Effect of burning conditions on properties of artificial hydraulic lime mortar obtained from limestone and siliceous waste materials

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The present study was carried out to produce an artificial hydraulic lime for repair and conservation of historic masonry. Lime mortar is preferred to cement based mortar for conservation work because it is more compatible with the stone and ancient brickwork, as well as being a more sustainable material. The study focused on the effect of burning conditions on the properties of an artificial hydraulic lime mortar obtained by burning limestone and siliceous waste materials. The raw meals were prepared from five types of silicicous materials obtained as byproducts from industrial processes (pulverised fuel ash, glass cullet, silica sand, crushed rock and spent oil shale) with the amount of silica between 3 and 16%. The raw meal was burned in an electric furnace at 975°C for 3 h. The mortar was prepared by mixing hot slaked lime putty (water/lime ratio ~ 1:6) and ‘Gowrie’ sand at a lime/sand ratio of 1:3 by weight. The limes and lime mortar were prepared and tested according to BS EN 459-2:2001. The investigations carried out on the products included free lime analysis, strength test and microstructural examination. The results show that the glass cullet lime is the most hydraulic product and can be classified as feebly hydraulic. It suggests that this hydraulic lime could be produced using a traditional kiln at a low cost.

Keywords: Waste materials, Glass cullet, Mortar, Hydraulic lime, Burning conditions

Introduction
The present study was carried out to produce an artificial hydraulic lime, which is appropriate for use in repairing and conserving traditional masonry. In building conservation work, lime based mortars including hydraulic lime is preferable to cement based mortar because it is more compatible with stone and traditional brickwork, as well as being a more sustainable material.1,2

Lime becomes hydraulic because of the presence of silica containing minerals (e.g. clay) in the limestone.3,5 Much of the lime produced in the past and used in Scottish masonry was hydraulic but there are no currently available sources to support the local building conservation works and nearly all of the hydraulic lime is imported.2 Industrial byproducts, with similar chemical properties, are a potential source of silica for local production of hydraulic lime.

Materials and methods
Five siliceous materials, pulverised fuel ash (PFA), mixed coloured glass cullet (GC), silica sand (SS), crushed rock (CR) and spent oil shale (SOS) with silica contents from 46 to 98%, and ‘Shap’ limestone (97%CaCO3) were used in the present study. The raw meal was prepared by mixing a proportion of limestone and siliceous materials. The amount of silica in the raw meals was varied between 3 and 16%. The hydraulic limes were produced by slowly heating the raw meals at a rate of 4 K min⁻¹ from room temperature to ~ 975°C. The heating was continued at the high temperature for 3 h before the product was slowly cooled in the furnace. When cool, the fired product was crushed to pass a 2.36 mm sieve before slaking and use in mortar. A sample was crushed further to pass a 75 μm sieve for determination of free lime.

The available free lime in the burnt product was extracted by means of ethyleneglycol and the extract was titrated with hydrochloric acid, using bromocresol green as indicator.

The mortar was prepared by the hot lime method6 in which the burnt product is added to water (in this case, in the proportions 1-6 lime to 1-0 water by weight) and the heat evolved in the slaking process breaks down the particles to give a fine putty. The finer particles in the putty react more quickly when used in mortar.2 The putty was then mixed with ‘Gowrie’ sand at a lime/sand ratio of 1:3 by weight. The mortars were prepared and tested according to BS EN 459-2:2001 (Ref. 7), the European standard for methods of testing fresh and