Current research work on lime mortared masonry

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Lime Mortars

- Binders
  - Hydraulic limes (NHL, HL, FL)
  - Non-hydraulic limes (CL, putties, quick limes)
- Aggregates
  - Silicate (sands)
  - Calcitic (limestones)
  - Volumetric ratios (lime:aggregate) 1:2 – 1:3

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Benefits of lime mortars

- Greater tolerance to masonry unit movement – reduced need for movement joints
- Beneficial lower strength (recycling; movement)
- Improved water vapour permeability
- Improved aesthetics
- Workability
- Environmental impact (Embodied carbon; Eco-points)

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Strength development

- Mortar hardening
  - Initial hydraulic set
  - Carbonation
- Influence of mix
  - Lime type and grade
  - Binder:aggregate ratio
  - Water:lime ratio
- Influence of aggregates
  - Grading; Shape; Mineralogy
  - Porosity; Water absorption; Suction rate
  - Surface roughness and reactivity
  - Water soluble chloride and sulphate content
  - Loss on ignition; organic matter
  - Strength; density; freeze-thaw resistance

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Bonding with masonry

- Masonry units
  - Water absorption characteristics
  - Surface characteristics
  - De-watering of mortar
  - Densification of mortar
- Quality of masonry work
  - Disturbance of joint
  - Joint thickness
  - Mix quality and use
- Environmental conditions (curing)
  - Temperature and RH (hydraulic set and carbonation)
  - Frost damage

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Recent and Current Lime Mortar Research & Development

- University of Bristol (IAC)
  - Foresight project
  - Engineering with Lime (STI)
  - EPSRC projects
- University of Bath
- University of Bradford
- University of Manchester
- Paisley University
- English Heritage

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Current research project

- Develop improved understanding of lime mortared masonry
- Generate performance data for lime mortared brickwork
- Universities of Bath, Bradford and Bristol
- Partners: Lime Technology, BRE, BDA, Castle Cement, Lhoist UK, Buro Happold, Network Rail

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Work completed to date: University of Bath

- Hydraulic lime mortar tests (BS EN 1015)
  - Lime grade (NHL 2, 3.5 and 5)
  - Sand grading
- Brickwork tests (BS EN 1052)
  - Flexural strength (bond wrench, panel tests)
  - Shear strength
  - Compressive strength

  - Brick properties (IRA, water absorption, sorptivity)
  - Mortar (lime grade, mix proportions, sand grading)

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Experimental study: Preparation of materials

- Mixing of lime mortars
  - Batched by mass
  - Dry and initial wet mix
  - Stand for 50 mins
  - Remix 2-3 mins
- Masonry construction
  - Experienced bricklayer
- Curing of specimens
  - Initial 7 days under plastic
  - $20^{o}C$ and 65% RH (after 7 days)

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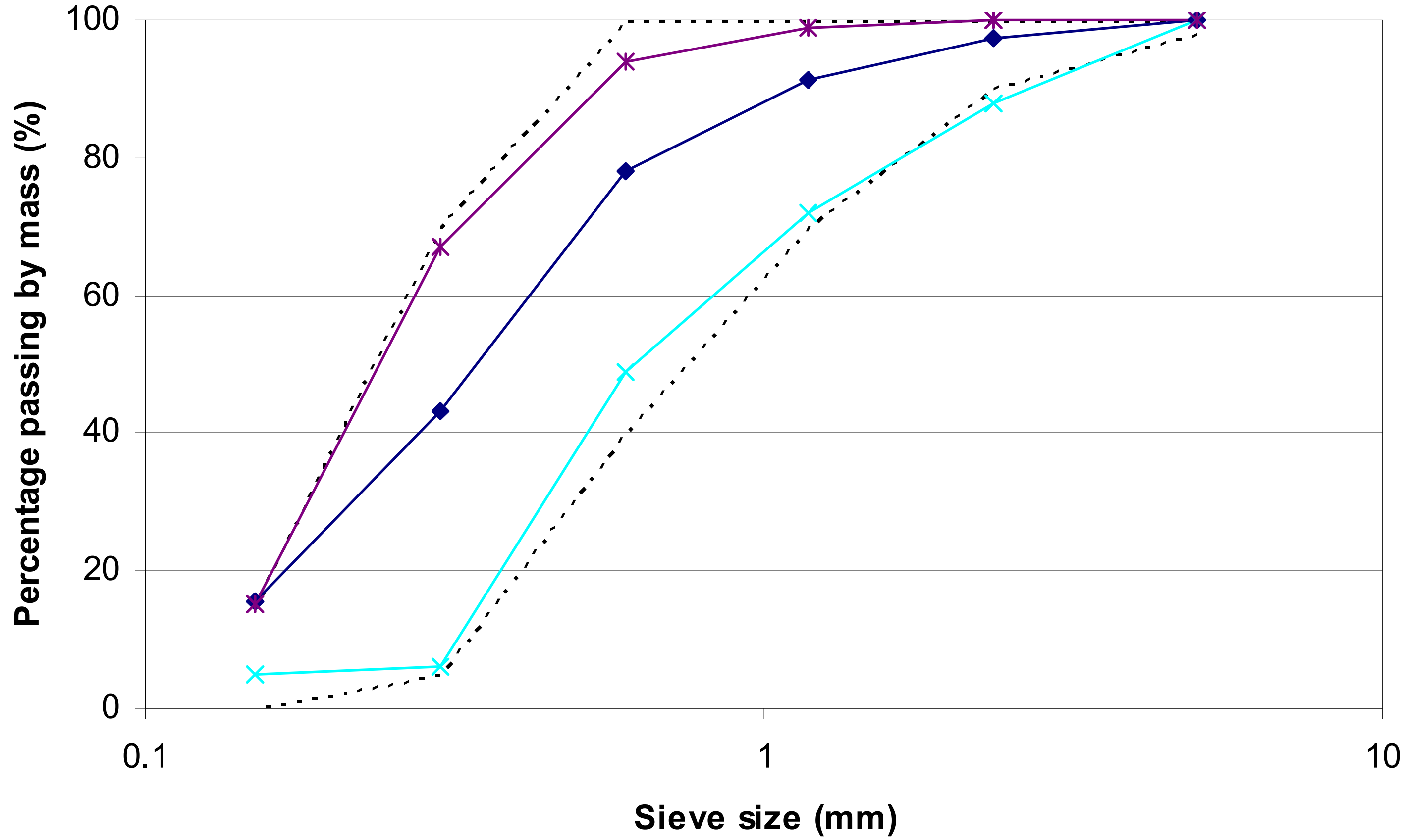

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Mortar strength tests

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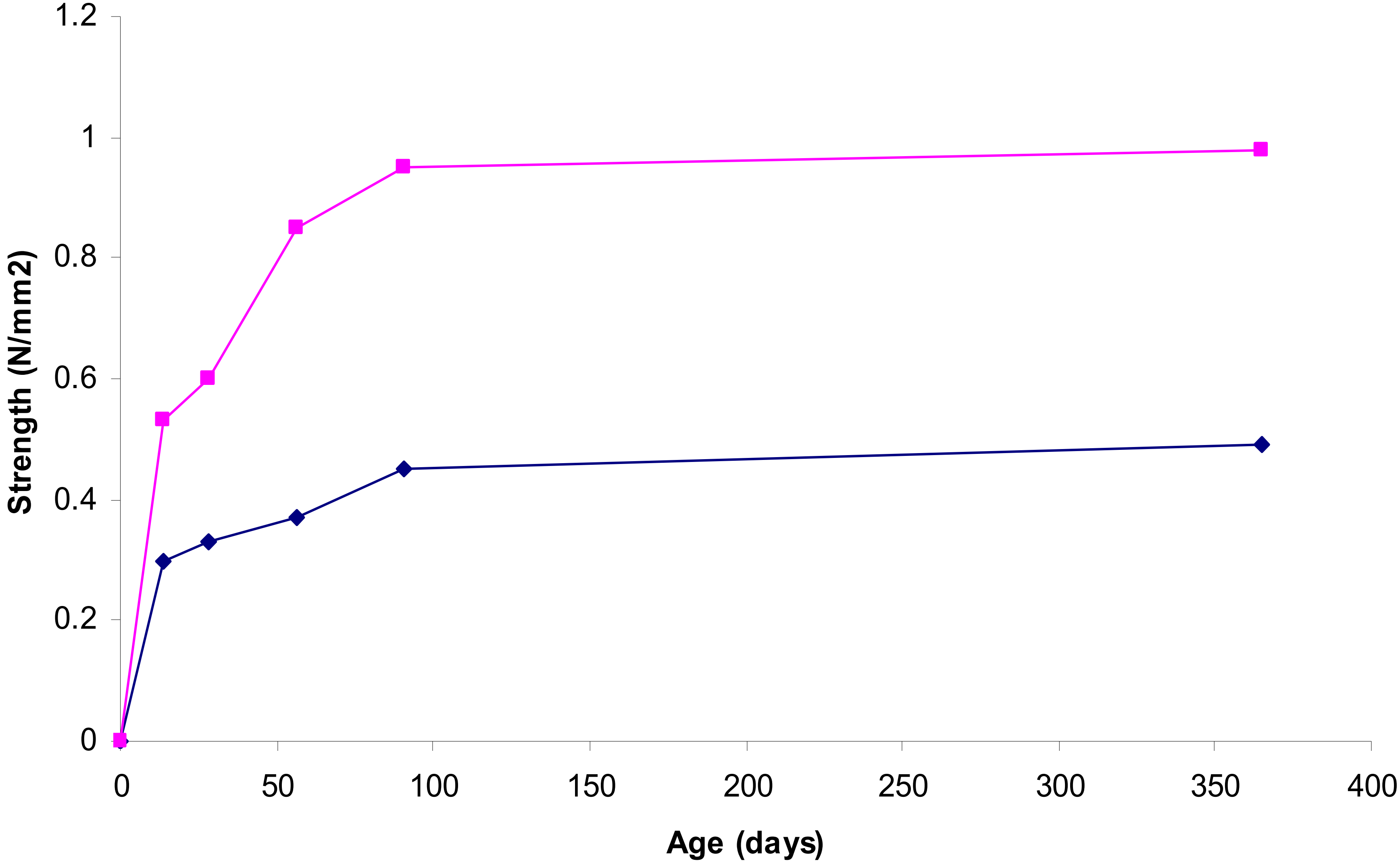
Mortar strength development



Mortar strength (N/mm²)
Influence of binder:aggregate ratio

	14days		28days		56days		91days		365 days	
	Flexure	Compr.	Flexure	Compr.	Flexure	Compr.	Flexure	Compr.	Flexure	Compr.
NHL3.5										
1:2	-	-	0.36	0.69	-	-	0.40	1.20	-	-
1:2.25	0.30	0.53	0.33	0.60	0.37	0.85	0.45	1.00	0.49	1.00
1:2.5	-	-	0.31	0.54	-	-	0.36	0.81	-	-
1:2:9	0.58	1.76	0.71	2.30	0.72	2.16	0.72	2.24	-----	-----
1:3:12	0.30	0.72	0.33	1.00	-----	-----	0.40	1.19	-----	-----

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Mortar strength (N/mm^2)
Influence of NHL grade

	14days		28days		56days		91days		365 days	
	Flexure	Compr.	Flexure	Compr.	Flexure	Compr.	Flexure	Compr.	Flexure	Compr.
NHL2	-----	-----	0.28	0.54	-----	-----	0.40	0.97	-----	-----
NHL3.5	0.30	0.53	0.33	0.60	0.37	0.85	0.45	1.00	0.49	1.00
NHL5	0.23	0.61	0.24	0.76	0.25	0.76	0.36	1.28	-----	-----

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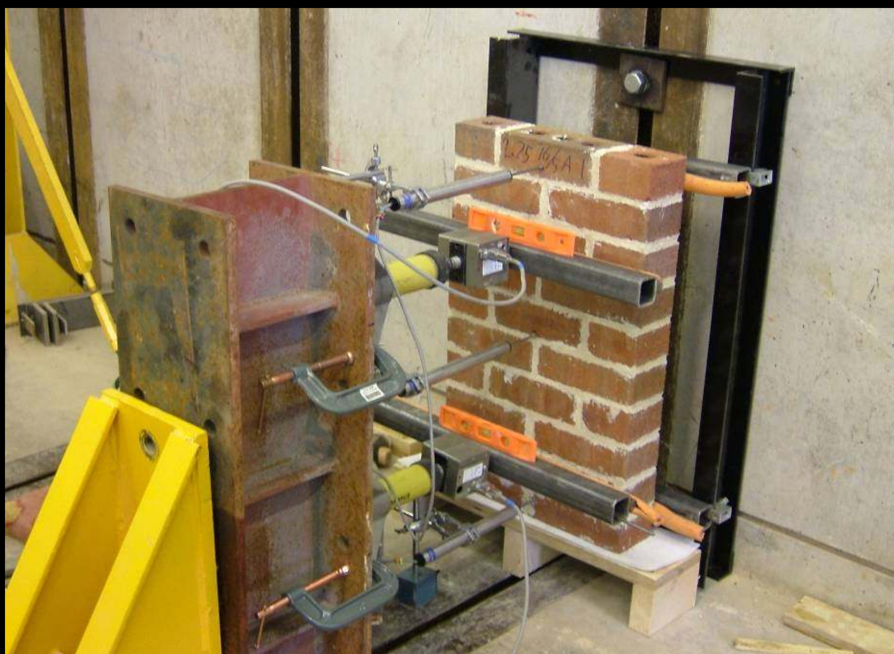
Mortar strength (N/mm^2)
Influence of sand grading

	14days		28days		56days		91days		365 days	
	Flexure	Compr.	Flexure	Compr.	Flexure	Compr.	Flexure	Compr.	Flexure	Compr.
Binnegar (medium sand)	0.30	0.53	0.33	0.60	0.37	0.85	0.45	1.00	0.49	1.00
Allerton Park (coarse sand)	-----	-----	0.34	1.13	-----	-----	0.34	1.52	-----	-----
Yellow Pit (fine sand)	-----	-----	0.27	0.50	-----	-----	0.27	0.76	-----	-----

Flexural panel tests



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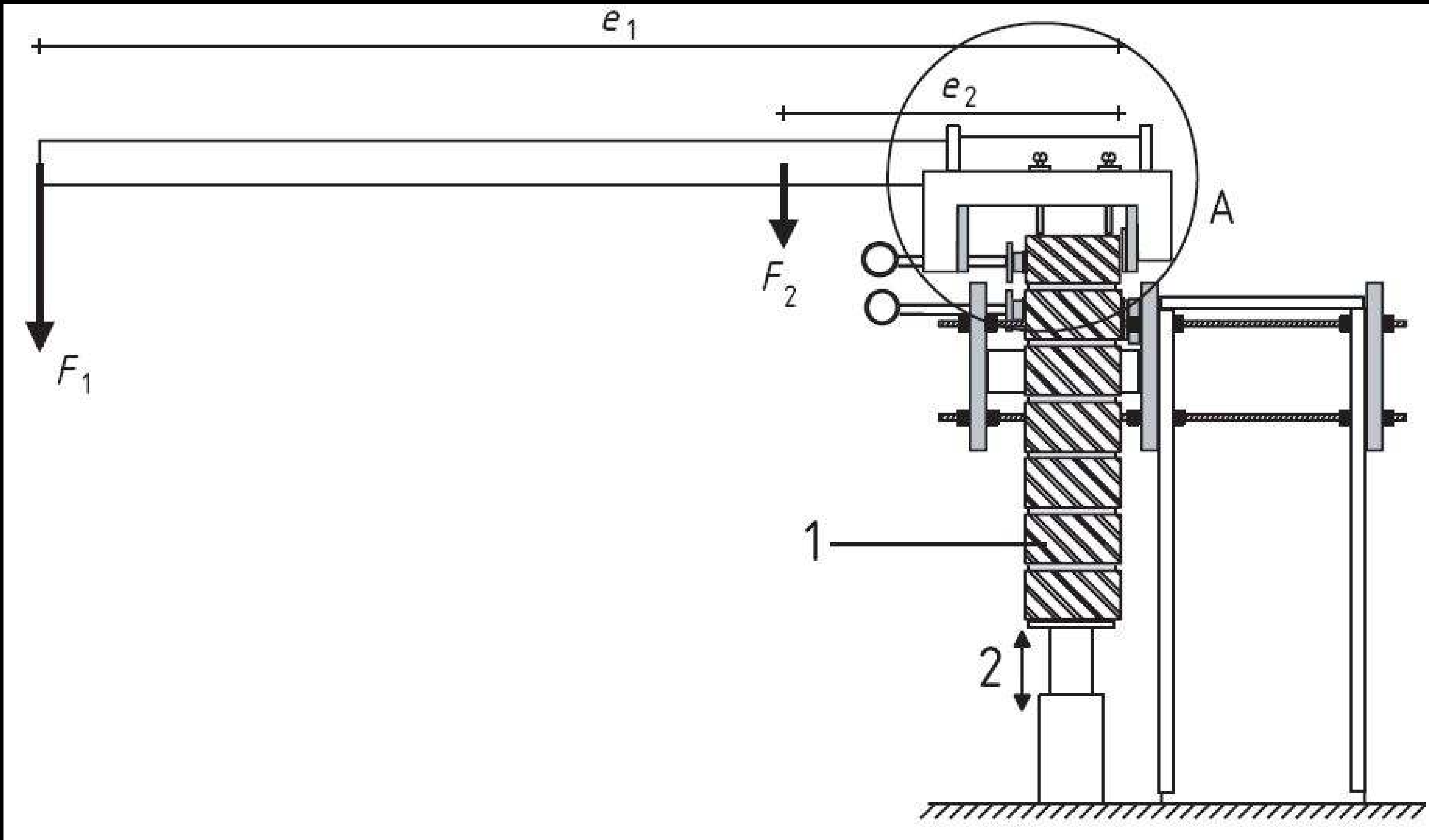
Panel test results

	Parallel (N/mm^2)		Perpendicular (N/mm^2)		Orthogonal ratio
	Average	Charac.	Average	Charac.	
Brick: 5.1% water absorption; 1.3 $kg/m^2/min$ IRA; 0.40 $mm.min^{½}$ sorptivity					
NHL2 (91days) (0.97 N/mm^2)	0.25	0.19	0.79	0.49	2.58
NHL3.5 (91days) (1.06 N/mm^2)	0.48	0.38	1.18	0.67	1.76
NHL5 (91days) (1.28 N/mm^2)	0.42 *	-	1.35	0.85	-
1:2:9 (28days) (2.30 N/mm^2)	0.45	0.35	1.73	1.34	3.83
1:3:12 (28days) (1.00 N/mm^2)	0.41	0.31	1.49	1.21	3.90
Brick: 2.3% water absorption; 0.1 $kg/m^2/min$ IRA; 0.02 $mm.min^{½}$ sorptivity					
NHL3.5 (91 days)	0.21	0.16	0.82	0.52	3.25
Brick: 14.8% water absorption; 2.3 $kg/m^2/min$ IRA; 2.08 $mm.min^{½}$ sorptivity					
NHL3.5 (91 days)	0.09	0.05	0.43	0.24	4.80

Bond wrench test
BS EN 1052-5:2005



Bond wrench tests

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Bond Strength (N/mm²)
Influence of lime grade

Bond Strength (N/mm²)	14days (Charac)	28days (Charac)	56days (Charac)	91days (Charac)	365days (Charac)
Brick: 5.1% water absorption; 1.3 kg/m²/min IRA; 0.40 mm.min^{½} sorptivity					
NHL2 (91days) (0.97 N/mm²)	-	0.24 (0.15)	-	0.29 (0.21)	-
NHL3.5 (91days) (1.06 N/mm²)	0.21 (0.17)	0.30 (0.21)	0.40 (0.25)	0.46 (0.36)	0.65 (0.59)
NHL5 (91days) (1.28 N/mm²)	0.28 (0.24)	0.35 (0.25)	0.37 (0.27)	0.63 (0.45)	-

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Bond Strength (N/mm^2)
Influence of mortar mix

Bond Strength (N/mm^2)	**14days (Charac)**	**28days (Charac)**	**56days (Charac)**	**91days (Charac)**	**365days (Charac)**
Brick: 5.1% water absorption; 1.3 kg/m^2/min IRA; 0.40 mm.min^{½} sorptivity					
1:2 (NHL3.5) (1.20 N/mm^2)	-	0.34 (0.22)	-	0.61 (0.45)	-
NHL3.5 (91days) (1.06 N/mm^2)	0.21 (0.17)	0.30 (0.21)	0.40 (0.25)	0.46 (0.36)	**0.65 (0.59)**
1:2.5 (NHL3.5) (0.81 N/mm^2)	-	0.28 (0.22)	-	0.38 (0.31)	-
1:3:12 (28 days) (1.00 N/mm^2)	0.35 (0.24)	0.49 (0.37)	-	**0.90 (0.56)**	-

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Bond Strength (N/mm^2)
Influence of sand grading

Bond Strength (N/mm^2)	14days (Charac)	28days (Charac)	56days (Charac)	91days (Charac)	365days (Charac)
Brick: 5.1% water absorption; 1.3 $kg/m^2/min$ IRA; 0.40 $mm.min^{½}$ sorptivity					
NHL3.5 (91days) (1.06 N/mm^2)	0.21 (0.17)	0.30 (0.21)	0.40 (0.25)	0.46 (0.36)	0.65 (0.59)
Allerton Park coarse sand (1.52 N/mm^2)	-	0.29 (0.22)	-	0.42 (0.34)	-
Yellow Pit fine sand (0.76 N/mm^2)	-	0.23 (0.15)	-	0.37 (0.25)	-

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Bond Strength (N/mm²)
Influence of brick absorption

Bond Strength (N/mm²)	14days (Charac)	28days (Charac)	56days (Charac)	91days (Charac)	365days (Charac)
Brick: 5.1% water absorption; 1.3 kg/m²/min IRA; 0.40 mm.min½ sorptivity					
NHL3.5 (91days) (1.06 N/mm²)	0.21 (0.17)	0.30 (0.21)	0.40 (0.25)	0.46; *0.48* (0.36*; 0.38)*	0.65 (0.59)
Brick: 2.3% water absorption; 0.1 kg/m²/min IRA; 0.02 mm.min½ sorptivity					
NHL3.5 (91days) (1.06 N/mm²)	0.08 (0.05)	0.16 (0.12)	0.18 (0.13)	0.23; *0.21* (0.15; *0.16)*	-----
Brick: 14.8% water absorption; 2.3 kg/m²/min IRA; 2.08 mm.min½ sorptivity					
NHL3.5 (91days) (1.06 N/mm²)	0.09 (0.03)	0.10 (0.04)	0.18 (0.06)	0.09; *0.09* (0.03; *0.05)*	-----

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Other tests

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Main findings to date

- Mortar tests
  - Compressive strength improved using coarser graded sand
  - Lime mortar ceased (significant) strength development at 91days
- Masonry tests
  - Bond strength increased with mortar strength (sand type)
  - Bond impaired by high AND low brick IRA and sorptivity
  - No direct correlation between brick total water absorption and bond strength
  - Bond wrench strength comparable with panel strength
  - Bond strength continued to develop though apparent mortar strength had fully developed
  - Bond not improved by using coarser sand

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Future work

- Influence brick properties on bond
  (water absorption, IRA, sorptivity, type)
- Development of bond strength
  (nature, age (beyond 1 year), influence of curing conditions)
- Mortar characteristics
  (dewatering - brick moulds)

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- Partnership between University of Bath and Building Research Establishment
- 30 staff and PG students
- Areas of work:
  - Advanced composites
  - Low carbon materials
  - Concrete, steel and masonry structures
  - Reuse of materials

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Current research work

- Innovative concrete structures
  - FRP strengthening and reinforcement
- Structural masonry
  - Lime mortars
- Timber materials and engineering
  - Engineered timber products; Traditional carpentry; Timber concrete composites
- Natural fibre composites
- Low carbon materials
  - Earthen architecture; Hemp-lime; Straw bale
- Masonry/geotechnical engineering
  - Dry-stone wall masonry

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