Review of Available Data on the Characteristic Initial Shear Strength of Masonry

In order to try to provide data to support figures to be used for Characteristic Initial Shear Strength in prEN 998-2, the known data has been reviewed.

Results from Greenfield[1] are included in Table 1 and the brick and mortar properties are given in Tables 2 and 3. The tests were carried out in accordance with prEN GGGG-3 :1991, which initially required that testing be at zero precompression. However, the programme included tests at different precompressions and extrapolation of the results back to zero precompression, as eventually adopted in EN1052-3. These results are reported in Table 1. The programme concluded that testing at zero precompression produced results which were too variable to be reliable. The brick and mortar properties have been derived in accordance with the relevant British Standards.

Table 1: Characteristic Initial Shear Strength

Brick Type	Mortar Type	Characteristic Initial Shear Strength (N/mm^2)
3-Hole Low Strength	1:¼:3	0.43
	1:1:6	0.33
	1:5 Masonry Cement	0.25
	1:6 + Plasticiser	0.18
Engineering Class A	1:¼:3	0.43
	1:1:6	0.56
23-Hole Perforated	1:¼:3	0.38
	1:1:6	0.38
Deep Frogged	1:¼:3	0.33
	1:1:6	0.32
3-Hole Perforated	1:¼:3	0.76
	1:1:6	0.74
	1:5 Masonry Cement	0.33
	1:6 + Plasticiser	0.23
Stock	1:¼:3	0.30
	1:1:6	0.33
Solid Calcium Silicate	1:1:6	0.19
Frogged Calcium Silicate (Acid Dipped)	1:1:6	0.46

Table 2: Brick Properties

Brick Type	Compressive Strength N/mm^2		Water Absorption %		Initial Rate of Suction Dimensions Kg/m^2/min	
3-Hole Low Strength	39.0	(9.5)	15.4	(3.0)	2.05	(10.0)
Engineering Class A	156.0	(18.4)	2.7	(38.0)	0.54	(22.0)
23-Hole Perforated	52.0	(12.7)	7.4	(6.0)	0.50	(14.4)
Deep Frogged	30.8	(9.2)	24.9	(1.4)	1.87	(22.8)
3-Hole Perforated	51.4	(16.5)	8.4	(4.2)	0.50	(24.3)
Stock	25.7	(25.7)	21.2	(8.2)	3.49	(23.5)
Solid Calcium Silicate	41.7	(5.2)	15.9	(3.5)	0.57	(10.1)
Frogged Calcium Silicate (Acid Dipped)	33.8	(2.2)	16.6	(6.4)	0.97	(16.3)

(Figures in Brackets are coefficients of variation)

Table 3: Mortar Properties

Mortar Type	Compressive Strength N/mm^2		Consistence mm	Flow %	Water Retentivity %	Air Content %
1:1:	5.5	(1.6)	11.1	135.5	89.8	2.6
1:¼:3	15.3	(0.8)	10.7	132.5	91.3	2.6
1:5 Masonry	2.98	(2.7)	14.4	36.2	89.0	11.8
1:6 + Plasticiser	3.26	(10.6)	12.5	31.5	88.3	31.5

In 1999 further work[2] was carried out primarily aimed at determining whether manufacturers should aim for some advantage by declaring values obtained by test, as opposed to referring to tabulated values. Consequently, values are determined using a standard consistence mortar defined by the dropping ball value (d.b.) and at values both greater and smaller than would usually be specified. The results from the tests on two of the bricks in the programme proved to be quite variable and as a result they were repeated. In order to consider the variation caused by variation in the sand used as standard for most programmes at CERAM, a further set of tests were carried out with a lightly washed sand. The tests were repeated six months after the initial trials when the sand was being won from a new area in the quarry. The results are given in Tables 4, 5 and 6.

Table 4: Characteristic Initial Shear Strengths[2]

Brick Type	Mortar Type (Target d.b in mm)							
	9.5-10.5 d.b		10.5-11.5 d.b		11.5-12.5 d.b		10.5-11.5 d.b Washed Sand	
	Characteristic Initial Shear Strength (N/mm^2)							
	N/mm^2		N/mm^2		N/mm^2		N/mm^2	
Engineering A	0.21		0.17		0.16		0.22	
3 Hole Perf.	0.42		0.29		0.23		0.20	
3 Hole Perf. (lower strength)			0.29					
Multi Perf.			0.29					
Deep Frogged			0.19					
Stock	0.29		0.33		0.28		0.41	
	Mortar Strength and d.b N/mm^2							
	N/mm^2	mm	N/mm^2	mm	N/mm^2	mm	N/mm^2	mm
	3.25	9.5	3.75	11.0	3.55	12.5	5.40	11.2

Table 5: Characteristic Results from Repeat Tests and those from Initial Programme

Brick Type	Characteristic Initial Shear Strength (N/mm^2)	
	Initial Programme	Repeat Programme
	N/mm^2	N/mm^2
Engineering A	0.17	0.35
3 hole perforated (high strength)	0.29	0.52

Table 6: Characteristic Results from Initial Programme and 6 Months Later

Brick Type		Mortar Type (Target d.b in mm)		
		9.5-10.5 d.b	10.5-11.5 d.b	11.5-12.5 d.b
		Characteristic Initial Shear Strength (N/mm^2)		
		N/mm^2	N/mm^2	N/mm^2
Engineering	(Initial)	0.26	0.21	0.20
	(6 months)	0.40	0.25	0.32
3 hole high strength	(Initial)	0.52	0.37	0.29
	(6 months)	0.45	0.42	0.50
Stock	(Initial)	0.36	0.41	0.35
	(6 months)	0.34	0.42	0.61
Dropping Ball (mm)	(Initial)	9.5	11.0	12.5
	(6 months)	9.5	11.3	12.2

Results from two reports[3,4] of work carried out in Germany in the mid 1990's, were made available by Dr Meyer. These mainly concentrated on the effect on results when the units were laid in a wet or dry condition. The results from these tests are given in Tables 7 and 8.

The results in Table 7 relate to Group 2 clay units which were tested without any precompression normal to the bed joints and without the height being cut down as required in BSEN 1052-3. Although the height reduction was for convenience of testing and may not affect the results, the use of zero precompression on the units in Table 1 led to unsatisfactory variability. However, the units in table 7 were tested in both the dry and wet condition (as laid) and although the variability when wet laid was quite high and that when dry laid was low, the bond was poorer for the dry laid, especially for the lightweight, thermal insulating mortar.

Table 7: Mean Initial Shear Strength[3]

Brick Type		Mortar Type	Mortar Strength (N/mm^2)	Unit Water Content (%)	Mean Initial Shear Strength (N/mm^2)
Group	Dimensions l x b x h (mm)				
2	244 x 297 x 236	Lt. Wt. Thermal Ins.	1.6	0	0.06
2	244 x 297 x 236	Lt. Wt. Thermal Ins.	1.6	18	0.12
2	248 x 369 x 243	Masonry Mortar	12.8	0	0.25
2	248 x 369 x 243	Masonry Mortar	12.8	16	0.26
2	246 x 362 x 238	Masonry Mortar	12.8	0	0.21
2	246 x 362 x 238	Masonry Mortar	12.8	20	0.22
2	299 x 368 x 238	Lt. Wt. Thermal Ins.	1.6	0	0.06
2	299 x 368 x 238	Lt. Wt. Thermal Ins.	1.6	19	0.16
2	244 x 297 x 236	Masonry Mortar	8.2	0	0.24
2	244 x 297 x 236	Masonry Mortar	8.2	18	0.51
2	244 x 297 x 236	1:1:6	5.1	0	0.14
2	244 x 297 x 236	1:1:6	5.1	18	0.11

The results in Table 8 are for zero precompression on a further range of clay unit types.

Table 8: Mean Initial Shear Strength[4]

Unit Group	Mortar Strength (N/mm^2)	Water Content of Unit %	Mean Initial Shear Strength (N/mm^2)
1	8.42	4.7	0.34
1	8.42	15.7	0.60
1	8.5	0.1	0.39
1	8.5	2.1	0.48
2	6.9	0.5	0.60
2	6.9	3.1	0.74
2	4.43	3.0	0.24
2	4.43	21.5	0.33
2	4.43	3.7	0.21
2	4.43	20.4	0.25
2	4.43	0.2	0.35
2	4.43	11.7	0.43

The Autoclaved Aerated Concrete Products Association (AACPA) commissioned work on two block types and two mortar designations. The results are given in Table 9.

Note: Space removed between two and block.

Table 9: Characteristic Initial Shear Strengths for Autoclaved Aerated Concrete[5]

Block Strength N/mm^2	2.95		3.95	
Mortar Type	**(i)**	**(iii)**	**(i)**	**(iii)**
Characteristic Initial Shear Strength (N/mm^2)	0.25	0.24	0.30	0.30

In order to investigate further the effect of the inclusion of air entraining agent the Mortar Industry Association in the UK commissioned work[6] on brickwork made with mortars both with and without air entraining agent. The results are given in Table 10. It should be emphasized however that this was investigated in part by Greenfield in 1990, when a plasticised mortar with a very high air content was included in the test programme.

Table 10: Characteristic Initial Shear Strength of Brickwork with and without an Air Entraining Agent[6]

	Mortar Designation			
	(i)		(iii)	
Air Entraining Agent	**NO**	**YES**	**NO**	**YES**
	Class A Engineering Brick			
Characteristic Initial Shear Strength (N/mm^2)	0.52	0.41	0.35	0.22
	Stock Brick			
Characteristic Initial Shear Strength (N/mm^2)	0.45	0.18	0.33	0.38

The results from all of this work are summarized in Table 11 which reflects the layout of the tabulated values in Annex C to prEN998-2.

The intention of the work in Germany was to look for the worst case condition for clay units and it was suggested by Dr Meyer that the units should normally be tested dry. Results for the dry tests, albeit mean values with no precompression, have been included in Table 11.

Table 11: Comprehensive Set of Results : All Sources

Mortar Strength (N/mm^2)	<2.5	2.5< and <10	10<
Mortar Type	**General Purpose Mortars**		
Unit Type	**Characteristic Initial Shear Strength (N/mm^2)**		
Clay Group 1 Low Strength		0.33	0.43
Clay Group 1 High Strength		0.56	0.43
Clay Group 1 Med Strength (23h)		0.38	0.38
Clay Group 1 Deep Frog		0.32	0.33
Clay Group 1 Med Strength (3h)		0.74	0.76
Clay Group 1 Stock		0.33	0.30
Cal.sil Group 1 Solid		0.19	
Cal.sil Group 1 Frog		0.46	
Clay Group 1 Low Strength		0.25[1]	
		0.18[2]	
Clay Group 1 Med Strength (3h)		0.33[3]	
		0.23[2]	
Clay Group 1 High Strength		0.17	
Clay Group 1 Med Strength		0.29	
Clay Group 1 Lower Strength		0.29	
Clay Group 1 Med Strength (multi)		0.29	
Clay Group 1 Frog		0.19	
Clay Group 1 Stock		0.34	
Clay Group 1 High Strength		0.21[3]	
		0.16[4]	
		0.22[5]	
Clay Group 1 Med Strength		0.42[3]	
		0.23[4]	
		0.20[5]	
		0.29[3]	
Clay Stock		0.28[4]	
		0.41[5]	
Clay Group 1 High Strength		0.35[6]	
Clay Group 1 Med Strength		0.52[6]	
Clay Group 1 High Strength		0.20[7]	
Clay Group 1 Med Strength		0.33[7]	
Clay Group 1 Stock		0.34[7]	
Clay Group 1 High Strength		0.32[3,7]	
Clay Group 1 Med Strength		0.36[3,7]	
Clay Group 1 Stock		0.27[3,7]	
Clay Group 1 High Strength		0.26[4,7]	
Clay Group 1 Med Strength		0.40[4,7]	
Clay Group 1 Stock		0.48[4,7]	
aac Group 1 2.95	0.24	0.25	
aac Group 1 3.95	0.30	0.30	

Clay Group 1 High Strength Clay Group 1 Stock		0.35 0.22[8] 0.33 0.38[8]	0.52 0.41[8] 0.45 0.18[8]
Clay Group 1 1		0.34[9] 0.39[9]	
Clay Group 2 Clay Group 2 Clay Group 2 Clay Group 2 Clay Group 2 Clay Group 2		0.60[9] 0.24[9] 0.21[9] 0.35[9] 0.14[9] 0.24[9]	 0.25[9] 0.21[9]
Clay Group 2	0.06[9,10] 0.06[9,10]		

Notes to Table

1. 1:5 Masonry Cement
2. 1:6 + Plasticiser
3. Stiffer than usual consistency
4. Wetter than usual consistency
5. Washed sand
6. Repeated Tests
7. Tests carried out after 6 months with new consignment of sand.
8. Mortar containing air entraining agent
9. Mean Values
10. Lightweight Thermal Insulating Mortar

The Characteristic Initial Shear Strength of designed masonry mortars as currently included in prEN 998-2 is shown in Table 12.

Table 12: Tabulated Values in prEN 998-2

Mortar Type			
Mortar Strength (N/mm²)	**<2.5**	**2.5< and <10**	**>10**
	Characteristic Initial Shear Strength (N/mm²)		
General Purpose Mortars	0,10	0,15	0,20
Lightweight Aggregate Mortar	0,10	0,15	0,15
Thin Layer Mortar	1)	0,2	0,3
1) It is believed that thin layer mortars of <M2,5 are not placed on the market			

From the figures in Table 11 it seems clear that for general purpose mortars, both with and without air entraining agent, the values in Table 12 are supportable. The only real question at issue is whether for Group 2 units and lightweight aggregate mortar a separate line is needed with reduced values. As this would be based on only two results, both with zero water content, which is considered to be unlikely in practice, it is suggested that more evidence is needed before such a change can be made.

It is therefore suggested that the available data supports the figures given in the enquiry version of prEN 998-2 and in Table 12.

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