Construction Materials Consultants Ltd.

Wallace House, Whitehouse Road, Stirling, FK7 7TA
Tel 01786 434708 Fax 01786 475133
E-mail mail@cmcstirling.co.uk

North York Moors National Park Authority.
The Old Vicarage
Bondgate
Helmsley
York
YO62 5BP

Our Ref: M/1991/19/C3
Your Ref.: T2019

30th May 2019

CERTIFICATE OF ANALYSIS OF MORTAR SAMPLES FOR DETERMINATION OF MIX COMPOSITION & BINDER TYPE

Project Reference	:	North Yorkshire Moors – This Exploited Land of Iron
Sample Location	:	Bank Top Kilns
Sample Description	:	BTK1A – Typical Vault, Stonework mortar sample BTK1B – Typical Vault, Brickwork mortar sample BTK2 – Rear Retaining Wall, masonry mortar BTK3 – Front Wall/Facing, masonry mortar
Date Received	:	12th March 2019
CMC Sample Ref	:	SR 2705 – S1A = BTK1A – Vault, Stonework mortar sample SR 2705 – S1B = BTK1B – Vault, Brickwork mortar sample SR 2705 – S2 = BTK2 – Rear Retaining Wall, masonry mortar SR 2705 – S3 = BTK3 – Front Wall/Facing, masonry mortar
Date Analysed	:	13th March to 26th May 2019
Method of Test	:	Determination of binder type by X-Ray Diffraction analysis. Mix composition by acid digestion with grading analysis of recovered aggregate, and thin section examination.

Sample

A batch of samples which included four individual samples of mortar was received in CMC's Stirling Laboratory on the 12th March 2019. The samples were to be submitted to analysis in an attempt to determine the composition of the mortar in each sample, with grading analysis and identification of the aggregate in each.

In addition, to the above, further comment was also requested on the condition of the mortars as received, and, if possible, offer comment on the type and form of the binder used in the mortar production. The mortar samples were identified as having been obtained from the Bank Top Kilns, in the North Yorkshire Moors.

The samples were received from Structural and Civil Consultants Ltd., Northallerton, on behalf of the North York Moors National Parks Authority as part of their "This Exploited Land of Iron" project.

On receipt in the laboratory, the sample details were entered the sample register and the unique sample identification number SR2705 allocated. Details of the samples submitted for examination and analysis given below:

CMC Sample Ref.	Client Ref	Location Sampled
SR2705 – S1A	BTK1A	Mortar from Typical Vault masonry, Stonework,
SR2705 – S1B	BTK1B	Mortar from Typical Vault masonry, Brickwork,
SR2705 – S2	BTK2	Mortar from Rear Retaining Wall,
SR2705 – S3	BTK3	Mortar from Front Wall/Facing.

Method of Test

On receipt in the laboratory the samples were logged, with their mass and size recorded prior to being photographed, in the as-received condition. The samples were then submitted to an examination with the aid of a stereo-binocular microscope at a magnification up to x20 in preparation for analysis.

As all samples were received in a damp condition a portion from each sample was dried in an air circulating oven ay 70°C to a constant weight to determine the as-received moisture content and dry proportion of the samples to be used in the analysis.

During the microscopic examination the samples were exposed to a series of *ad hoc* droplet tests employing a range of reagents and indicator solutions to aid the identification of the components present and to assess the condition of the mortars as received.

Following the initial examination representative sub-samples from each sample were submitted to determination of mix composition by acid digestion, following the methods of the Scottish Lime Centre Trust (SLCT). With an aggregate grading determined on the residue recovered following acid digestion.

On the basis that a proportion of the aggregate may consist of limestone, or other acid soluble components, a petrographic thin section was prepared from each sample. In addition to clarifying the aggregate types present, this would permit clarification of the form in which the binder was used at the time of production, along with providing confirmation of the mix composition by modal analysis, thereby permitting a correction for the presence of any acid soluble aggregate components, and isolated lime inclusions present in the mix.

Identification of the binder type used in the production of the mortars, along with the presence of any contaminants or reaction products, was determined by X-ray Diffraction (XRD) analysis.

Observations from a Macro/Microscopic examination

On receipt in the laboratory the sample details were logged with the following determined:

Sample Ref.	Client Ref.	Mass of Sample (gram)	Dimensions of Largest piece (mm)	Colour by the Munsell Soil Colour Charts	Moisture Content % by dry mass
SR2705-S1A	BTK1A	79.8	48.7 x 48.0 x 12.2	10YR 8/1 "White"	1.8%
SR2705-S1B	BTK1B	123.2	86.9 x 69.0 x 13.2	7.5YR 8/1 "White"	4.9%
SR2705-S2	BTK2	656.5	134.0 x 99.1 x 59.8	5YR 7/2 "Pinkish Grey"	10.6%
SR2705-S3	BTK3	92.1	95.0 x 58.9 x 20.3	7.5YR 8/2 "Pinkish White"	5.8%

Sample SR2705-S1A (BTK1A): Typical Vault Stonework Mortar

The sample received consisted of four fragments of mortar along with a small quantity of fines. The mortar fragments were well compacted and hard, and the intact pieces could only be broken under persistent firm finger pressure, with the pieces breaking with an audible 'snap', indicating a degree of brittleness in the mortar. The freshly fractured surfaces were found not to be friable, and aggregates could only be loosened from the surface with the aid of a point pick.

On examination the mortar was noted to contain an abundance of small lime inclusions, with these measuring up to 1.5mm in size. The inclusions were observed to range from sub-angular fragments to sub-round and irregular in shape, and most could be powdered, in place, with the point pick.

The mortar was found from a phenolphthalein indicator test to be fully carbonated, and from water droplet tests it was noted that droplets placed onto freshly fractured surfaces were rapidly absorbed and diffused throughout the mortar to depth, thereby indicating a well-connected pore structure within the mortar paste. However, droplets placed onto outer soiled surfaces were supported for a period prior to slowly being absorbed, which is not uncommon on old lime mortars, a function of surface pore blocking with redeposited lime (calcite), soiling and organic colonisation (Algae etc.).

Plates No. 1 & 2: The left plate shows the intact pieces of mortar in the sample, as received, with the right plate showing a magnified image of a freshly fractured surface through the thickness of the sample. It was noted that the lime inclusions observed were small and randomly distributed throughout.

From the examination it was indicated that the mortar displayed the characteristics of a non-hydraulic lime mortar, with an abundance of small lime inclusions which are randomly distributed throughout the fabric. The inclusions appearing to have formed from a mixture of unmixed quicklime and fully encapsulated 'balled' lime hydrate.

The aggregates appear to be dominated by quartz with minor indeterminate lithic fragments also present, with rare small weathered brick fragments, up to 1.7mm in size, noted along with small slag or clinker fragments. The latter ranging from 0.5mm to 5.4mm in size.

The natural aggregates are round to sub-round quartz grains (<1.0mm) with minor lithic fragments.

Sample SR2705-S1B (BTK1B): Typical Vault Brickwork Mortar

This sample contained three mortar fragments along with a small quantity of fines. The larger fragments were well compacted and ranged from moderately hard to hard, requiring persistent firm finger pressure to break. The mortar in all fragments were noted to contain lime inclusions distributed throughout, with the inclusions being angular to sub-round in shape, measuring up to 3.6mm in size.

Plates No. 3 & 4: The left plate shows the three pieces in the sample received. These all displayed one face that was heavily soiled, with the soiling locally encapsulated with a coating of redeposited calcite. The right plate shows a freshly fractured surface through the thickness of the larger intact fragment, note the presence of an abundance of lime inclusions, with dark slag fragments and red brick fragments distributed throughout the mortar.

On testing freshly fractured surfaces with a phenolphthalein indicator solution, the mortar fragments tested were found to be carbonated throughout their thickness. Water droplets placed onto the outer soiled surfaces were supported for a period prior to being slowly absorbed, whereas, those applied to fractured surfaces were rapidly absorbed and diffused throughout the fabric of the mortar, to depth, indicating a well-connected pore structure within the mortar.

There was no evidence of air entrainment in the sample although small sub-round to elongated entrapped air voids were apparent, with the entrapped air voids measured up to 1.7mm in size. A number of the voids contained needle-like crystals (possibly sulphate minerals) along with a patchy calcite coating, which would infer water had percolated, through the mortar, had occurred over time.

The aggregates are sub-angular to sub-round in shape and are dominated by slag/ash clinker and coal fragments along with a low proportion of fine quartz and other lithic fragments. The natural sand grains are mostly finer than 0.4mm in size, with the coarser particles composed essentially of waste material, most likely from the Iron processing at the site, with these including coal, slag and ash clinker, with minor weathered brick fragments.

Sample SR2705-S2 (BTK2): Rear Retaining Wall, Masonry Mortar

This sample consisted of a one large and two small fragments of a well compacted, dense lime mortar.

The mortar fragments were very well compacted, hard to very hard, with a dense fabric. The fragment resisted breakage under persistent firm finger pressure, and it was necessary to use a hammer and chisel to break the pieces of mortar to permit examination of their internal fabric.

On testing freshly fractured surfaces with a phenolphthalein indicator the mortar was found to be fully carbonated, albeit some of the slag particles showed initially as pink, but this cleared quickly indicating that they probably had acted as pozzolans, reacting with lime binder. The pink colour indicating a retained weak patchy alkalinity.

Plates No. 5 & 6: The left plate shows the three intact pieces of mortar in the sample, as received. The right plate shows a close-up of a freshly fractured surface, where the dense condition of the fabric can be seen. Note the abundance of small white lime inclusions, randomly distributed throughout. The lower piece is discoloured where it had been tested with the phenolphthalein indicator solution, with no colour observed in the paste, suggesting that the mortar was fully carbonated.

From the water droplet test it was indicated, by placing droplets onto the outer surfaces, that the droplets were supported for an extended period, thereby confirming surface pore blocking in response to soiling and pore blocking due to the presence of redeposited calcite. Whereas, when droplets were placed onto freshly fractured surfaces, these were quickly absorbed, again confirming the presence of a well-connected pore structure within the thickness of the mortar.

The aggregates are angular to sub-round and locally flaky in shape and are dominated by dark minerals, possibly ore, coal and slag materials, with a very low proportion of quartz and indeterminate lithic fragments also apparent.

The natural aggregates particles had a maximum size of 6mm but were mostly finer than 0.2mm. The coarser aggregates are very similar to those observed in sample SR2705-S1B (BTK1B) are considered to be from the spoil heap at the iron kilns.

Sample SR2705-S3 (BTK3): Front Wall/Facing, Masonry Mortar

This sample consisted of four fragments of mortar and a small quantity of fines.

The mortar fragment were all well compacted, and most were very hard, although one of the fragments was weaker and moderately hard, and this piece could be broken under firm finger pressure, whereas the others required a hammer impact to break and disrupt.

Plates No. 7 & 8: The left plate shows the intact pieces of mortar in the sample received. With the right plate showing a close-up of a fractured surface, through the largest intact piece, where the dense condition of the fabric is seen, along with an abundant of lime inclusions. The lower fragment is shown after testing with a phenolphthalein indicator, note pink colour.

The above right image shows that on testing a freshly fractured surface with a phenolphthalein indicator solution, the mortar was found to be only partially carbonated, with the carbonation being invasive from the outer surfaces whilst within the centre of the largest fragment it was noted to be patchy. This may infer that the mortar was maintained in a damp condition over most of its service life, the presence of a prolonged high moisture content inhibiting carbonation.

It was noted from the water droplet test that droplets placed onto the outer surfaces were supported for an extended period, whereas those applied to sawn and fractured surfaces were quickly absorbed. This indicated that the mortar had a well connected pore structure and that water vapour could migrate through the mortar, with the low porosity demonstrated by the outer surfaces being due to the sealing of the outer, soiled, surfaces with redeposited calcite, again inferring that the masonry had been affected by water percolation over time.

On examination of the fractured surfaces an abundance of white lime inclusions were observed, with these measuring up to 5.8mm in size. The inclusions are angular to sub-round in shape and have the appearance of being formed from quicklime.

The aggregates are angular to sub-round and locally flaky in shape and are dominated by dark minerals and are considered to be ore or slag materials from the waste material reportedly present in the vicinity of the kilns. A low proportion of quartz and indeterminate lithic fragments also apparent and the mortar appears similar to the earlier sample examined. The aggregates had a maximum size of 6.5mm but were mostly finer than 0.2mm and are similar in appearance to those in samples SR2705-S1B (BTK1B) and SR2705-S2 (BTK2) and are again considered to be waste material from the Iron Kilns.

Results of XRD Analysis for Binder Type

To help clarify the mineral and crystalline components present in the mortars a representative sub-sample was obtained from each mortar sample, with these crushed and lightly ground in an agate mortar and pestle. During grinding care was taken to minimise the crushing of aggregate particles, as if present in abundance, in the analysis sample, they could mask any hydraulic components present, which may only be present in trace proportions. The powdered materials were sieved over a 63µm sieve to remove the aggregate component and permit a binder rick sub-sample to be obtained for analysis.

The prepared powdered samples were back-packed into proprietary sample holders for presentation in the diffractometer, with this technique employed to ensure, as close as possible, the true random orientation of the components present.

All samples were analysed in a Diffractometer which was fitted with a single crystal monochromator, set to run over the range 3° to 60° 2θ in steps of 0.1° 2θ at a rate of 1° 2θ/minute using CuKα radiation. With the digital output analysed by a computer program, which matched the peak positions against the JCPDS International Standard Mineral Data-base sub files using a search window of 0.1°.

The results obtained from the analysis are presented in the following attached Figures, in the form of labelled X-ray Diffractograms:

Figure No. 5: SR2705-S1A (BTK1A) Mortar Typical Vault Stonework, Bank Top Kilns,

Figure No. 6: SR2705-S1B (BTK1B) Mortar Typical Vault Brickwork, Bank Top Kilns,

Figure No. 7: SR2705-S2 (BTK2) Mortar ex Rear Retaining Wall, Bank Top Kilns,

Figure No. 8: SR2705-S3 (BTK3) Mortar ex Front Wall/Facing, Bank Top Kilns.

The abbreviations used on the charts, to identify peak positions, are as follows:

- **cc** = Calcite ($CaCO_3$) Calcium Carbonate, carbonated lime from lime binder and any limestone aggregate present in the mortar,
- **ar** = Aragonite ($CaCO_3$) another crystalline form of Calcium Carbonate, from limestone, commonly associated with shell and found in some forms of redeposited leached lime binder,
- **po** = Portlandite (Ca(OH)2) Calcium Hydroxide, hydrated lime, component of the binder,
- **br** = Brucite ($Mg(OH)_2$) Magnesium Hydroxide, hydrated calcined dolomitic/magnesian limestone,
- **qz** = Quartz (SiO_2) Silicon Oxide, a dominant component of the aggregate in some of the mortars,
- **he** = Hematite (Fe_2O_3) Iron oxide, from the iron ore and slag in the aggregate,
- **go** = Goethite (FeO(OH)) Iron Oxide Hydroxide, hydrated iron oxide, corrosion product (rust) present as a component of the slag, in the aggregate,
- **be** = Belite (C_2SiO_4) *di*-Calcium Silicate, clinker component and occasionally found in iron slags,
- **hy** = Hydrocalumite ($Ca_2Al(OH)_6Cl_2H_2O$) Calcium Aluminium Chloride Hydroxide Hydrate, hydration product, also known as Friedel's Salt, from hydration of clinker and in some pozzolanic reactions,
- **na** = Nacrite ($Al_2Si_2O_5(OH)_4$) Aluminium Silicate Hydroxide, pozzolanic reaction product and also a possible component of the slag/ash present in the aggregate,
- **ett** = Ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12}26H_2O$) Calcium Aluminium Sulphate Hydroxide Hydrate, hydration product in Portland Cements and some Hydraulic limes, also sulphate reaction product,
- **fs** = Feldspar, with Anorthite and Albite of the Plagioclase group of feldspar, both detected in the samples analysed, present as aggregate components,
- **ill** = Illite, clay mineral from the alteration of mica and alkali feldspars, present as an aggregate or weathering component.

The data from the XRD analysis was further processed by Rietveld Refinement, using the MAUD computer program. This to permit quantification of the components present and help in assessing the form of binder formed from any hydraulic or pozzolanic reactions that may have occurred.

The following results were obtained:

Component	**Proportion (% by Mass)**			
Sample:	**SR2705-S1A BTK1A**	**SR2705-S1B BTK1B**	**SR2705-S2 BTK2**	**SR2705-S3 BTK3**
Calcite	73.0	60.2	50.8	56.8
Aragonite	8.4	4.8		17.1
Portlandite				0.4
Brucite		11.5		
Quartz	15.7	12.2	28.3	16.3
Hematite	1.5	5.1	14.3	4.9
Goethite	0.8	1.6	3.2	
Belite (C_2S)			0.6	
Hydrocalumite	0.4	1.8	1.4	1.2
Nacrite				2.1
Ettringite		2.6		0.2
Feldspar (Anorthite)	0.2	0.2		
Feldspar (Albite)			0.4	
Illite (Clay)			1.0	
Total	**100.0**	**100.0**	**100.0**	**100.0**

From the XRD analysis, it is indicated that the mortars samples received are representative of at least two, or possibly three, variants. With the mortar in sample SR2705-S1A (BTK1A) being either a very feebly hydraulic lime, or, most likely, a high Calcium air lime (Non-Hydraulic), with contamination from the slags present in the other samples, with the proportion present being very low in comparison to the other samples analysed.

Whilst sample SR2705-S1B (BTK1) is again a high calcium lime mortar, there is an abundance of components present that would infer that the aggregates used in the mortar included slag or other waste from the Iron works, with these likely to be pozzolanic, to a degree. As in sample S1A (BTH1A) there is Aragonite present, which may suggest that a proportion of shell was present within the limestone burnt in the production of the lime (with the aragonite detected from unburnt limestone particles) or alternatively, the mortar having been subjected to a high degree of leaching with the redeposited lime, in part in the form of Aragonite.

However, sample (S1B – BTK1B) also differs from the other three samples analysed, in that it contained Brucite (Magnesium Hydroxide) which, if originating from the binder, would infer that a proportion of Dolomitic or Magnesian Limestone had been included in the feedstock of the Lime kiln. Though, in the absence of any evidence of Dolomitic or Magnesian lime in any of the other samples, from this structure, it is perhaps likely that the Dolomitic limestone was present in the waste from the Iron processing kilns, where it was calcined, and was included in the aggregate as a hydrated component.

The mortar in sample SR2705-S2 (BTK2) again appears to have been made from a high calcium lime, mixed with a slag/ash waste aggregate, won from the waste material from the Iron kilns. With a proportion of the waste having acted as a pozzolan in the mortar mix, with this reaction imparting the strength to the mortar apparent in the hand specimen.

Sample SR2705-S3 (BTK3) is again similar to that in sample S2 (BTH2) albeit there are additional slag minerals present, which is likely to highlight that the variation in the composition of the waste material, which would be as would be expected, given the period that work was carried out.

The presence of a trace proportion of Portlandite would additionally suggest that the binder in this sample is not fully carbonated, although from the earlier examination this is limited to the interior of the mortar fragments, and perhaps to individual inclusions.

The Ettringite detected in samples S1B (BTK1A) and S3 (BTK3) would suggest that either the aggregates contained sulphate minerals, not uncommon in Iron slags, or the lime binder had been affected by sulphate carrying groundwaters, or both. With the possibility that some of the ettringite may also by a hydration or pozzolanic product. This may be clarified during the microscopic examination.

Mix Composition

The results of the composition analysis, determined by acid digestion, on the samples received, are presented below:

Sample Ref. No.	**SR 2705–S1A (BTK1A)**		**SR2705-S1B (BTK1B)**	
Mortar type (from XRD)	Non-Hydraulic Lime			
Binder/Aggregate Ratio	1.0 : 2.9		1.0 : 0.9	
Binder form:	Quicklime	Hydrate	Quicklime	Hydrate
Weight proportions calculated mix ratio by dry mass.				
Lime	1.0	1.0	1.0	1.0
Aggregate	5.2	3.8	1.6	1.8
Approximate volume Proportions calculated on the basis of a Non-Hydraulic lime				
Lime	1.0	1.0	1.0	1.0
Aggregate	1.5	1.5	0.5	0.5

Sample Reference	**SR2705– S1A (BTK1A) Masonry Mortar**		**SR2705– S1B (BTK1B) Masonry Mortar**	
British Standard Sieve Size	**Percentage Retained**	**Percentage Passing**	**Percentage Retained**	**Percentage Passing**
8.00mm	0	100	0	100
4.00mm	2.7	97.3	20.1	79.9
2.00mm	2.8	94.5	24.3	55.6
1.00mm	2.7	91.8	8.9	46.7
0.500mm	22.4	69.4	10.2	36.5
0.250mm	56.4	13.0	9.9	26.6
0.125mm	8.2	4.8	10.0	16.6
0.063mm	2.0	2.8	6.4	10.2
Passing	2.8		10.2	

Table No. 1: Results of the grading on recovered aggregate.

Sample Ref. No.	**SR 2705–S2 (BTK2)**		**SR2705-S3 (BTK3)**	
Mortar type (from XRD)	Non-Hydraulic Lime			
Binder/Aggregate Ratio	1.0 : 1.3		1.0 : 1.0	
Binder form:	Quicklime	Hydrate	Quicklime	Hydrate
Weight proportions calculated mix ratio by dry mass.				
Lime	1.0	1.0	1.0	1.0
Aggregate	2.2	1.6	1.8	1.3
Approximate volume Proportions calculated on the basis of a Non-Hydraulic lime				
Lime	1.0	1.0	1.0	1.0
Aggregate	0.65	0.65	0.5	0.5

Sample Reference	**SR2705– S2 (BTK2) Masonry Mortar**		**SR2705– S3 (BTK3) Masonry Mortar**	
British Standard Sieve Size	**Percentage Retained**	**Percentage Passing**	**Percentage Retained**	**Percentage Passing**
8.00mm	0	100	0	100
4.00mm	26.2	73.8	14.2	85.8
2.00mm	11.7	62.1	15.5	70.3
1.00mm	10.7	51.4	8.9	61.4
0.500mm	14.5	36.9	9.0	52.4
0.250mm	14.2	22.7	14.5	37.9
0.125mm	10.9	11.8	21.7	16.2
0.063mm	6.4	5.4	6.4	9.8
Passing	5.4		9.8	

Table No. 2: Results of the grading on recovered aggregate.

The aggregates from the acid digestions were recovered and the particle size distribution determined, with the results obtained presented in tables No. 1 and 2, above. With the gradings displayed in the form of aggregate filled histograms in the appended Figures No. 1, 2, 3 and 4, at the end of this report.

The natural aggregates in the mortar are dominated by quartz grains with sandstone, silt and shale fragments also present, along with minor limestone and indeterminate lithic fragments.

However, samples SR2705-S1B (BTK1B), S2 (BTK2) and S3 (BTK3) all contain a high proportion of bank slag/waste material from the Iron processing, along with a proportion of coal ash and unburnt coal fragments.

All mixes are indicated, from the acid digestion, to be binder rich, particularly samples SR2705-S1B (BTK1B), S2 (BTK2) and S3 (BTK3), which given the high abundance of lime inclusions apparent in the mortars, in hand specimen, is as would be expected. Therefore, the results of this analysis, on their own, should not be taken as the basis of mix designs for use in any proposed restoration/conservation works, but can be used, along with knowledge of the structure, and its environment, to guide the selection of materials to be used in conservation/restoration mortars.

Microscopic Examination

To clarify the form in which the binder was used, in the samples, and to permit comparison of the binder and fabric between all samples, a petrographic thin section was prepared from each for examination in the polarised light microscope.

To achieve this a slice was sawn from the largest intact piece in each sample of the mortar, with these dried and impregnated with a blue dyed resin in preparation for manufacturing thin sections.

Observations from the examination of the thin sections are presented below:

Sample SR2705-S1A (BTK1A): Mortar from Typical Vault Stonework

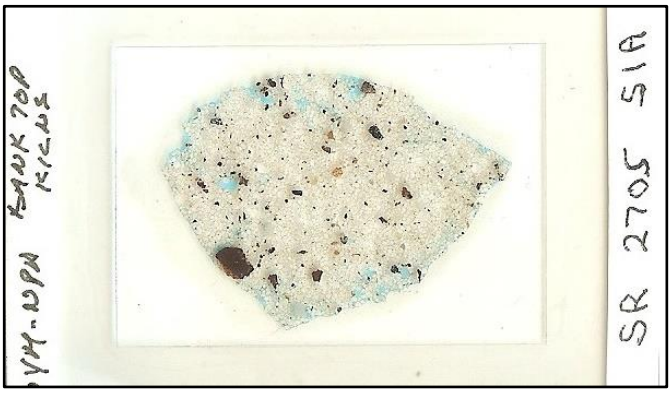

Plate No. 9:

Thin section prepared from mortar sample SR2705-S1A (BTK1A).

Although it can be seen that this sample contains some dark aggregates, these are relatively few in comparison with the other samples from the kilns.

Aggregate

The aggregates in the mortar sample are dominated by quartz grains with minor sandstone and siltstone, along with trace proportions of limestone and weathered lithic fragments. In addition, there are opaque minerals present, which are composed of a mixture of coal and ironstone fragments.

The coal fragments appear fresh with no evidence of them having been burnt and it is most likely that the coal is a component of the aggregate and not a contaminant from the lime kiln, added to the mortar with the lime.

The aggregates are sub-angular to sub-round in shape, and all show evidence of water worn surfaces. The aggregates are similar in appearance to those observed in lime mortars samples submitted from other structures sampled as part of this programme, and therefore may be from a source local to the kilns.

The natural aggregates range in size from <0.01mm to 1.2mm (very fine silt/clay to coarse sand) in the section examined, with coal fragments up to 3.4mm in size. The presence of the clay or fine silt materials observed within the sample would infer that aggregate was probably used in the as-dug condition, rather than having been washed and processed.

Binder

The binder is a non-hydraulic lime, with the presence, and abundance, of lime inclusions observed suggesting that the mortar had been mixed as a hot mixed mortar (HMM).

The paste is fully carbonated with the lime inclusions observed being mostly round to sub-round, and occasionally angular, in shape, with a low proportion of the inclusions also showing features consistent with the presence of partially slaked quicklime within the mix at the time of placing.

The inclusions range in size from 0.2mm to 1.4mm and it is inferred from the examination of these and the encapsulating fabric that the quicklime was slaked to a hydrate, with the sand but perhaps not screened, prior to the dried material being re-mixed prior to placing as a cold mortar.

Voids and microcracks

The voids observed are irregular and, locally elongated in shape, and are considered to be placing artefacts. The voids range in size and shape, from 0.12mm to 2.4mm, with the larger voids being irregular in shape, and formed in response to entrapped air. Most of the voids are free of coating and infillings, with a minor occurrence of patchy fine Calcite crystals observed lining some of the surface connected voids, suggestive of water percolation through the voids.

Cracks are rare and where observed take the form of random drying shrinkage features. The cracks are variable in length ranging from <0.4mm to 3.7mm, and typically <0.02mm in width. Cracks are free of secondary mineral deposits.

The results of a point count (modal) analysis carried out on this sample are presented in the following table:

Sample Ref:	**SR2705-S1A (BTK1A)**	
Constituents	**%**	
Aggregate	**Inclusions as binder**	**Inclusions as Aggregate**
Quartz	44.5	44.5
Lithic grains	2.2	2.2
Limestone	0.7	0.7
Sandstone/Siltstone/clay	0.6	0.6
Ironstone	0.6	0.6
Opaque	3.2	3.2
Lime inclusions	-	8.9
Total Aggregate	**51.8**	**60.7**
Binder (Lime)	39.2	39.2
Clinker	0	-
Lime inclusions	8.9	-
Secondary products/Calcite and gypsum	0.1	0.1
Total Binder	**48.2**	**39.3**
Total Constituents	**100.0**	**100.0**
Cracks/Voids	**7.0**	**7.0**
	Total	**Effective**
Binder: Aggregate Ratio	**1.0 : 1.1**	**1.0 : 1.55**

Table No. 3: Result of modal analysis (600-point count) on thin section from BTK1A.

Photomicrographs:

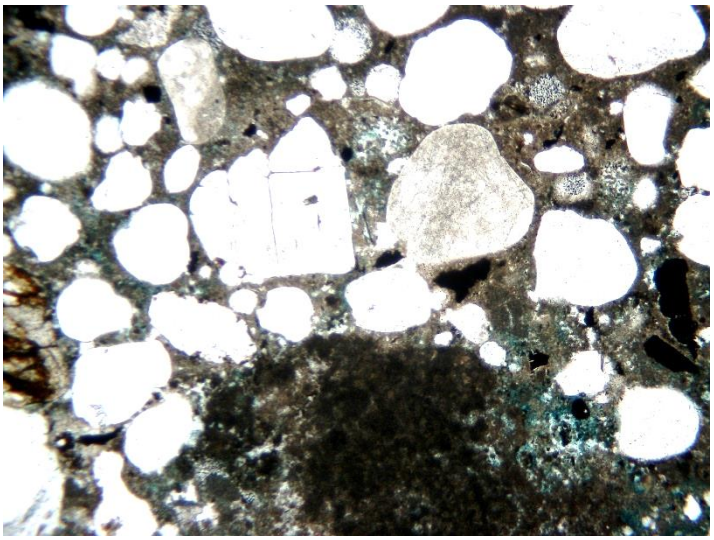

Plate No. 10:

A view in plane polarised light (ppl) showing a typical area of the mortar, with a partially hydrated inclusion seen in the lower centre of the plate. The paste is dense and fully carbonated, with no evidence of hydraulic clinker observed within the section. The aggregates are dominated by quartz, white and grey in this view, with minor lithic grains. The opaque particles (black in image) are coal with the localised clusters of fine material being ash particles.

Porosity is highlighted by the blue dyed resin. Field of view 2.4mm.

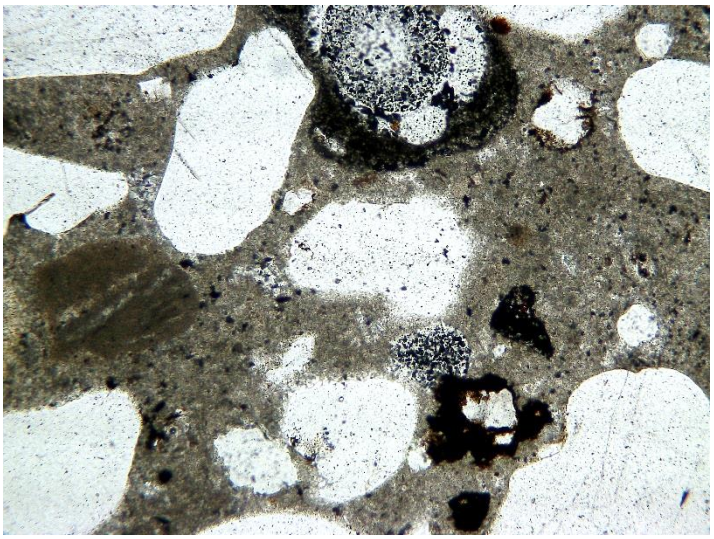

Plate No. 11:

A magnified view in ppl, of an area of paste where two inclusions can be seen, centre left and upper centre. That in the top part of the plate is heavily depleted, with that in the left being sub-angular in shape and retaining an imprint of the relic rock fabric. The paste is dense and fully carbonated, with localised evidence of leaching, with minor fringes of redeposited fine calcite observed lining the perimeter of voids, see void in the centre and lower centre. Aggregates in view are mostly quartz, with minor lithic grains and opaque minerals.

Porosity and voids are highlighted by the blue dyed resin. Field of view 1.2mm.

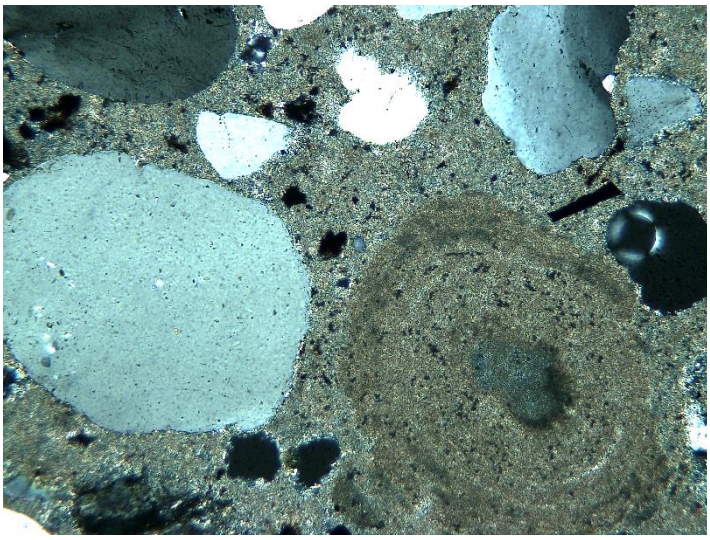

Plate No. 12:

A view in cross polarised light (xpl), of an area of dense fully carbonated paste. A rounded lime inclusion can be seen in the lower right, Aggregates in view consist of quartz grains, with minor opaque minerals.

Small irregular shaped voids (black in view) can be seen distributed across the section, these are commonly rimmed with fine calcite crystals.

The impregnating resin, porosity and voids all show dark in xpl. Field of view 1.2mm.

Sample SR2705-S1B (BTK1B): Mortar from Typical Vault Brickwork

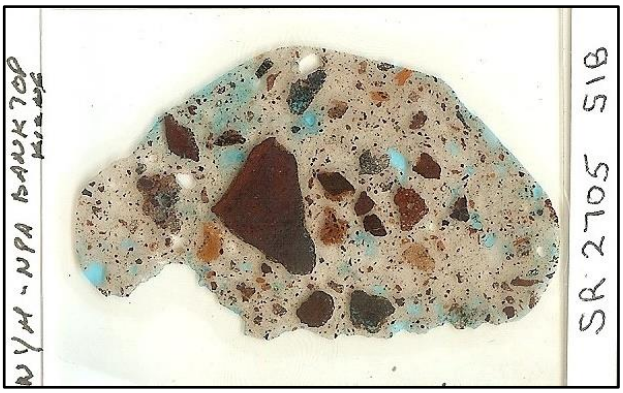

Plate No. 13:

Thin section was prepared from the intact piece of mortar in sample SR2705-S1B (BTK1B).

This sample contains a high proportion of slag minerals, coal fragments along with fine ash particles.

This mortar sample differs totally from the mortar in sample S1A (BTK1A), in that the particles observed are dominated by opaque minerals which were observed to be composed of coal, ash clinker (partially burnt coal), ironstone with small weathered brick fragments.

Aggregate

The aggregates contain only minor proportions of natural aggregate in the form of fine quartz grains, limestone fragments and weathered lithic grains, along with a high proportion of processed material. It is, therefore, considered that most, if not all, of the aggregates used in this mortar have been won from the waste reported to exist adjacent to the Iron kilns. The natural sand minerals perhaps present in the waste as natural contaminants of the rock being worked and/or as weathering/soiling materials.

The processed material was observed in the thin section mostly in the form of opaque particles, with these dominated by coal fragments which contained a significant proportion partially burnt coal, along with coal ash, slag and brick fragments.

The presence of the slag and ash will have resulted in the mix having a high pozzolan content. With this reacting with the lime binder imparting the strength noted the mortar received. The brick fragments are too large to have been added as a pozzolan and are most likely contaminants in the waste from the kiln lining, or as waste materials from the construction.

The aggregates are angular to sub-angular and locally irregular in shape.

The maximum size of the aggregate is 15mm (coal), 2.4mm (slag), 2.6mm (ash clinker) and 1.2mm (brick) with the quartz and other rock particles mostly finer than 0.25mm in the section examined. There is also high proportion of small opaque fragments, comprising of crushed waste material, and it is this that is likely to have acted as a pozzolan in the mortar.

Binder

The paste in this sample is generally dense, though locally patchy, with evidence of leaching of lime from inclusions and paste. A proportion of the lime inclusions present have formed from incompletely slaked non-hydraulic quicklime, with both a low abundance of over and under burnt limestone fragments also observed. This presence of slaked and incompletely slaked, but incompletely mixed inclusions would infer that the mortar had been mixed as a Hot Mixed Mortar (HMM), though not necessarily placed whilst hot.

The lime inclusions are all from calcium limestone, with no evidence to suggest the presence of Dolomitic or Magnesian limestone having been incorporated in the kiln feedstock. The inclusions are mostly angular to sub-angular in shape, with both fully slaked and partially slaked inclusions retaining a clear outer boundary, where the lime has not diffused into the surrounding paste, with the inclusions thereby acting as aggregates in the mix, rather than binder.

The presence of ash and burnt ironstone fragments/slag in the mortar, along with rare coal clinker grains, would account for the hardness of the mortar in the sample received. With the presence of reaction rims around fine opaque grains being indicative of hydration products apparent within the paste, with these in sufficient abundance to confirm that a pozzolanic reaction had occurred.

Voids and microcracks

Voids are abundant and range from 0.15mm to 2.6mm in size, with the larger voids being irregular to angular in shape, whilst those <0.4mm in size being spherical to sub-round in shape. The voids have formed from the dissolution of lime inclusions are commonly lined with coarse calcite crystals, and locally sulphate minerals, whereas most of the smaller entrapped air voids are generally free of coatings. This would indicate that water had percolated through the mortar over time, slowly depleting unmixed but slaked lime inclusions.

Cracks are abundant, randomly distributed, and are typical of drying shrinkage cracks. Mostly are fine, typically 0.01mm to 0.04in width, with rare wider cracks. The latter commonly connected to depleted lime inclusions. The fine cracks are free of any secondary minerals, with the wider cracks, appear to have acted as water percolation pathways are lined with redeposited calcite, with patchy ettringite also present.

The results of a point count (modal) analysis is presented in the following table:

Sample Ref:	**SR2705-S1B (BTK1B)**	
Constituents	**%**	
Aggregate	**Inclusions as binder**	**Inclusions as Aggregate**
Quartz	0.3	0.3
Lithic	0.4	0.4
Brick	2.5	2.5
Slag	3.7	3.7
Opaque (Coal, Ash, Ironstone)	37.4	37.4
Lime inclusions	-	9.1
Total Aggregate	**44.3**	**53.4**
Binder (Lime)	44.8	44.8
Clinker	0.3	-
Lime inclusions	8.8	-
Secondary products/Calcite and gypsum	1.8	1.8
Total Binder	**55.7**	**46.6**
Total Constituents	**100.0**	**100.0**
Cracks/Voids	**6.3**	**6.3**
	Total	**Effective**
Binder: Aggregate Ratio	**1.0 : 0.8**	**1.0 : 1.15**

Table No. 4: Result of modal analysis (600-point count) on thin section BTK1B

Photomicrographs:

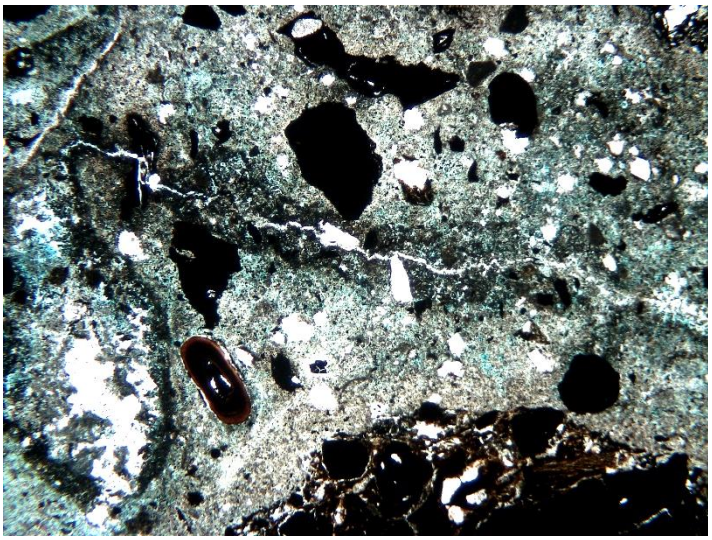

Plate No. 14:

A view in plane polarised light (ppl) of a typical area of the mortar. This shows the dense fabric with alteration of paste adjacent to crack paths, most marked across the centre of the plate. The aggregates in view are a combination of coal, ironstone and slag, with an abundance of ash particles in the upper right and left of centre. Minor quartz grains (white in plate) are also apparent. A partially depleted lime inclusion can be seen in the lower left side of the plate. Cracks are typical of shrinkage cracks, with evidence of water migration along the centre crack.

Porosity is highlighted by the blue dyed resin. Field of view 2.4mm.

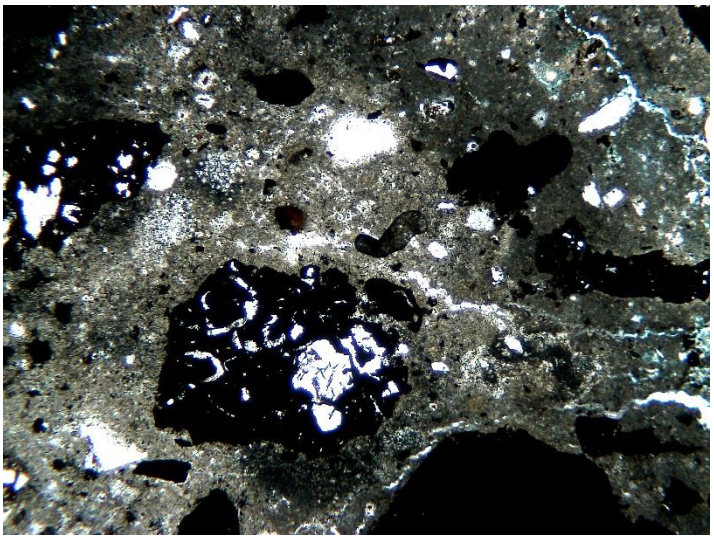

Plate No. 15:

A magnified view in ppl of an ash and slag rich area of fabric. An ironstone fragment can be seen in the lower centre. The paste is dense throughout, with patchy microporosity apparent, and is transected by a number of fine shrinkage cracks. Ash and fine slag particles show evidence of having reacted with the paste, most noticeable, upper left and upper and lower centre in plate. The cracks in view are mostly free of secondary minerals, although small voids are rimmed with redeposited coarse calcite. Porosity and voids are highlighted by the blue dyed resin. Field of view 1.2mm.

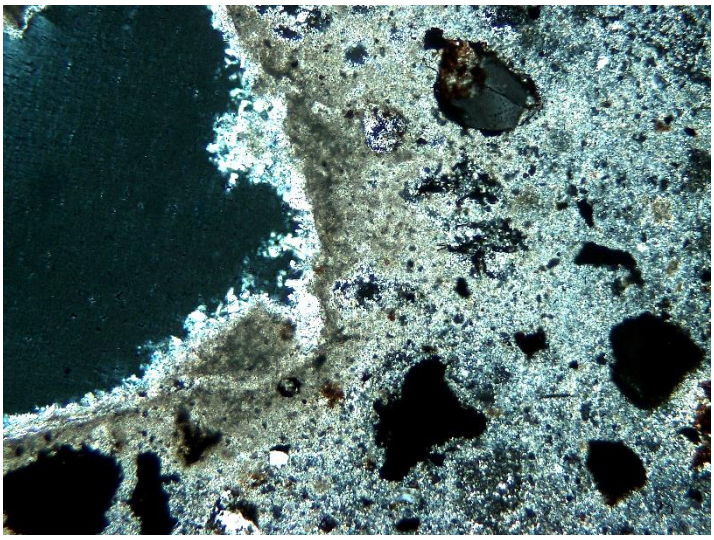

Plate No. 16:

A view in Cross Polarised Light (xpl), of an area of dense paste adjacent to a depleted angular lime inclusion socket, left side of plate. The perimeter of the lime inclusion is highlighted by a layer of coarse calcite crystals, with minor sulphate minerals also present. The paste adjacent to the socket void is very dense and there is evidence of late slaking and expansion of the lime inclusion, post placing, i.e. a mixed and placed as an HMM.
The paste is dense and contains an abundance of fine ash and slag particles. Porosity, the blue impregnating resin and opaque minerals all appear black in xpl. Field of view 1.2mm.

Sample SR2705-S2 (BTK2): Mortar from Rear Retaining Wall

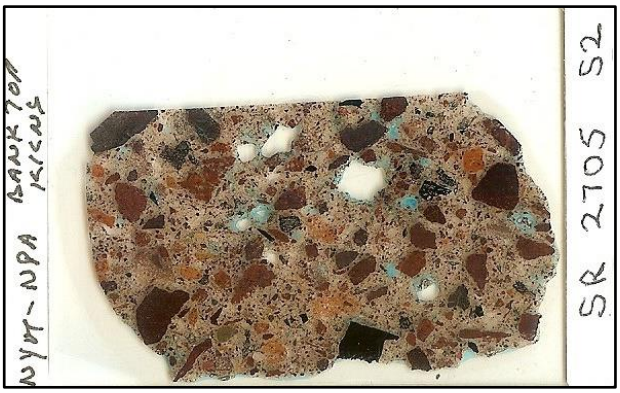

Plate No. 17:

This thin section was prepared from an intact piece of mortar from sample SR2705-S2 (BTK2).

The aggregates in this sample are dominated by slag and ash, with coal fragments, similar to sample S1A (BTK1B), but with more fine ash.

This sample had the appearance of a well compacted mortar, with a dense the fabric, having a relatively uniform appearance throughout its thickness.

Aggregate

The aggregates in this mortar are similar to those in sample S1B (BTK1B) with the aggregates dominated by coal, coal clinker and coal ash with minor slag and ironstone fragments, although there is more of the fine ash in this sample. In addition, there are several particles of Oolitic limestone present, all of which are overburnt, and may have been included in the mix with the aggregate rather than the binder. It is, therefore, considered that the mortar sampled was from a mix which again used the waste from the Iron Kilns as the sole source of aggregate.

As in sample BTK1B, the presence of the slag and ash will be the source of pozzolanic material which would account for the hardness and strength apparent in the hand specimen.

The aggregates are dominated by angular to sub-angular and locally irregular shaped particles and the maximum size of the aggregate is 8.0mm but mostly finer than 2mm down to <0.02mm (medium silt to very coarse sand). The presence of an abundance of silt sized grains observed is consistent with aggregates being dominated by ash and crushed, or ground, coal clinker and slag.

Most of the coarse ash clinker and slag particles are relatively fresh with only minor evidence of alteration. Whereas, there are an abundance of reaction rims around fine ash and slag particles, along with pseudo-morph grains also apparent. This, thereby indicating that a pozzolanic reaction had occurred between the fine ash and slag material and the lime paste.

Binder

The paste in this sample is patchy, ranging from localised zones that are particularly dense with these most apparent adjacent to lime inclusions, suggesting that the mix had been mixed and placed as a Hot Mixed Mortar (HMM), and still expanding. Outwith these zones the paste is microporous and adjacent to crack paths, is locally depleted. Although most of the inclusions observed in the section are fully slaked, there is a significant proportion where the lime in the inclusion had not diffused into the paste, and these have therefore performed as aggregates in the mortar. From an examination of the lime inclusions, some of which retained a faint imprint of the original rock fabric, it is indicated that the source of the lime was a calcium limestone, displaying micritic and bioclastic forms. No Dolomitic limestone was detected in the sample examined.

The lime inclusions are mostly sub-round to sub-angular in shape, and although most are fully slaked there are a number of inclusions that retain a clear outer boundary and do not diffuse into the surrounding paste, thereby acting as aggregates in the mix and will have contributed nothing to the binder in the mix.

The presence of slag, ash and burnt ironstone fragments in the mortar would account for the hardness of the sample received, with hydration/pozzolanic reaction products apparent within the paste, confirming that pozzolanic reactions had occurred.

Voids and microcracks

Voids range in size from 5.2mm to <0.2mm, and are predominantly sub-round in shape, with minor sub-angular voids. The sub-rounded voids had formed from the dissolution of lime inclusions along with a low abundance having formed from entrapped air at the time of placing. A number of the voids, particularly those formed due to depletion, are lined to locally infilled with secondary minerals, with both calcite and ettringite observed.

Cracks are rare in the sample examined, and are very fine to fine, typically 0.006mm to 0.04 in width, random in occurrence and orientation and are drying shrinkage cracks. A few of the wider cracks have acted as water percolation channel ways with these typically 0.04mm in width, some of which display a patchy infilling of secondary minerals, including calcite and sulphate minerals.

The results of a point count (modal) analysis are presented in the following table:

Sample Ref:	**SR2705-S2 (BTK2)**	
Constituents	**%**	
Aggregate	**Inclusions as binder**	**Inclusions as Aggregate**
Quartz	1.9	1.9
Limestone	0.8	0.8
Lithic	0.2	0.2
Brick	1.3	1.3
Slag	2.6	2.6
Opaque (Coal, Ash, Ironstone)	33.6	33.6
Lime inclusions	-	10.5
Total Aggregate	**40.4**	**50.9**
Binder (Lime)	48.2	48.2
Clinker	0	-
Lime inclusions	10.5	-
Secondary products/Calcite and gypsum	0.9	0.9
Total Binder	**59.6**	**49.1**
Total Constituents	**100.0**	**100.0**
Cracks/Voids	**16.6**	**16.6**
	Total	**Effective**
Binder: Aggregate Ratio	**1.0 : 0.65**	**1.0 : 1.0**

Table No. 5: Result of modal analysis (600-point count) on thin section from BTK2

Photomicrographs:

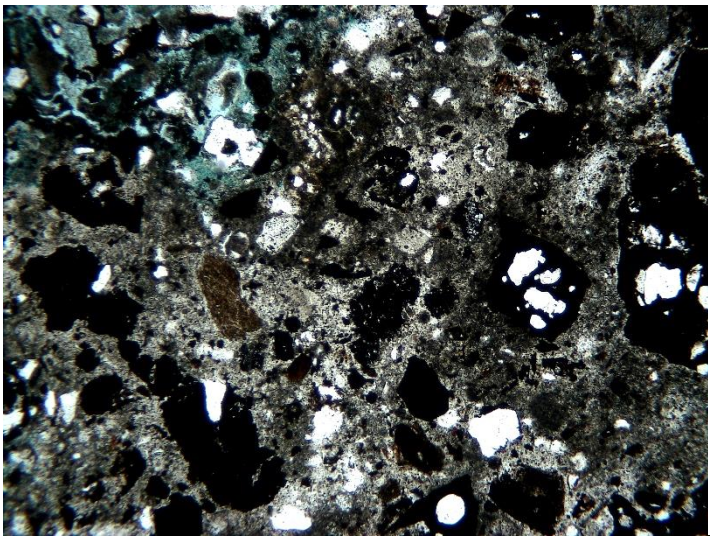

Plate No. 18:

A view in plane polarised light (ppl) showing a well compacted area of the mortar. The paste is relatively dense and fully carbonated . Minor quartz and lithic particles are present although the aggregates are dominated by opaque particles (Coal, Ironstone, Ash clinker), with reaction rims apparent around ash clusters and slag particles, confirming a pozzolanic type reaction with the paste.

Very fine shrinkage cracks are apparent, upper left, lower centre.

Porosity is highlighted by the blue dyed resin. Field of view 2.4mm.

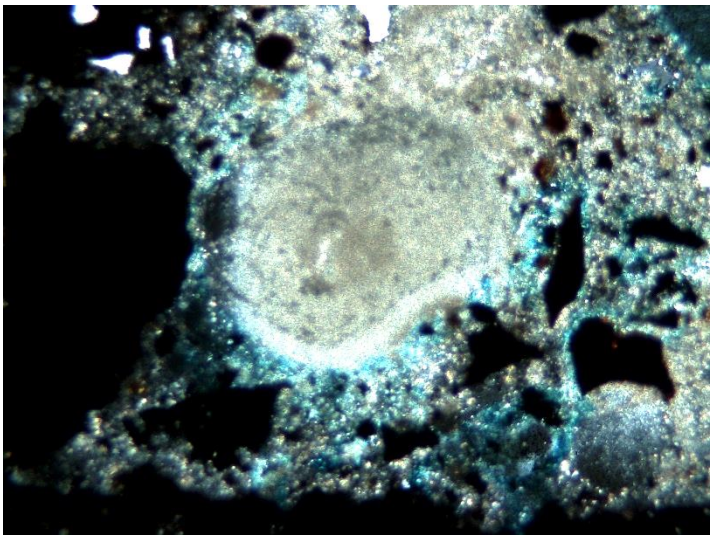

Plate No. 19:

A view in cross polarised light (xpl) of a partially depleted lime inclusion, which retains a fully hydrated lime core, centre of plate. The lower margin is infilled with redeposited coarse calcite crystals, with fine sulphate minerals distributed through the partially depleted part of the inclusion, upper right of centre. Aggregates are again mostly of opaque minerals, dominated by coal fragments, with minor ash and slag fines in the upper left and lower right of centre.
Porosity, the blue impregnating resin and opaque minerals all appear black in xpl. Field of view 2.4mm.

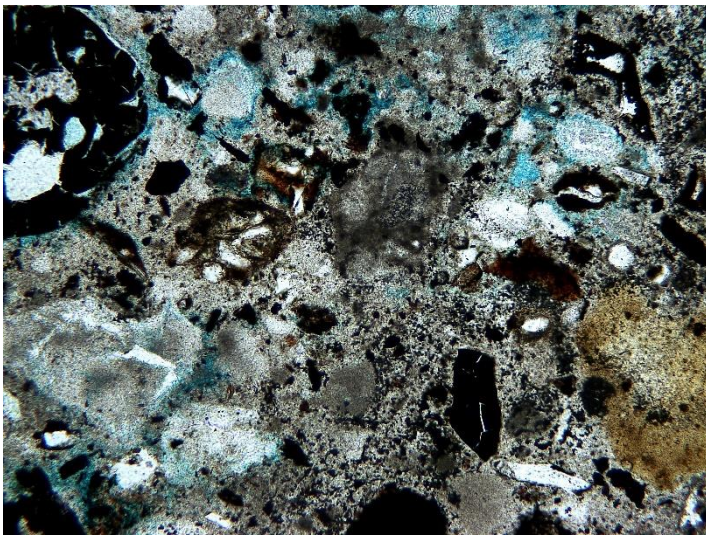

Plate No. 20:

Another view in xpl, of an area of the mortar, again showing a dense fully carbonated paste in which there is a range of aggregates apparent, along with small sub-angular and sub-rounded lime inclusions.
All inclusions show some partial depletion and are bounded by fine fringes of redeposited lime. The void in the lower left of centre is partially infilled with sulphate minerals. A large coal clinker fragment can be seen in the upper left corner
Porosity, the blue impregnating resin and opaque minerals all appear black in xpl. Field of view 1.2mm.

Sample SR2705-S3 (BTK3): Mortar from Front Wall/Facing

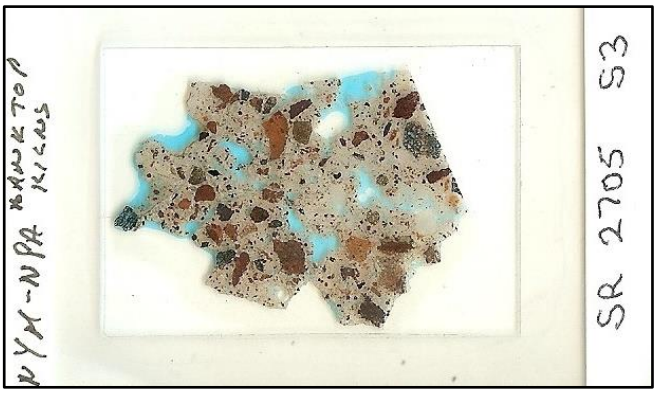

Plate No. 21:

This thin section was prepared from an intact piece of mortar from sample SR2705-S3 (BTK3).

This sample is again visually similar to the section made from samples S1B and S2 (BTK1B & BTK2).

This sample is very similar to the previous two samples and it is indicated visually to have been made from the same materials.

Aggregate

The aggregates are very similar to those in samples SR2705-S1B (BTK1B) and S2 (BTK2) in that it is composed mostly of coal, coal clinker, ash, slag and ironstone with a trace proportion of brick fragments and minor quartz grains. This sample contained a several fragments of overburnt Oolitic limestone, measuring up to 5.4mm in size.

As in the previous samples examined the presence of the slag and ash will have resulted in the mix having a high pozzolan content, with the source of this considered to be the waste or spoil heaps adjacent to the Iron kilns.

The aggregates are angular to sub-angular and locally irregular in shape. With the maximum size of being 6.7mm but mostly finer than 2mm down to <0.02mm (ranging from medium silt to very coarse sand and medium gravel) in the section examined. The presence of an abundance of silt sized grains observed is consistent with aggregates containing a significant proportion of ash and crushed, or ground, coal ash clinker and slag.

Binder

The paste in this sample is again dense with the presence of an abundance of inclusions suggesting that the mix had been mixed as a Hot Mixed Mortar (HMM). However, unlike sample SR2705-S2 (BTK2) there is a high proportion of partially burnt and partially slaked quicklime in this sample. With many of these acting as aggregates, with no diffusion of lime from the inclusion into the surrounding paste.

Again, this sample has the appearance of a binder rich mix and the paste is locally very dense, with depletion of binder restricted to the margins of cracks and water percolation pathways. Within the dense areas there are rare patches of partially carbonated paste, with a low proportion of the inclusions also retaining uncarbonated cores. This would suggest that the mortar sampled had been maintained in a damp condition over an extended period of time, with the saturated condition inhibiting full carbonation.

The condition of the fabric and the evidence of delayed expansion, with subsequent shrinkage would infer that this mortar had been both mixed and placed as a hot mixed mortar (HMM).

The presence of slag, ash and burnt ironstone fragments in the mortar would account for the hardness and strength of the sample received, with the evidence of the reactivity of the fine aggregate grains and presence of hydration products apparent within the paste, confirming that a pozzolanic reaction had occurred.

Voids and microcracks

Voids are present, and range up to 4.8mm in size, they also vary from irregular voids which are placing artefacts to smaller sharp featured angular and sub-rounded voids formed from the depletion of lime inclusions. All voids retain, at least in part, a lining of redeposited calcite.

Cracks are abundant in this sample and are mostly wider than 0.02mm and locally extend up to 0.16mm in width. A high proportion of the cracks link lime inclusions and skirt around coarse aggregate particles, with these having the appearance of plastic and early drying shrinkage features.

All of the wider cracks are lined with secondary minerals, including both coarse calcite crystals and fine needle shaped sulphate minerals. These, therefore, appear to have functioned as water percolation channel ways, with water having accessed them over an extended period of time.

The results of a point count (modal) analysis are presented in the following table:

Sample Ref:	**SR2705-S3 (BTK3)**	
Constituents	**%**	
Aggregate	**Inclusions as binder**	**Inclusions as Aggregate**
Quartz	1.5	1.5
Limestone	2.2	2.2
Lithic	0	0
Brick	1.5	1.5
Slag	2.9	2.9
Opaque (Coal, Ash, Ironstone)	26.8	26.8
Lime inclusions		16.8
Total Aggregate	**34.9**	**51.7**
Binder (Lime)	47.0	47.0
Clinker	0	-
Lime inclusions	16.8	-
Secondary products/Calcite and gypsum	1.3	1.3
Total Binder	**65.1**	**48.3**
Total Constituents	**100.0**	**100.0**
Cracks/Voids	**14.3**	**14.3**
	Total	**Effective**
Binder: Aggregate Ratio	**1.0 : 0.55**	**1.0 : 1.1**

Table No. 6: Result of modal analysis (600-point count) on thin section from BTK3

Photomicrographs:

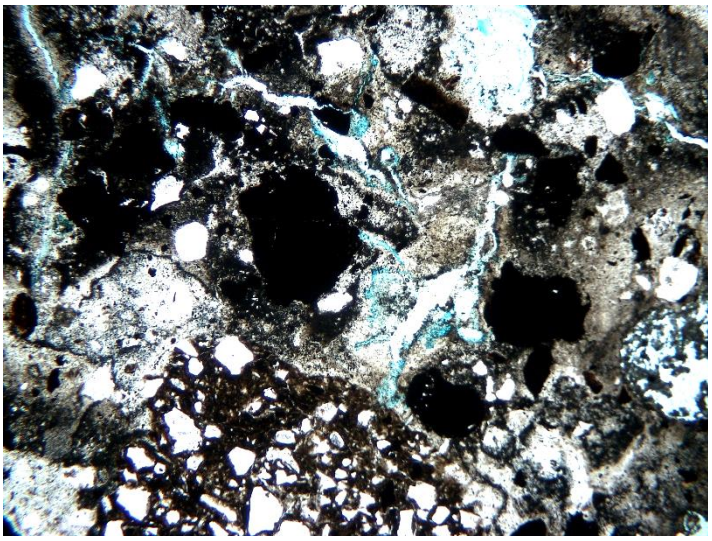

Plate No. 22:

A view in plane polarised light (ppl) of a typical area of the mortar. This shows the mortar composition, with an abundance of opaque particles distributed through a dense paste. Minor quartz and limestone particles are present, along with ironstone, coal, ash clinker and slag. Note the abundance of fine cracks within the area in view. A partially hydrated lime inclusion can be seen in the centre right, with a small partially depleted inclusion in the centre of the image, squeezed between coal particles.

Porosity is highlighted by the blue dyed resin. Field of view 2.4mm.

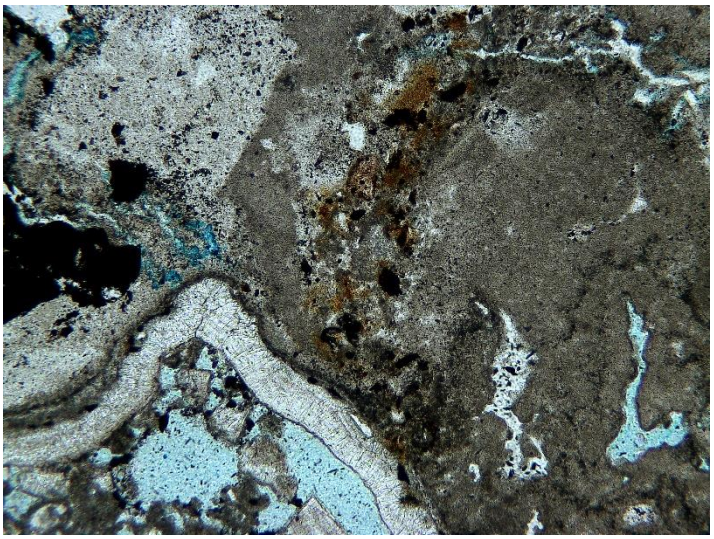

Plate No. 23:

A magnified view in ppl of an area of the slide, where a fully slaked lime inclusion fills the right part of the plate, this also shows cracking and partial depletion. An angular partially burnt limestone particle is seen in the upper left, with a thick coating of redeposited calcite seen coating the margin of a large depleted lime inclusion in the lower left. Note compaction of the paste adjacent to the depleted particle indicating after placing expansion, as in an HMM had occurred. Fine ettringite crystals can be seen below the calcite crust. Porosity and voids are highlighted by the blue dyed resin. Field of view 1.2mm.

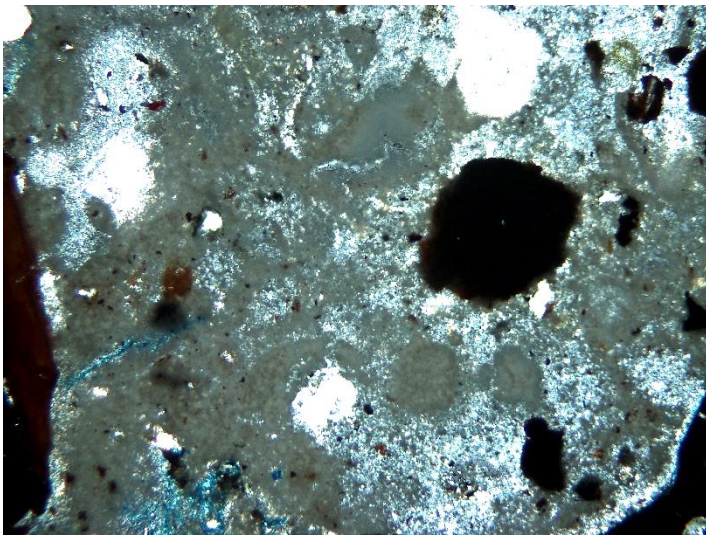

Plate No. 24:

A view in Cross Polarised Light (xpl), of a large fully slaked lime inclusion, in which rare particles are incorporated. These include coal and ash particles. Some of the ash particles display reaction rims indicating a pozzolanic reaction. The lime is only partially carbonated with globules of hydrated but uncarbonated lime putty distributed throughout (grey in image). The voids in the upper left and right and lower centre are filled with coarse calcite crystals.
Porosity, the blue impregnating resin and opaque minerals all appear black in xpl. Field of view 1.2mm.

Summary

On the basis of the examination and analysis of the mortar samples received from the Bank Top Kilns, it is indicated that the mortars sampled were from two different mixes, with that in sample BTK1A being different from the other three samples examined. This may suggest that it was from a different period of the work, or simply mixed using a different aggregate source. The mortar in this sample appears to have been mixed with the quicklime, and the quicklime slaked with the sand, as in a Hot mixed Mortar (HMM) but there was no evidence to confirm that it was placed as a hot mix mortar, and was probably slaked to dry condition, stored and remixed prior to use in the form of a cold mixed mortar. The presence of quicklime inclusions within the mortar fabric, however, suggesting that it may not have been screened prior to remixing.

Although all three remaining samples are similar in appearance and in aggregate type and content, a significant difference was noted between sample BTK1B and samples BTK2 and BTK3, with the former containing Brucite, not found in any of the other samples. This would either suggest that a proportion of the lime used in the binder was Dolomitic or that there was Periclase (Magnesium Oxide) or Brucite (Magnesium Hydroxide) in the waste material used as aggregate. As no Dolomite was observed within the inclusions from the microscopic examination of the thin section, from sample BTK1B, it was, therefore, considered that the Brucite had most likely originated from within the waste material from the iron processing, not an uncommon occurrence, and may be confirmed from a review of the local geology.

Sample BTK1B is again a hot mixed mortar, but as in sample BTK1A, it appears to have been remixed and placed as a cold mortar.

The mortar in samples BTK2 and BTK3 are very similar with respect to mineral composition and mix proportion, and it is concluded that both mortars were made from the same materials, and to the same design. In addition, there are indications within the fabric of both mortars to suggest that although, as with sample BTK1A and BTK1B, they were mixed as HMM, but unlike samples BTK1A and BTK1B, which were placed cold, both of these mortars were placed whilst the mortars were still slaking, as hot placed mortars.

The lime used in all four samples is a high calcium lime produced by calcining a local limestone, with both bioclastic, micritic limestone, and possibly, Oolitic varieties all used. The fuel in the firing of the kiln appears to have been coal, with the possibility that a low proportion of the unburnt/partially burnt fuel was carried over into the mortars, most likely as a contaminant, with the quicklime. However, the majority of the coal, both fresh and partially burnt, along with coal clinker and ash had originated from the waste from the Iron processing kilns.

A summary of the mortar mixes determined is reproduced below:

Sample Ref. No.		**BTK1A**	**BTK1B**	**BTK2**	**BTK3**
Binder form:		Quicklime	Quicklime	Quicklime	Quicklime
Approximate volume proportions calculated on the basis of a Non-Hydraulic lime					
Mix composition by Acid Digestion					
Lime : Aggregate Ratio		1.0 : 1.5	1.0 : 0.5	1.0 : 0.65	1.0 : 0.5
Mix composition by Modal Analysis					
Lime : Aggregate	Total	1.0 : 1.1	1.0 : 0.8	1.0 : 0.65	1.0 : 0.55
	Effective	1.0 : 1.55	1.0 : 1.15	1.0 : 1.0	1.0 : 1.1

The effective binder content determined from the modal analysis is calculated on the basis that the inclusions are acting as aggregate rather than binder, and this is probably a truer measure of the binder content of the mix, relating to its performance as a mortar. Whereas, the total lime content reflects the mix composition at the time the mortar was made and placed, including the inclusions as part of the added lime binder., and reflects the mix proportioning at the time of mixing.

Quality Statement

We confirm that in the preparation of this report we have exercised reasonable skill and care.

The results presented, and comments offered relate only to the samples of mortar received in CMC's laboratory on the 12th March 2019 from Structural & Civil Consultants Ltd., which were identified as mortars from the Bank Top Kilns, in the North Yorkshire National Park.

W A Revie
For CMC Ltd.

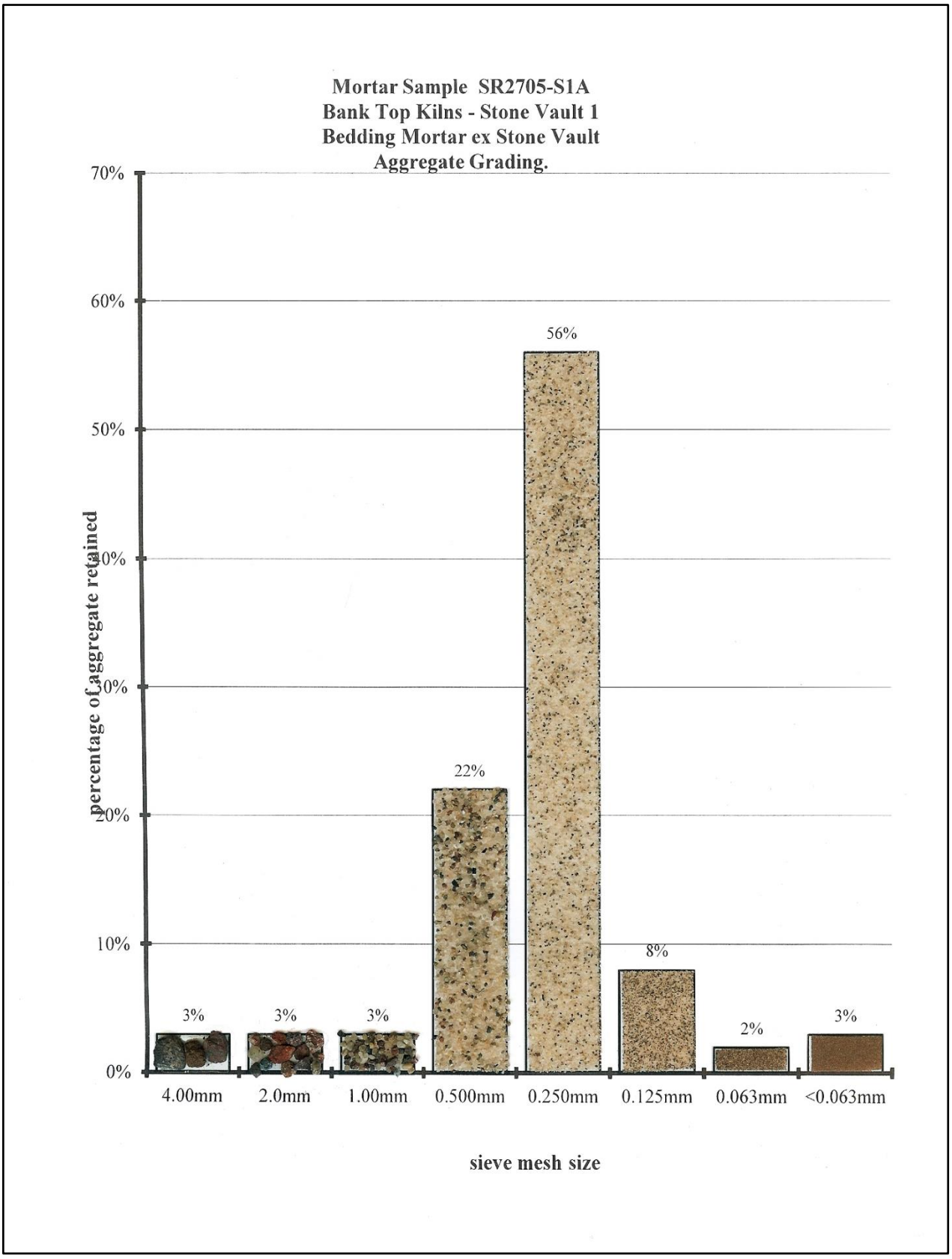

Figure No. 1: Aggregate Grading on Aggregate recovered from sample BTK1A.

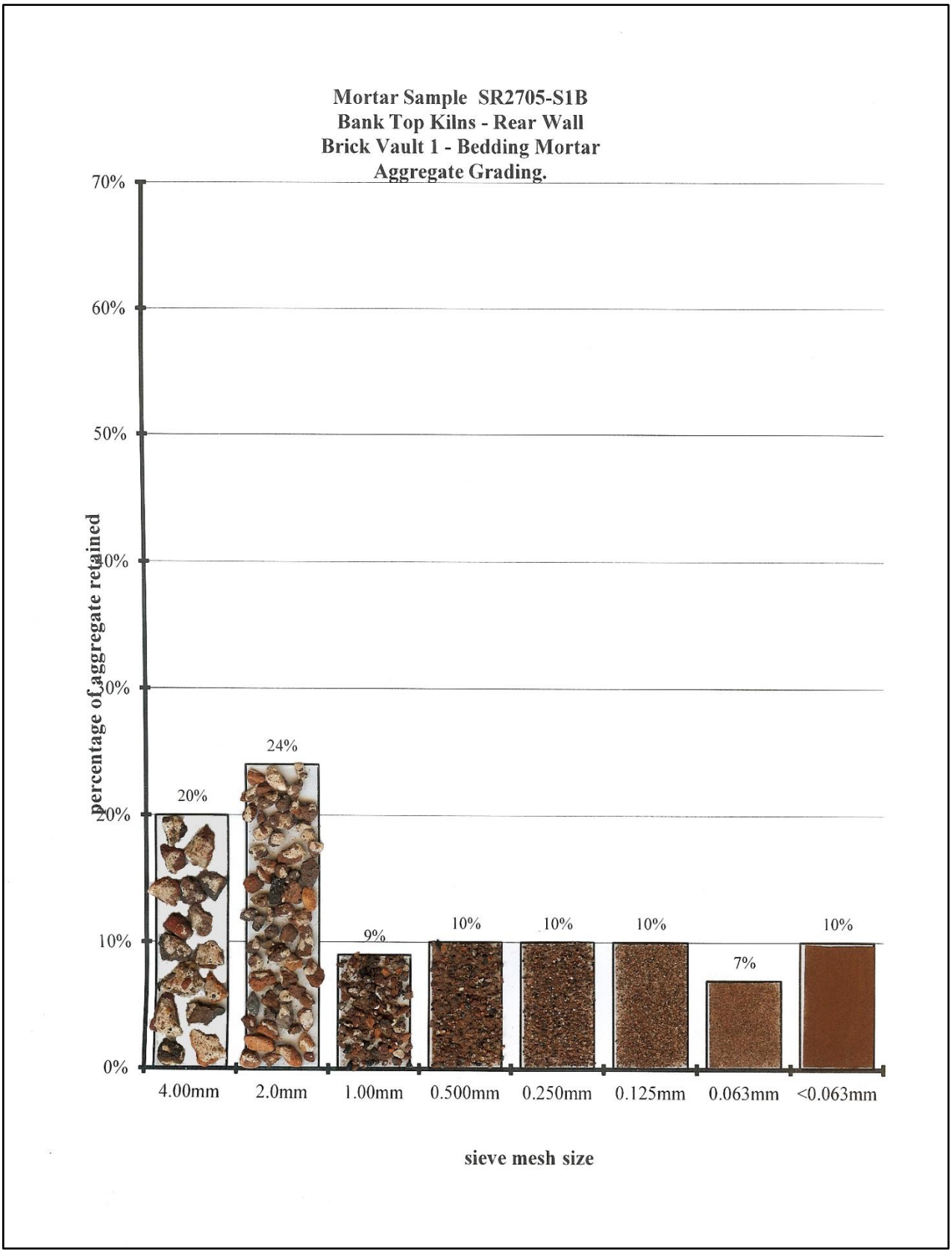

Figure No. 2: Aggregate Grading on Aggregate recovered from sample BTK1B.

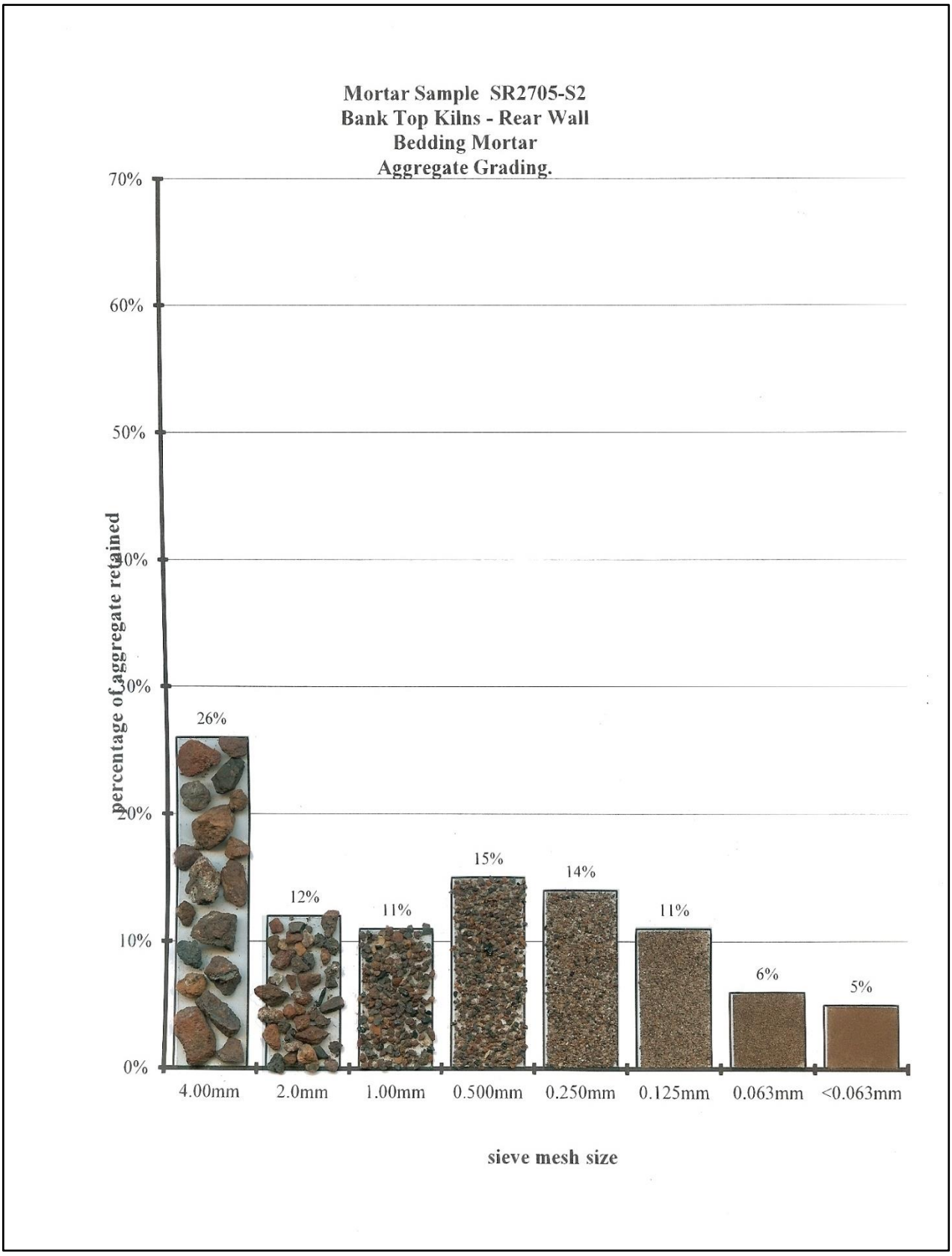

Figure No. 3 – Aggregate Grading on Aggregate recovered from sample BTK2.

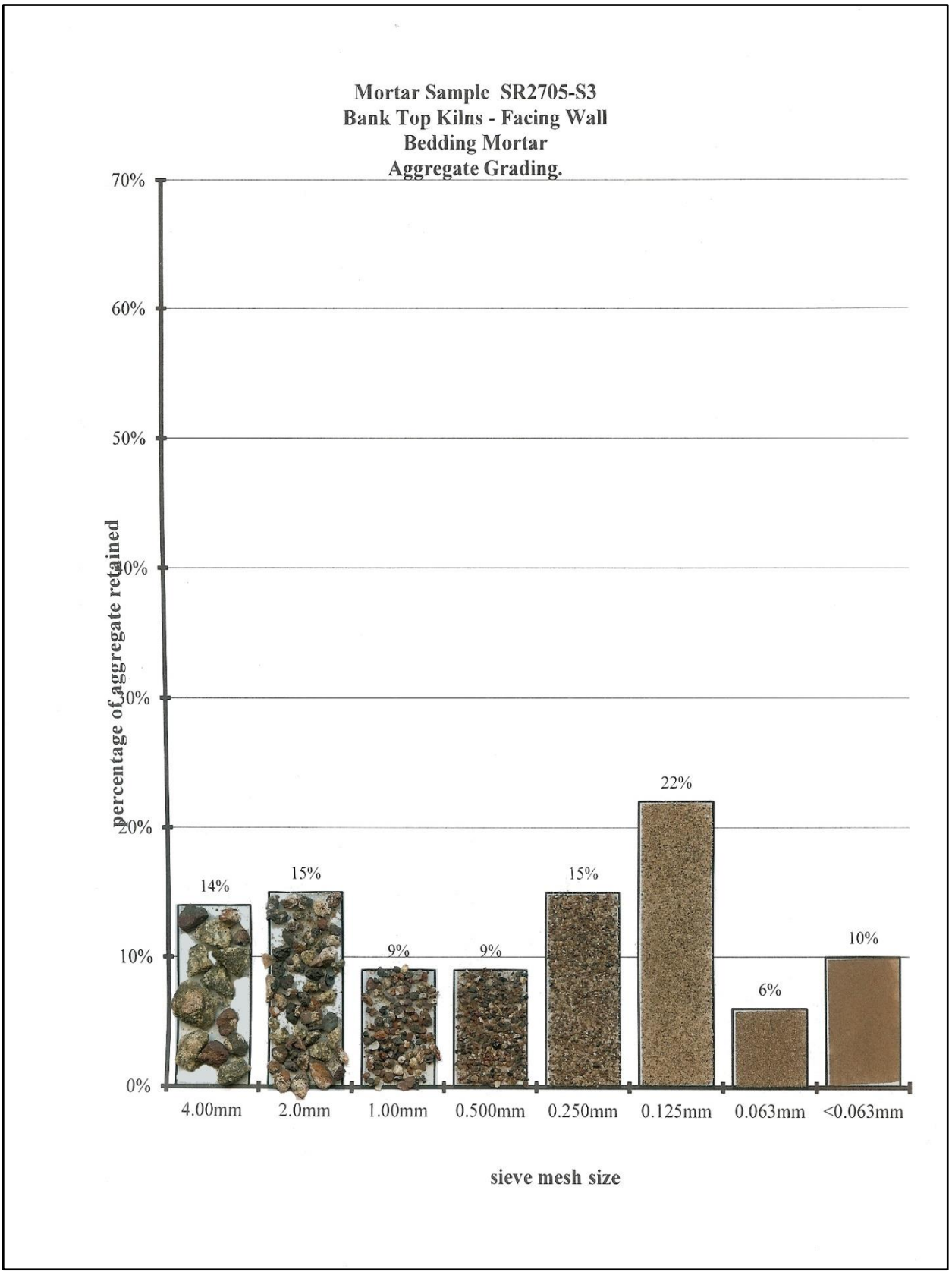

Figure No. 4 – Aggregate Grading on Aggregate recovered from sample BTK3.

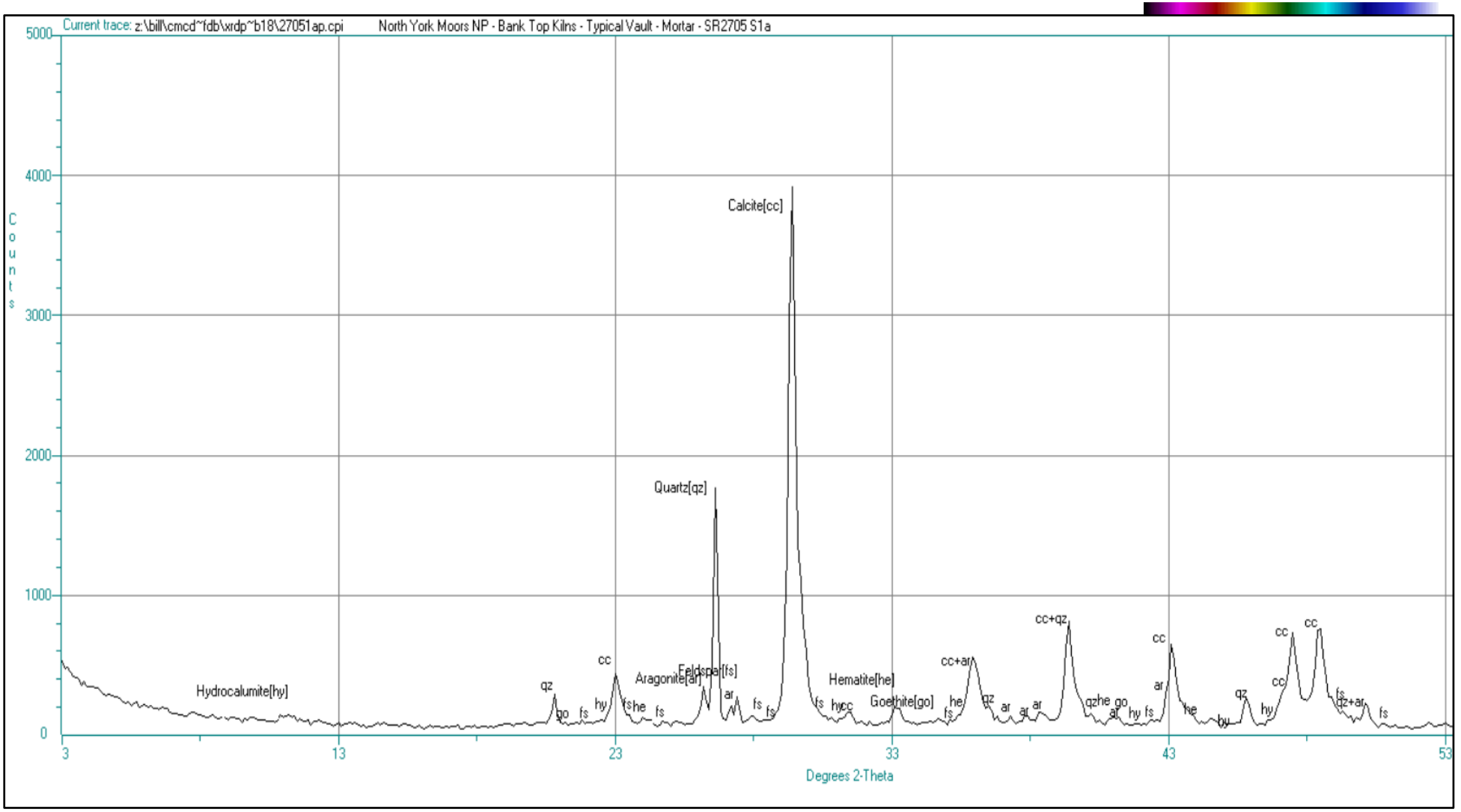

Figure No. 5: SR2705-S1A (BTK1A) Mortar Typical Vault Stonework, Bank Top Kilns.

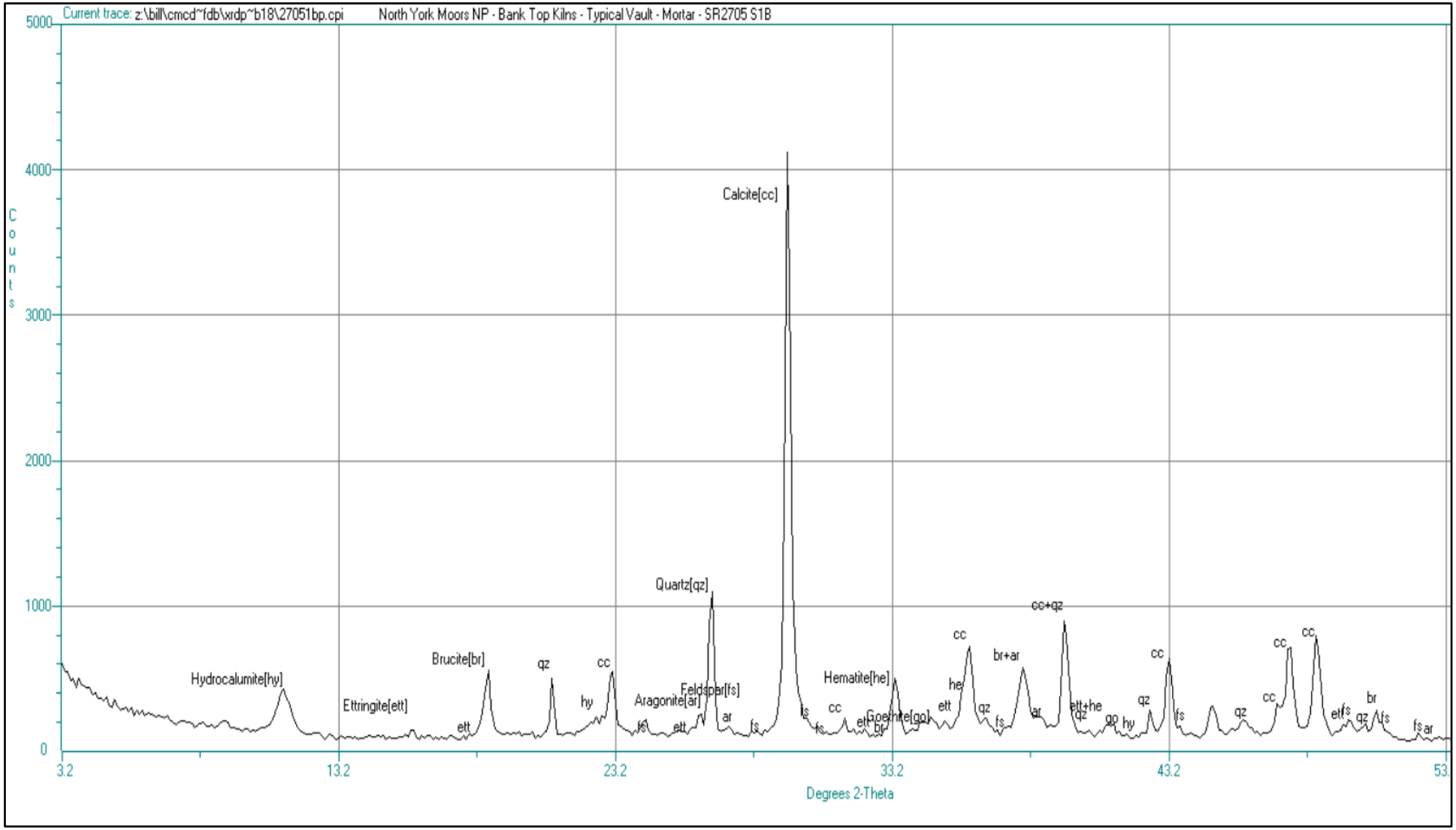

Figure No. 6: SR2705-S1B (BTK1B) Mortar Typical Vault Brickwork, Bank Top Kilns.

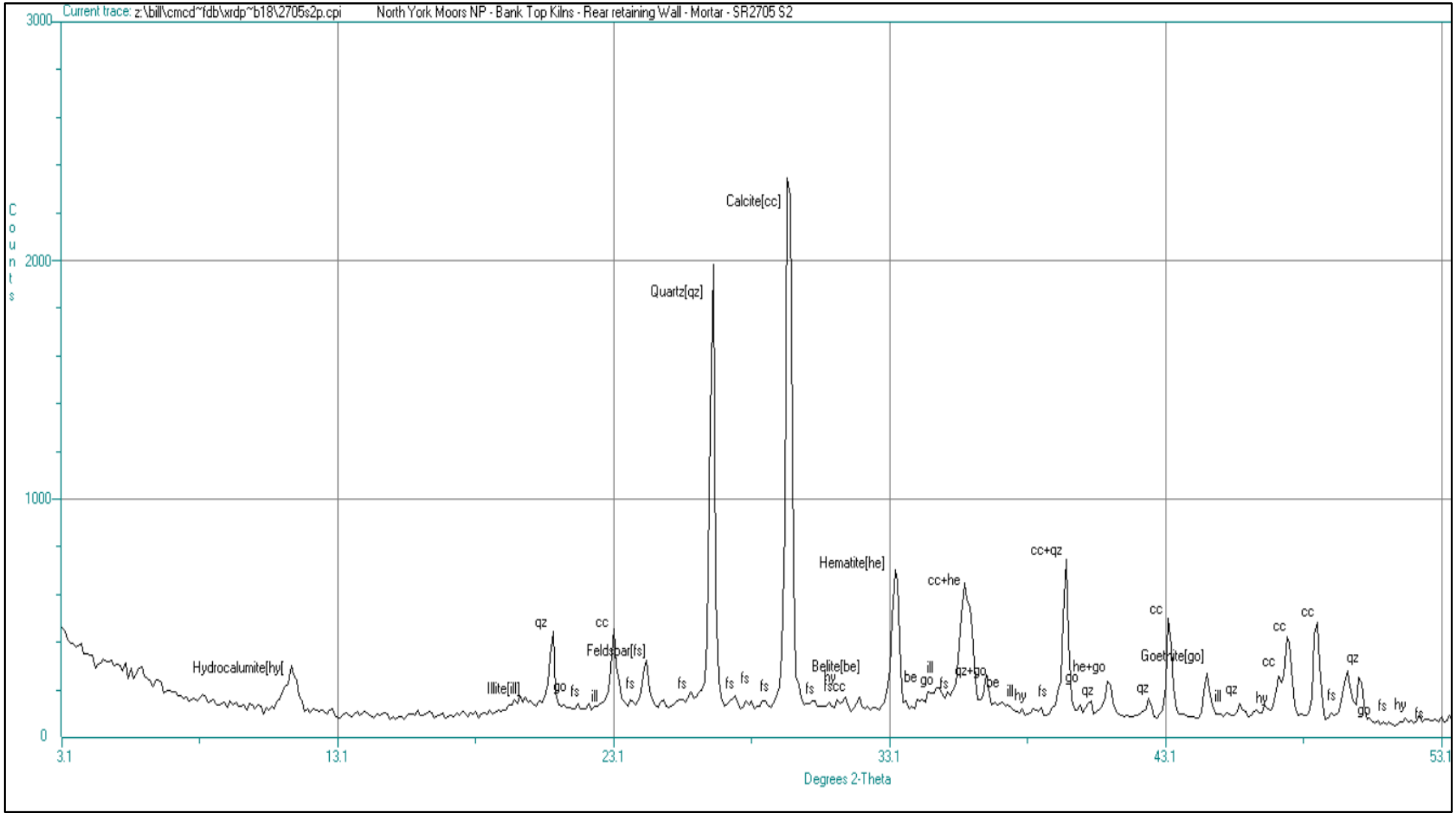

Figure No. 7: SR2705-S2 (BTK2) Mortar ex Rear Retaining Wall, Bank Top Kilns

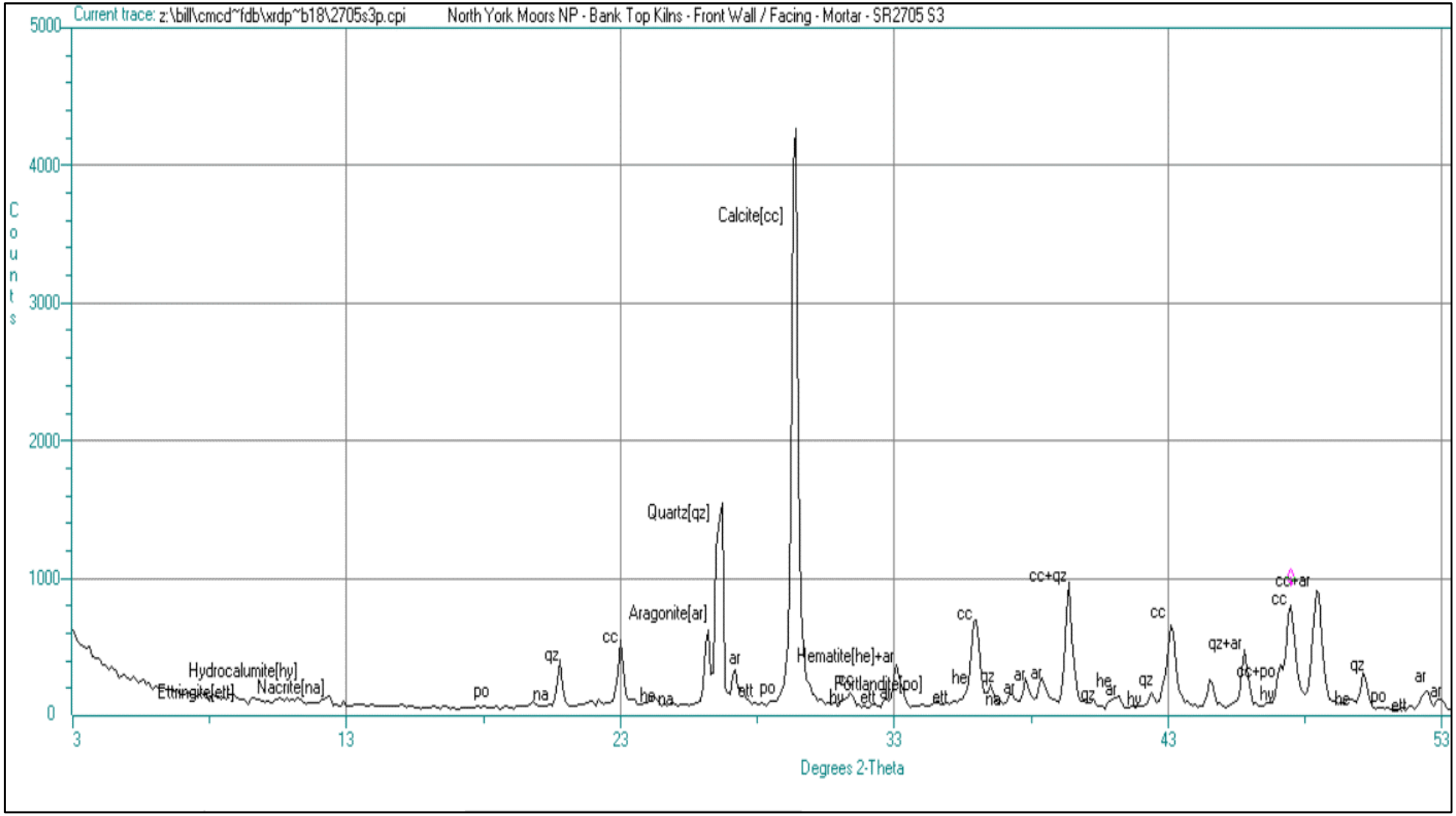

Figure No. 8: SR2705-S3 (BTK3) Mortar ex Front Wall/Facing, Bank Top Kilns.