REPORT ON MORTAR ANALYSIS BY PETROGRAPHY

AP 3779
Abbot Hunter's Tower/ Mauchline Castle,
Mauchline

Sample 1

Mortar

SITE	Abbot Hunter's Tower/ Mauchline Castle, Mauchline
CLIENT	Wylie Shanks Architects
DATE SAMPLE RECEIVED	17/02/2022
ANALYSIS DATES	17/02/2022 – 25/04/2022
ANALYSIS, INTERPRETATION & REPORT BY	Dr Katie Strang and Roz Artis
CLIENT REQUIREMENTS	Mortar Analysis by petrography
STRUCTURE DATE	17th century
STRUCTURE TYPE	Castle
MORTAR DATING	Unknown
LOCATION/ FUNCTION IN BUILDING	Mortar sample taken from north façade.

SUMMARY AND KEY FINDINGS

The Scottish Lime Centre Trust were asked by Wylie Shanks Architects to analyse the mortar from Abbot Hunter's Tower, Mauchline Castle to establish the binder type.

Due to the nature of the lime inclusions and clinker observed, analysis indicates that the binder was a feebly to moderately hydraulic lime, most likely prepared as a 'hot mixed' lime mortar. The mix proportions were calculated through point counting as 1 part lime : 0.79 parts aggregate (by volume). The colour of the mortar, as assessed on a freshly fractured surface against the Munsell Soil Colour Chart, was found to be 10YR 7/2 "light grey" to 8/2 "very pale brown".

METHODS

PETROGRAPHY

Upon receipt in the laboratory the sample was prepared by cutting a slice through one of the larger intact pieces of the mortar, with the specimen aligned such that the slice extended through the full thickness of the sample.
The slice was prepared for thin sectioning by washing the soiling from the sample, which was then dried to a constant weight prior to the vacuum impregnation of the sub-sample with an epoxy resin, to which a fluorescent blue dye had been added. One side of the resin impregnated slice was polished and mounted onto a glass slide (48 x 64mm), with the mounted sample ground and polished to give an approximate thickness of 30 microns.
The thin section was submitted to a microscopic examination, which was undertaken with the aid of a Polarised Light microscope, fitted with a digital camera, to permit recording of photomicrographs, some of which are included in this report, for reference purposes. The presence of dyed epoxy resin within the sample enables an assessment of the mortar fabric to be made, including an assessment of the visual porosity, void size and distribution along with the evaluation of any crack patterns and physical depositional features apparent in the sample under examination.

The analysis results and interpretations made from it provide information on the composition and characteristics of the mortar sample(s) received by the SLCT laboratory. **Provided the sample was representative of the mortar generally**, the analysis will give a reasonable indication of the original materials and provide a **basis for specification** of repair mortars. If more detailed information is required (for example, for purposes of historic research) more sophisticated analytical procedures can be undertaken.

MORTAR EXAMINATION AND ANALYSIS

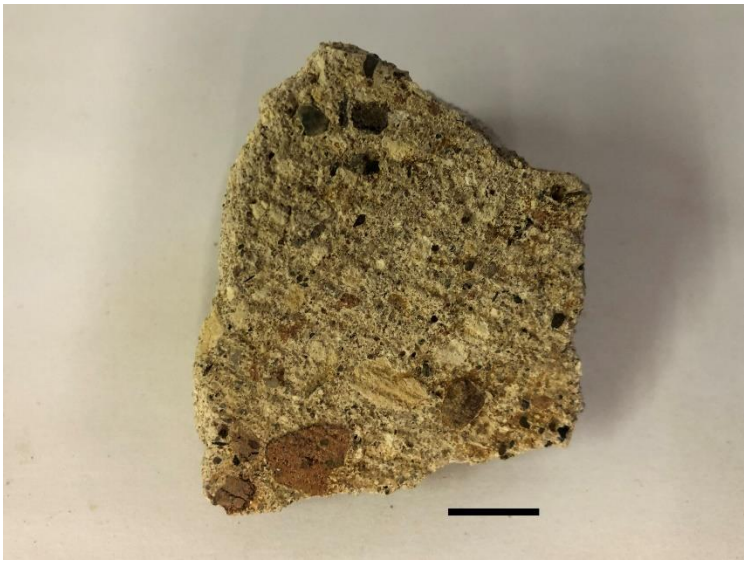


Figure 1. Image showing a freshly sawn face of the mortar. Scale bar = 10mm.

PROCEDURE	OBSERVATIONS
PRELIMINARY VISUAL ANALYSIS OF SAMPLE BY BINOCULAR MICROSCOPE (X40 MAGNIFICATION)	The colour of the mortar, as assessed on a freshly fractured surface, against the Munsell Soil Colour Chart was found to be 10YR 7/2 “light grey” to 8/2 “very pale brown”. In response to a phenolphthalein indicator test the mortar was found to be fully carbonated throughout its depth. Water droplet tests indicated that the outer, weathered, surface was absorbent with droplets absorbed relatively quickly. Droplets placed onto freshly fractured surfaces, again showed fast absorption into the binder. The mortar was weak and friable, requiring little finger pressure to disrupt. The mortar doesn’t appear over air entrained, although there is a low abundance of small, entrapped air voids, up to 1.7mm in size, noted within the surfaces examined. Redeposited calcite, in the form of calcium carbonate, was observed to coat some surfaces surfaces/voids, suggested that water penetration through the sample had occurred, with localised leaching of binder components and their redeposition within the micro-crack pathways. The aggregate in the mortar consists mostly of sub-angular quartz grains, along with smaller proportions of crystalline lithic fragments, and a very small proportion of shell fragments. The particles range in size from 6mm down to <0.1mm.

PETROGRAPHIC ANALYSIS - SUMMARY OF MICROSCOPIC OBSERVATIONS

Aggregate

The aggregate is composed primarily of sub-rounded to rounded quartz grains, along with a significant proportion of well weathered crystalline lithic fragments. The latter tend to be coarser in size compared to the quartz grains and are up to 5.2mm in diameter. They have the appearance of water worn abraded particles and include fragments of crystalline igneous and metamorphic rock and sandstone. Feldspar is preserved in minor amounts and there is a small proportion of shell fragments. Aggregate size ranges from 0.1mm to 5mm with an average size of approximately 0.7mm. The finer aggregate fraction includes common angular particles and are dominated by quartz. The aggregate particles are generally in a sound condition, although some display signs of natural weathering but cracks are rarely observed within the particles. The aggregate is moderately well bonded within the binder and aggregate tends to be well distributed.

Binder

The binder is lime rich and fully carbonated, containing relics of lime inclusions up to 3.2mm in diameter. Hydraulic components were readily observed, and the inclusions have the appearance of the lime having been used in the form of a quicklime, in a "hot lime" mortar. The inclusions commonly contain hydration/shrinkage cracks associated with hot lime mortars. The binder, particularly towards the internal margins of the sample, is disrupted by an abundance of microcracks and voids. Voids range from 0.1mm – 0.5mm wide and in some areas, they connect voids such that binder material forms a skeletal framework within the pore spaces. The outer surface is disrupted due to secondary calcite precipitation, and many voids are fringed with calcite.

Unhydrated clinker components are common throughout the paste, and a high proportion of the belite is partially hydrated and exists as pseudomorphs. The clinker ranges in size from 15µm to 130µm in size, which is coarse for Portland cement, but not for a hydraulic lime. Alite is commonly associated with belite in clusters. Lime inclusions occasionally show clinker components within. Fine shrinkage cracks can be seen throughout and the patchy fabric of the paste, along with high porosity would suggest that the mortar was placed at a high workability and poorly to moderately well compacted at the time.

Point count

Components	**%**
Quartz	35.3
Sandstone	2.6
Shell fragments	0.8
Metamorphic	5.5
Igneous	2.8
Other Opaque	6.5
Lime inclusions (as aggregate)	0.5
Total aggregate	**54.0**
Binder (carbonated)	33.8
Lime Inclusions	8.3
Total binder	**42.1**
Secondary Products (salts, calcite etc)	**3.9**
Total Components	100.0
Cracks/Voids (counted separately)	**8.5**

The table above details the proportions of the constituents observed during point counting. Cracks and voids were counted separately and form 8.5% of the sample (visual volumetric porosity). The mortar has an approximate mix ratio (volumetrically) of 1 part lime : 0.79 parts aggregate. The secondary products were excluded from this calculation.

Photomicrographs:

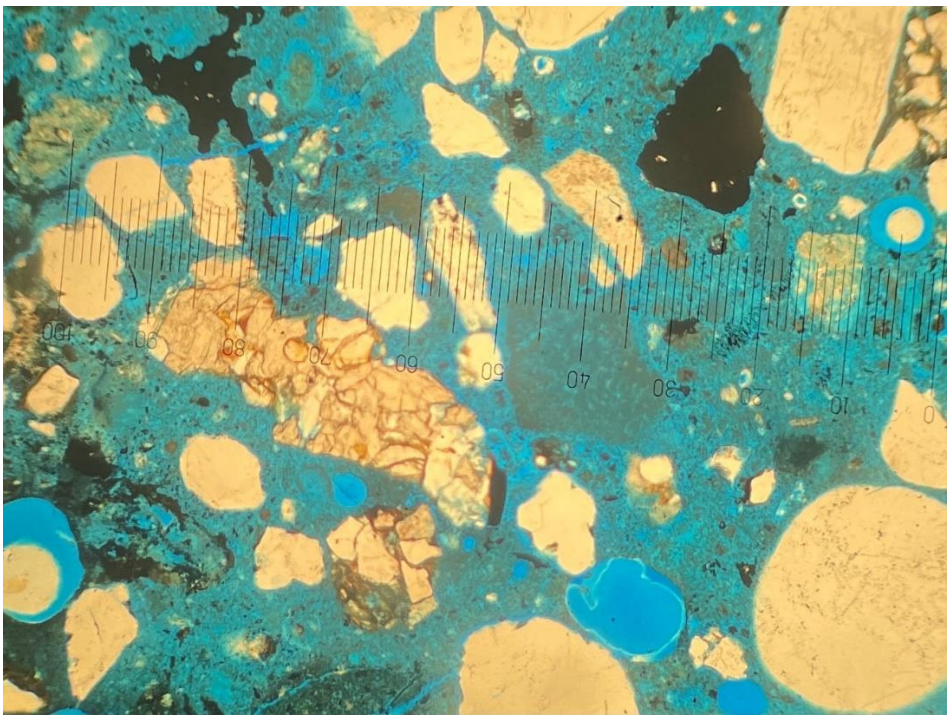


Figure 2. Thin section of the sample under plane polarised light. Pore spaces are highlighted in bright blue, while areas of dark/dull blue indicate the lime binder that has absorbed some of the blue dye. The binder is predominately heterogeneous throughout the sample. Image showing a typical view of large rounded aggregate grains and carbonated binder.

Field of view: 4.2mm.

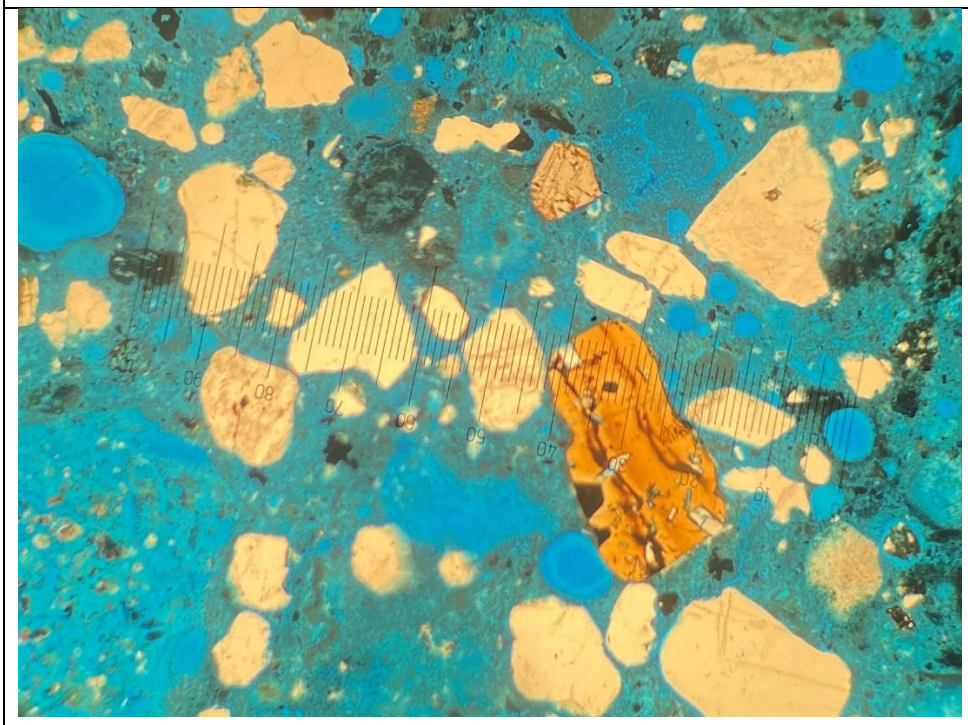
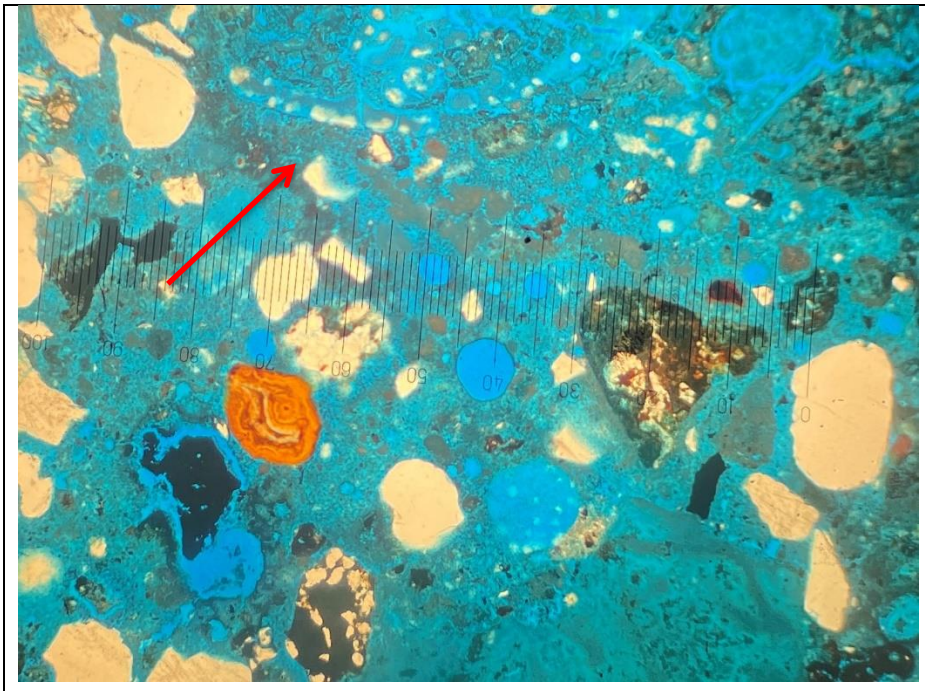
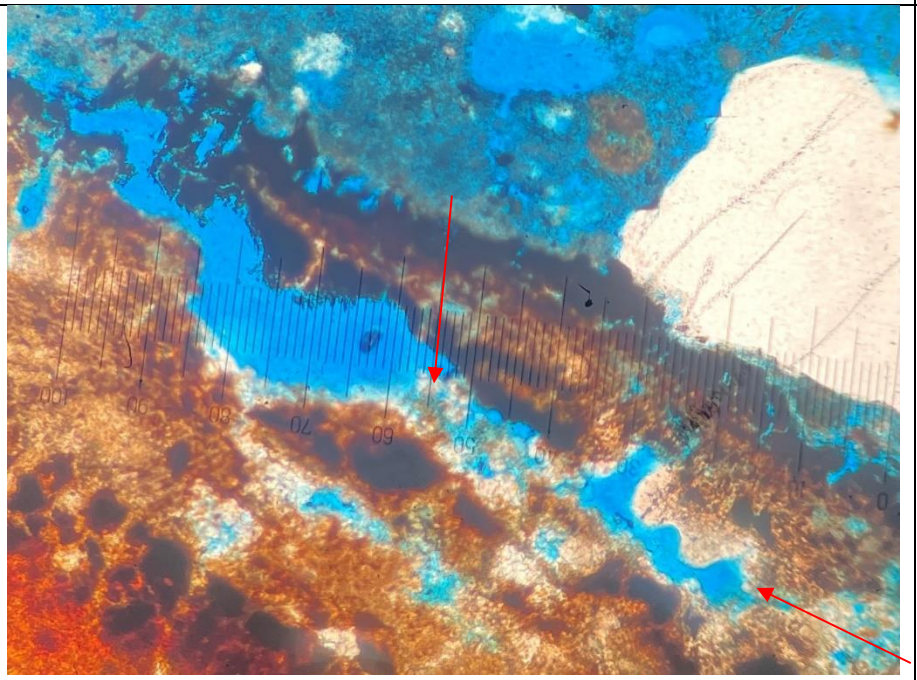


Figure 3. Thin section of the sample under plane polarised light. Pore spaces are highlighted in bright blue, while areas of dark/dull blue indicate the lime binder that has absorbed some of the blue dye). This image shows an area of the binder with a high proportion of opaque, amorphous material.

Field of view: 4.2mm

	**Figure 4. Thin section of the sample under plane polarised light. Pore spaces are highlighted in bright blue, while areas of dark/dull blue indicate the lime binder that has absorbed some of the blue dye. Most lime inclusions show a diffuse contact with the surrounding paste (highlighted by red arrow).** **Field of view: 4.2mm.**
	**Figure 5. Thin section of the sample under plane polarised light. Pore spaces are highlighted in bright blue, while areas of dark/dull blue indicate the lime binder that has absorbed some of the blue dye). Microcracks in some areas are lined by secondary binder products - evidence of abundant binder leaching and dissolution, highlighted by red arrows.** **Field of view: 1.1mm.**

Discussion

Due to the nature of the lime inclusions and clinker observed, analysis indicates that the binder was a feebly to moderately hydraulic lime, most likely prepared as a 'hot mixed' lime mortar. The mix proportions were calculated through point counting as 1 part lime : 0.79 parts aggregate (by volume). The main findings, based on the petrographic analysis, are as follows:

- The mortar is made up of a feebly to moderately hydraulic lime mortar most likely prepared as a 'hot mixed' lime mortar.
- The mortar contains a high proportion of secondary calcite precipitation.
- Lime inclusions had the appearance of a hot mixed mortar and commonly show evidence of later slaking and diffusion into the binder.
- The mix proportions were calculated through point counting as 1 part lime : 0.79 parts aggregate volumetrically.
- There was no direct evidence for the addition of pozzolanic material in the thin section, however some areas of binder showed an abundance of fine-grained opaque, amorphous material dispersed throughout, which could indicate the presence of a fine Pozzolan. There was not enough detail present to confirm this.
- Angular coal fragments were observed throughout.