A NEW TEST METHOD FOR THE EVALUATION OF THE WORKABILITY OF CONCRETE BLOCK MASONRY BEDDING MORTARS

J. M. CASALI[1], and L. R. PRUDÊNCIO JR[2]

[1] Doctoral Student at the Federal University of Santa Catarina
[2] Professor at the Federal University of Santa Catarina
Florianópolis Santa Catarina Brazil

SUMMARY

This article presents a novel test method for evaluating the workability of concrete block masonry bedding mortars. The proposed test (GTec Test) simulates the laying of a concrete block. Workability was evaluated by two masons and evaluations were carried out using both the GTec test and the flow table test. The results obtained from the most workable mortars were used to establish requirements in terms of limits of consistency, plasticity, and cohesion. These limits were verified on three different job sites. The experiment showed that the GTec Test is simple, practical, and suitable for evaluating the workability of bedding mortars.

INTRODUCTION

In recent years, the use of structural masonry with concrete blocks has been increasing in Brazil, mainly for the purpose of enhancing the productivity of construction, by allowing its rationalization.

Improved productivity during masonry construction is only achieved if the bedding mortar exhibits suitable workability. This property of plastic mortar is difficult to define because it is a combination of a number of independent, though interrelated, properties such as consistency, plasticity, cohesion, water retentivity, setting time, weight, and adhesion (Panarese et al., 1991; Taly, 2001).

The experienced mason judges the workability of mortar by the way it adheres to or slides from his trowel (Panarese et al., 1991). Mortar of good workability should spread easily on the concrete masonry unit, cling to vertical surfaces, extrude readily from joints without dropping or smearing, and permit easy positioning of the unit without subsequent shifting due to its weight or the weight of successive courses (Panarese et al., 1991).

Workability has proved difficult to quantify and many test methods attempt to evaluate it by establishing some relationship with how it is assessed by a master craftsman. Bowler et al. (1996) described and evaluated several test methods.

The flow table test is commonly prescribed by masonry standards to evaluate mortar workability. This test presents good reproducibility in evaluating consistency when a single type of mortar is considered. However, when different types of workable mortars are compared, the measured flows differ, making it difficult to develop new products in laboratory.

In the NBR 8798/1995 Brazilian Standard, the flow table has been adopted as reference equipment for the determination of consistency. Said standard recommends that the flow table measure for concrete masonry bedding mortars fall within 230±10mm. However, a field survey conducted at job sites in Florianópolis, Brazil, demonstrated that this limit does not always lead to proper mortar workability and the actual limit values that were measured at job sites varied a great deal, and did so mainly when different types of mortars were used. The results of the flow table test do not reflect the effect of the resistance presented by the mortar bed when subjected to the constant force of the block's weight, as the block is being laid.

In this context, the main objective of this article is to present a novel test method for evaluating the workability of concrete block masonry bedding mortars.

METHODOLOGY

The Proposed Test– GTec Test

The proposed test (GTec Test) simulates the laying of a concrete block. It is based on the determination of (1) the strength of the mortar bed when subjected to a constant force simulating the block's weight, and (2) the energy necessary to obtain a joint thickness of 10 mm. The main objective of this test is evaluating the behavior of bedding mortar (25 mm in width and 100 mm in length) subjected to a constant force equivalent to the weight of a concrete block when being laid. This behavior is evaluated with respect to three fundamental properties of workability: consistency, plasticity, and cohesion.

The equipment used in this methodology is the GTec device (Figure 1). This device was conceived by the Material Technologies and Portland Cement-based Components Group (Grupo de Tecnologia em Materiais e Componentes a Base de Cimento Portland), or *GTec*, at the Federal University of Santa Catarina.

A set of components (G, H, J, K and L), whose total mass is 1140.0 g, simulates the average force that would be exerted by a block of concrete weighing approximately 11500 g, on a joint that is 100 mm long by 25 mm wide. The sliding mass (K) weighs 204.0 g and the base (G) of the pestle is 100 mm long by 25 mm wide.

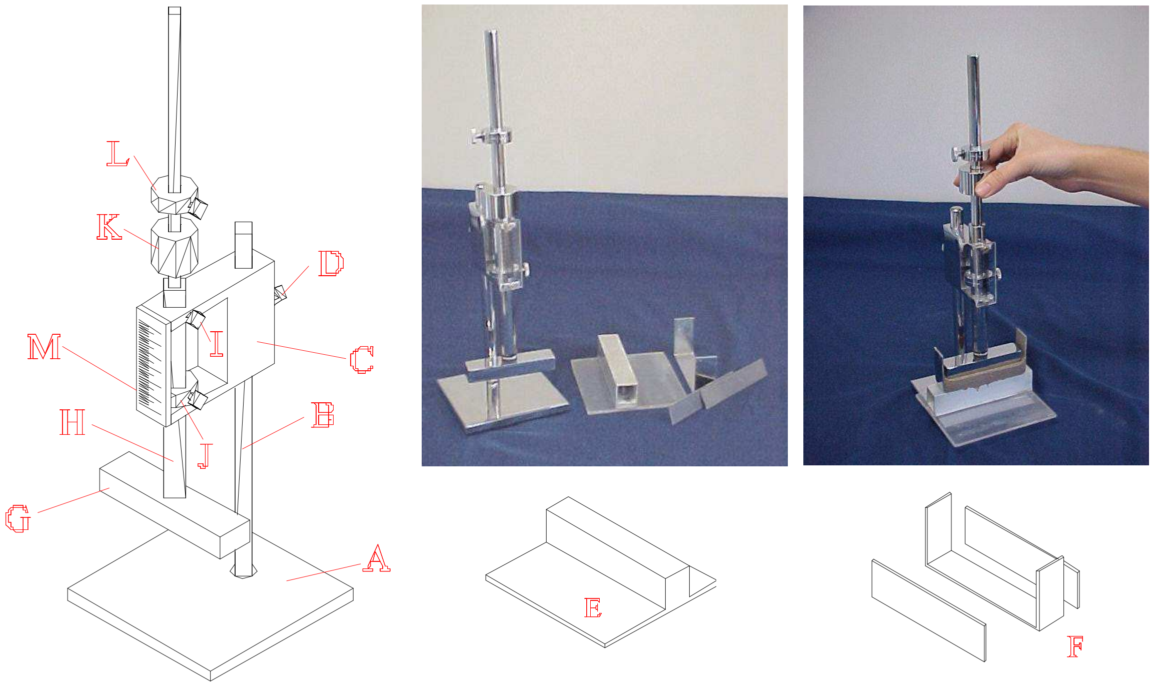

Figure 1. Diagram of the device used for the GTec test

The test procedure can be summarized as follows:

1) Place the base (E) on the support base (A);
2) Rest the receptacle (F) against the salient part of the base (E);
3) Unscrew the fastening bolt (I) and rest the pestle's base (G) on the bottom of the receptacle (F);
4) Slide ring 1 (J) along the pestle staff to the position corresponding to zero on the scale (M);
5) Raise the pestle and, using the bolt (I), fasten it at such a height that its base will be positioned over the top of the receptacle (F);
6) Remove the receptacle from the device and set it down against the base (E);
7) Adjust the receptacle's sides (whose height can be changed according to the thickness of the joint when the block is laid) and fill it with mortar using a spatula;
8) With the spatula, level the mortar in the receptacle and eliminate any air pockets;
9) Remove the excess mortar so that the height of the mortar bed will be equal to that of the sides of the receptacle (F);
10) Align the top of the salient part of the base (E) with the pestle's base (G);
11) Place the entire receptacle (F) squarely above the salient part of the base (E);
12) Remove the receptacle's sides by sliding them downward;
13) Unscrew the fastening bolt (I) and rest the base of the pestle on the mortar bed, thus determining the Initial Measure (Li) of the mortar bed's thickness;
14) Slide the mass (K) up along the shaft until it reaches ring 2 (L);
15) Let the mass drop freely and then measure the mortar bed's thickness (L1) after the jolt;
16) Repeat steps "14" and "15", taking readings L2, L3,..,Lm,..,Ln – where n is the number of jolts necessary to make the mortar bed 10 mm thick, and m is the number of the jolt for which any detachment of the mortar bed's edges first occurred.

MATERIALS

In this study, three prepacked mortars and two cement-lime based mortars were evaluated. The mixture proportions for the cement-lime based mortars was 1:1:5 (cement: lime: sand) in volume. The five mortars were chosen in such a way that the proposed device could be tested for mortars with different characteristics and, in so doing, its capacity for measuring the workability of bedding mortars could be evaluated.

For the cement-lime based mortar, (6-14% filler) Composed Portland Cement (CP II – F – 32) was used. Hydrated lime of type CH – III was also used. The characteristics of the cement and hydrated lime are shown in Tables 1 and 2, respectively.

Table 1. Characteristics of the cement

Physical Characteristics	(%)	Chemical Components	(%)	Age (day)	Compressive strength (MPa)
% water demand	25.9	SiO_2	18.90		
Specific Gravity (Kg/l)	3.08	Al_2O_3	4.09	1	14.0
Bulk density (Kg/l)	1.10	Fe_2O_3	2.59	3	27.8
Blaine specific surface (m^2/kg)	3.320	CaO	60.30	7	33.8
		MgO	4.61	28	41.5
Initial setting time (minutes)	155	SO_3	3.20		
		Loss on ignition	5.17		
Final setting time (minutes)	195	Free Lime	1.08		
		Insoluble residue	1.13		

Table 2. Characteristics of the hydrated lime

Chemical Components	(%)	Chemical Components	(%)
CaO	37.7	Insoluble residue	8.97
MgO	25.9	Bulk density (Kg/l)	0.63
Loss on ignition	26.55	Specific Gravity (Kg/l)	2.42

The sand used for the cement-lime based mortar was natural. For the prepacked mortar, manufactured sand was used. The basic characteristics of the sands are shown in Table 3.

Table 3. Characteristics of the sands used for the mortars

Mortar	MU	T	A	M1 e M2
Sieve / Size number ASTM/ABNT	% Retained Cumulative			
4.75 mm / N° 4	0.00	0.00	0.00	0.05
2.36 mm / N° 8	0.00	0.00	0.00	0.85
1.18 mm / N° 16	0.43	4.12	2.69	7.92
0.60 mm / N° 30	21.84	47.84	30.23	31.28
0.30 mm / N° 50	52.75	65.70	53.36	55.60
0.15 mm / N° 100	84.12	84.51	79.24	89.14
Pan	100	100	100	100
Fineness Modulus	-	-	-	1.85
Specific Gravity (Kg/l)	2.80	2.78	2.82	2.61

Preparation of mortars

The mixture for the prepacked mortar and the necessary amount of water were determined by the manufacturer. The cement-lime based mortars were mixed according to the NBR 13276 Standard (2005). The mortar preparation procedure and the amount of materials used are described in Table 4.

Table 4. The procedure and the amount of materials used for the mortars

Mortar	Dry Material (g)	Cement (g)	Lime (g)	Sand (g)	Water (ml)	Procedure for mixture
MU	2500.0	-	-	-	370.0	30 seconds low speed + 60 seconds stopped
T	2500.0	-	-	-	400.0	30 seconds low speed + 60 seconds stopped + 30 seconds low speed
A	2500.0	-	-	-	375.0	30 seconds low speed + 60 seconds stopped
M1	2510.7	337	182.0	1991.7	488.6	240 seconds low speed
M2	2527.0	350	189.0	1988.0	472.5	240 seconds low speed

One day before the production, the off-the-shelf hydrated lime was mixed with moist sand (10%) to produce the cement-lime based mortar.

After the mixture was produced, the properties of plastic mortar were evaluated: the specific gravity and entrained-air content (measured through the density method as per ABNT – NBR 13278/2005); workability, measured with the GTec Test as well as with the flow table consistency test (as per ABNT – NBR 7215/1996); water retentivity, measured through the loss of workability (evaluated with the GTec Test) after 20 minutes in a room with a controlled environment (temperature 23±2°C and humidity 60±10 %).

The repeatability limits of the GTec Test were evaluated. To do so, four different M1 mortars were prepared and workability was evaluated with the GTec Test just after mixing.

The workability of mortars was also judged by two experienced masons who graded them on a scale from one (poor workability) to five (good workability). The experienced masons laid two prisms, each of which was three blocks high.

The results obtained from the most workable mortars were used to establish requirements in terms of limits of consistency, plasticity, and cohesion. These limits were checked in the field on three different job sites with concrete block structural masonry. This way, it would be possible to check for the existence of any correlation between workability measured in the lab and on-site.

RESULTS AND DISCUSSION

Table 5 shows the properties of plastic mortar.

Table 5. Properties of plastic mortar

Mortar	Water / Dry Material (%)	Theoretical Specific Gravity (kg/l)	Real Specific Gravity (kg/l)	Entrained-air content (%)
MU	14.8	2.27	1.84	18.90
T	16.0	2.23	2.01	9.80
A	15.0	2.28	1.87	18.00
M1	19.5	2.08	2.04	2.11
M2	18.7	2.10	2.02	3.39

In Table 5, it can be seen that the water/dry material values obtained for all prepacked mortars (MU, T and A) were lower than those obtained for the cement-lime based mortars (M1 and M2).

As expected, the prepacked mortars (MU, T and A) have higher entrained-air content. These results can be explained by the presence of admixtures in these mortars. It is also worth noting that of these three mortars, MU and A presented the highest entrained-air content.

Table 6 presents the results of all workability evaluations: with the flow table, with the experienced masons, and with the GTec Test.

Table 6. Evaluation of workability with (a) the flow table, (b) the two experienced masons, and (c) the GTec Test

Mortar	(a)	(b) Masons		(c) GTec Test			
	Flow Table (mm)	Mason 1	Mason 2	Initial Measure (Li) (mm)	Number of Jolts	Plasticity* (mm/J)	Cohesion
MU	201.7	4	4	16.5	10	- 6.15	Yes
T	234.8	4	3	14.5	07	- 8.00	Yes
A	218.3	4	5	15.0	08	- 8.00	Yes
M1	246.6	5	5	18.0	08	- 11.42	Yes
M2	215.5	1	1	19.0	23	- 3.63	No (Lm=17)

*Plasticity – Rate of mortar deformation in Figure 3 (Joint thickness versus energy)

As shown in Table 6, the flow table values are different for each mortar and vary from 201.7 to 246.6 mm. The NBR 8798/1995 Brazilian Standard recommends a flow table limit of (230±10) mm for concrete block masonry bedding mortars. Only mortar T was found to satisfy this requirement. Figure 2 presents a comparison between the average of the grades given by the masons, on the one hand, and the flow table values on the other.

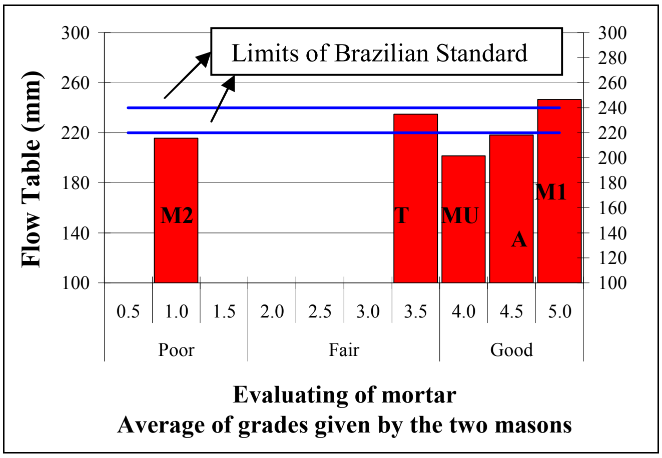

Figure 2. Average of grades given by the two masons versus Flow Table

In Figure 2, it can be clearly seen that the flow table result is not adequate for evaluating the workability of concrete block masonry bedding mortars: mortars M1 and A, which the masons considered as having good workability, had very different flow table values (A – 218.3 mm and M1 – 246.6 mm) that did not satisfy the requirement established by the Brazilian Standard. This means that there is no direct relationship between the flow table indicator and workability. The flow table can be used as an alternative for measuring consistency, but only for mortars of the same type. Bowler, Jackson, and Monk (1996) reached the same conclusion.

Table 6 shows that all mortars were evaluated as having good workability (having received a grade ranging from 4 to 5), except mortar M2 (which received a grade of 1). This is because M2 lacked consistency and cohesion (which was also observed with the GTec Test, as shown in Table 6). Mortar M1 received the highest grade, perhaps because the two masons usually worked with cement-lime based mortar. It is worth noting that this mortar (i.e., with ingredients in these proportions) was chosen because it is one of the most used in structural masonry construction and because it is recommended by American and British Standards.

For mortar M1, the initial measure (Li) was 18.0 mm, which means that with an initial thickness of 20.0 mm, the deformation of the mortar due strictly to the total weight of the various pestle components (simulating the weight of the concrete block) was 2 mm. This way, the mason gets a joint with good thickness (8 mm) to lay the concrete block until a final joint thickness of 10 mm is obtained (which is the recommendation for structural masonry).

Another important property evaluated with the GTec Test is plasticity (see Table 6), that is, the deformation of mortar obtained by exerting energy on the joint (thus simulating the laying of the block). It is thus possible to determine the force exerted by the mason to obtain a joint thickness of 10 mm. The plasticity is the mortar deformation rate, that is, the slope of the tangent to the curve (joint thickness versus energy) in Figure 3.

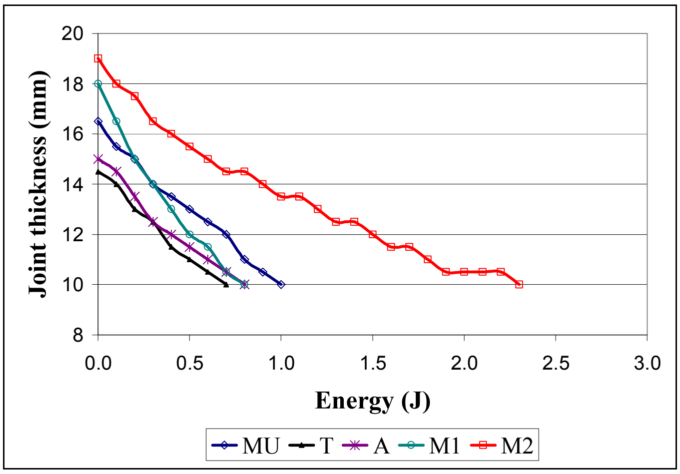

Figure 3. Joint thickness versus energy for the mortars

Mortar M2 had the lowest plasticity: -3.63 mm/J (see Table 6 and Figure 3), while the plasticity of mortars T, A, MU and M1 ranged from -6,15 to -11.42 mm/J. These mortars also received the best grades from the two masons (mortars T, A, and M1 received grades from 4 to 5, and mortar MU received 3.5).

When the masons were laying, they observed that mortar MU was rapidly losing plasticity (water rententivity). For this reason, loss of plasticity, with time, was analyzed. The behavior of mortars MU and M1 is presented in Figure 4.

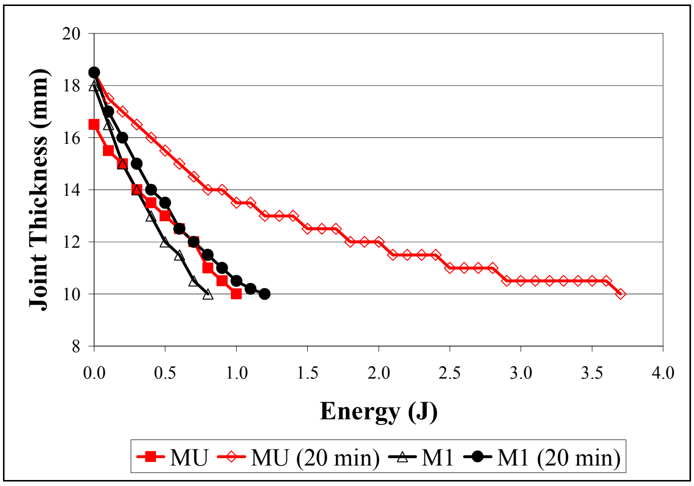

Figure4. Joint thickness versus energy, at two different times

As shown by Figure 4, for mortar MU, the energy necessary to obtain a joint thickness of 10 mm went from 1 J (10 jolts) to 3.7 J (37 jolts) after 20 minutes. However, mortar M1 suffered a smaller loss of plasticity, as the necessary energy went from 0.8 J (8 jolts) to 1.2 J (12 jolts). Mortars T, A and, M2 behaved very similarly to mortar M1, so we will forego discussing similar results related to these, here. It can be concluded that the GTec Test was also effective for evaluating loss of plasticity with time.

Figure 5 shows the results of the GTec Test with respect to repeatability.

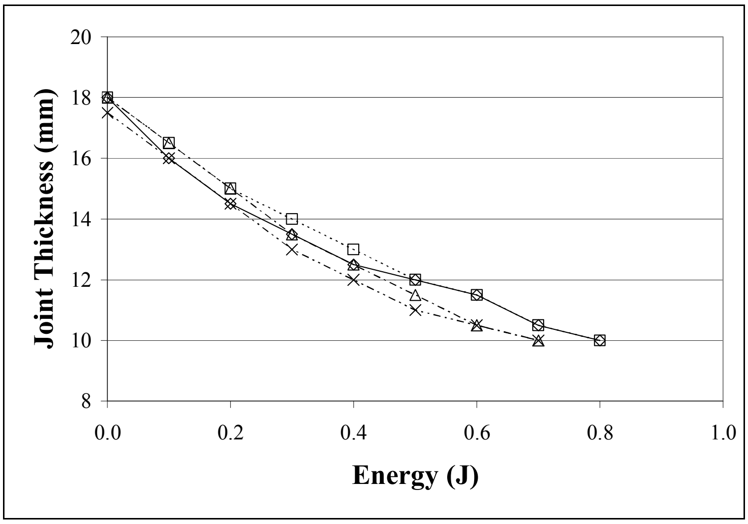

Figure 5. Joint thickness versus energy for the four M1 mortars.

The data presented in Figure 5 show that the results obtained with the GTec Test were very similar for the four mixtures analyzed. The initial measure (Li) varied from 17.5 to 18.0 mm (CV=1.4 %) and the number of jolts varied between 7 and 8 (CV=7.7 %), so it can be concluded that the method is repeatable.

From the results of this study and the evaluation given by the experienced masons, it is possible to define the parameter limits of the GTec Test, for mortar with good workability, as follows: initial measure (Li), from 16.0 to 18.5 mm; number of jolts, from 7 to 15; and plasticity, from -6 to -12 mm/J. Moreover, the mortar must present sufficient cohesion after the thickness of the joint reaches 10 mm.

Following the definition of the limits of the GTec Test, the workability of the mortars was verified in the field on three different job sites. On two of these sites, cement-lime based mortar was used. In these two cases, the results obtained with the GTec Test were found to be within the limits determined in lab (Li = 1.70 to 18.5 mm; number of jolts, 7 to 10). It should be emphasized that the masons underwent a training program.

On the third job site, the mortar used was prepacked and the initial measure (Li) value obtained with the GTec Test was 0.5 mm (initial thickness of the joint equal to 20 mm). For this parameter, the mortar was very fluid and laying was not possible. The thickness of joint used by the mason was thus evaluated and was found to be 40 mm, that is, twice the value specified by the GTec Test. It should be pointed out that only with this initial thickness of joint (40mm) can a mason lay a concrete block. However, if better mortar were used, it would be possible to spend only half of the volume, and thus improve productivity.

The results obtained show that in the lab, it is possible to set the proportions for – and carry out the evaluation of – mortar with adequate workability for use on job sites, when utilizing the parameter limits obtained with the GTec Test.

CONCLUSION

The results obtained show that the proposed test (GTec Test) is simple and effective for evaluating the workability of concrete block masonry bedding mortars. The test can simultaneously evaluate consistency (with the Initial Measure – Li), cohesion (through determination of the joint thickness for which any detachment of the mortar bed's edges occurs) and plasticity (by the energy necessary to obtain a joint thickness of 10 mm). Plasticity is a fundamental property with respect to more consistent mortars, which are necessary when thin joints are used because of structural requirements (thin joints facilitate the grouting of hollow concrete masonry blocks) or because one wishes to be economical by using less mortar. It was demonstrated that the flow table, adopted in the Brazilian Standard, does not lead to proper mortar workability and should only be used as an alternative for measuring consistency and only for mortars of the same type. As a result, the 230±10 mm value recommended in the Brazilian Standard cannot be applied to all types of mortars, as was shown in this study. The limits established by the GTec Test for a mortar with good workability are as follows: consistency (Li) of 16 to 18.5 mm; number of jolts, 7 to 15; plasticity of -6 to -12 mm/J. Moreover, the mortar must exhibit adequate cohesion. The GTec Test was demonstrated to be very effective for evaluating the workability of concrete block masonry bedding mortars both in the laboratory and on job sites.

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