean Δ (%)	0	0	5	5	-27	-27	13	13

*Original **C**onfinement Ring Welds Failed.

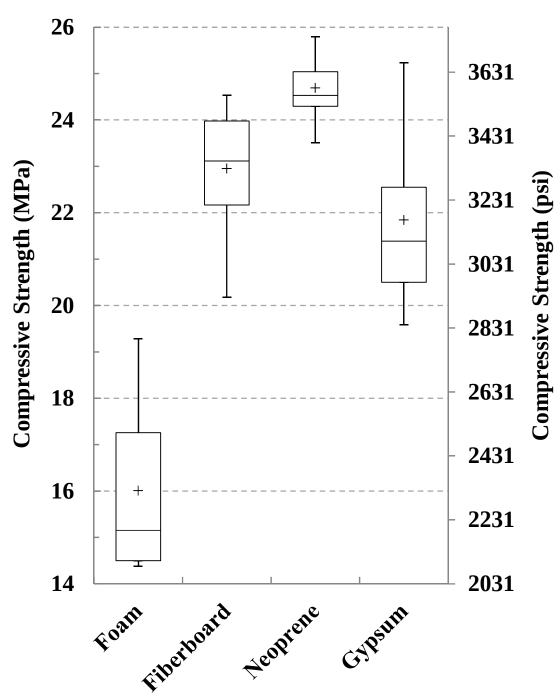

Figure 4. Statistical Results

DISCUSSION

Prism compressive strengths recorded using neoprene capping was slightly higher than previous tests by Crouch [9]. A possible reason for the increase in compressive strength was the introduction of additional confining stresses produced by the steel retainer. The steel retainer was welded to a base plate, which produced a small fillet where the sidewall and plate were joined. As the neoprene expanded, it was pushed away from the prisms. The possible additional confinement may have decreased the prisms compressive strain resulting in slightly higher apparent strength. Proper seating of the neoprene pad would reduce confining pressures and give more accurate results. The neoprene capping group also had a low coefficient of variation suggesting that neoprene capping may improve accuracy versus bonded methods. A lower CV was also observed during testing done by Crouch [9]. The low CV was likely a result of the durometer-shore hardness of the neoprene. Compared to other unbounded capping methods the neoprene more readily deformed to imperfections to create a uniform load distribution. However, the lower hardness also reduced the durability of the pad and there were significant signs of wear after the 8 tests.

The foam capping group performed poorly when compared to the control group with a relative strength of 73% and a CV of 11.2. Post-test inspection suggests areas of higher stress concentrations on the bearing surface. Though inspection of the foam showed excellent deformation and void filling, the foam was not rigid enough to distribute the load. Instead the foam compressed almost until the plastic laminate made contact with the prism surface. These contact points provided pathways for stress transmission to the prism and created areas of high stress concentration resulting in low apparent strengths.

The fiberboard capping procedure produced comparable results to those obtained with the gypsum capping. The fiberboard capping results though were roughly 20% higher than strengths reported by Knight and NCMA [10,13]. The board readily deformed but at the same time was rigid enough to resist excessive compression. Inspection of the failure pattern and the higher compressive strength suggest the development of confining pressure due to decrease lateral expansion. Theoretically confining pressures can be eliminated if the capping material is allowed to expand until it neared the lateral elongation of the masonry at failure and then confined against further strain. This however, would be difficult to achieve.

CONCLUSIONS

The findings from the research presented herein are listed below.

1. Material properties such as strength, elastic modulus, bonding capacity and strain compatibility are crucial in selecting a suitable capping material.
2. Gypsum capping requires significantly greater time and effort over unbonded capping.
3. Plastic laminated foam capping resulted in the lowest compressive strengths and the highest variation. This method was determined to be unacceptable based on the results.
4. Fiberboard capping yielded slightly higher compressive strengths compared to the control group but had slightly less variability. Fiberboard capping was the least expensive capping procedure.
5. Neoprene capping exhibited the lowest variation but had the highest compressive strengths. Correcting the manufacturing of the steel confinement ring could reduce the

measured strengths. The durometer hardness of 50 was low for this particular research resulting in excessive wear on the pad. A hardness of 65-70 would most likely result in improved durability without a significant increase in variation.

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