Refractory Ceramic through the Ages: an Archaeometric Study on Finds from Fenan, Jordan and other Sites

Dissertation

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Abstract

The ancient metal production cycle starts, after ore preparation, with smelting the ore in a crucible or furnace. The former was usually manufactured from clay based materials, furnaces were built with clay and/or stones, which were also lined by a clay layer. The air, if not natural, was induced to the firing chamber using clay based tubes (i.e. tuyère). Metal then was finally cast in moulds to ingots or finished objects. They were made of clay based materials too. Therefore, the study of such refractories, which were supposed to be stable about 100 °C above the copper’s melting point (1086 °C), lies mainly in the category of ceramic studies. Contrary to modern materials, ancient refractories are not expected to withstand temperatures higher than 1500 °C. This temperature was not reached in antiquity even in the hottest firing zone (near tuyère nozzle). Refractories, from the ancient point of view, are those materials that had to withstand temperatures more than the contemporary domestic pottery did. The district of Fenan (south Jordan) provides a good example for such comprehensive metal sequences that go back to the 4th millennium BC up until Roman-Byzantine Period and later. The present study is interested in such materials excavated from Fenan district, Hujayrat al-Ghuzlan and Mugharet al-Wardeh sites (Jordan), and from Bir Nasib (Sinai). For comparison high refractive crucibles from Post-Medieval sites in Dresden and Freiberg (Germany) were included in this study. A collection of 110 samples of crucibles, furnace installations, tuyères, casting moulds and pottery sherds have been investigated in order to acquire information about the raw materials that were utilized in their manufacture (non-plastic inclusions and clay). Moreover, manufacture technology and the degree of refractoriness and performance under firing have been investigated. Petrography using optical microscopy combined with XRD analysis were performed in mineralogical investigation, ICP-OES and SEM-EDX have been utilized in chemical analysis, and refiring test with SEM have been performed to trace the microstructural developments during firing. The results of this study indicate that the ancient refractory ceramics had developed in a very slow process (chrono logically and technically). This development was related to the different stages in the development of metallurgy, to the availability of the raw materials and the domestic pottery production tradition. It had passed through some local
innovations. Refractory ceramics in the Late Chalcolithic/Early Bronze Age I at Fenan area and Hujayrat al-Ghuzlan were thick-walled, coarse texture and porous vessels. They were manufactured as the domestic pottery using the available, usually, non-refractory clay mixed with coarse non-plastic and organic materials. The first local innovation was the use of pre-fired non-refractory calcareous clay-based clay rods to stabilize the non-refractory calcareous clay-based raw furnace walls of the Early Bronze Age II/III at Fenan area. A sintering process of the non-refractory calcareous clay rods provided them the stability during the smelting operation due to the formation of the high temperature mineral phases: gehlenite and diopside and stabilized the whole furnace structure during this process. The use of multi-layered tuyères in the Iron Age in Fenan area and Sinai was the second regional innovation. The Iron Age craftsmen were able to select the most available refractory kaolinite clay and mixed it with large amount of quartz to manufacture the earliest real composite refractory tuyère nozzles. While non-refractory clays mixed with available crushed slag were used for the tuyère back, furnace lining and domestic pottery. The Roman Period tuyères and domestic pottery from Fenan were manufactured using the same raw materials. More controlled process was used in their manufacture concerning the amount, size and type of the temper (quartz) and the homogeneity of the clays.

This points that the production of the tuyères and the domestic pottery was coherent and probably was performed by the potter using the wheel. The availability of the raw materials was controlled the production of the Middle Islamic Period tuyères and domestic pottery: more attention has been paid in manufacturing the tuyères by using non-calcareous clay and then mixed with coarse fragments of the available crushed iron ore (hematite). The post-Medieval crucibles from Dresden and Freiberg were manufactured using refractory kaolinite and graphitic kaolinite clays mixed with large amounts of quartz. In addition to their refractory composition (fireclay) they were pre-fired at a high temperature. As a result, a well developed network of mullite crystals was formed. The high refractory mullite crystals reinforced the fabric of the crucibles during the second firing. The spread of such crucibles in Western Europe and even America in the late 15th century was the root for the later revolution in refractory materials field.