X-Radiography and Ceramics

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Discovered by Wilhelm Röntgen in 1895, X-radiography was quickly put to use to investigate a multitude of human medical conditions. Soon, its potential for art, archaeology, and geology became apparent, and it was utilized to examine ancient human and animal mummies, metals, ceramics, paper, paintings, and soil (Lang and Middleton 2005). The first applications of X-radiography to ceramics date back to the 1930s and 1940s, but its full potential was only realized in the 1970s when Rye published his seminal work on the fundamental patterns and rules underpinning ceramic X-radiography (Rye 1977, 1981). This work was further expanded on by Carr (1990), Carr and Riddick (1990), and Berg (2008). X-radiography has major contributions to make to our understanding of ceramics. However, it is only one of the many tools that are available to researchers, and it is always recommended that as many techniques are used in conjunction with each other as possible.

X-radiography is a type of electromagnetic radiation that penetrates objects in proportion to the atomic density of the materials and thickness of the object, and captures the outgoing radiation as a grayscale image on a monitor or photographic medium. With the proliferation of digital X-radiography in medical and industrial contexts, it is now easier than ever to gain access to suitable facilities. While industrial facilities provide better-quality X-ray images, medical facilities are ubiquitous, may be portable, often offer good value for money, and are adequate for most research purposes. As each machine is different, researchers will need to experiment first to find the best exposure parameters for the given ceramic assemblage.

The advantages of X-radiography for the study of ceramic objects are manifold: Equipment and facilities are widely available, the technology is nondestructive, it can be used for both fragments and complete objects, it allows speedy acquisition of images, it provides quick image enhancement with commercially available software and relatively fast interpretation of the image, it offers good value for money, and it can be undertaken on individual objects as well as on large assemblages. The only known disadvantage is that ionizing radiation may change a thermoluminescence (TL) date of the object by up to 20 percent. It is important to note that most of the research has been carried out on pottery. However, the investigatory principles can be applied to any clay object, such as figurines, bricks, or even drainage pipes. X-radiography is most commonly utilized to answer the following research questions:

- identification of the object and its condition;
- identification of the material(s) present;
- identification of manufacturing method(s);
- identification of joins, faults, breaks, repairs, and reuse;
- identification of finishing methods and decoration;
- identification of forgeries.

Of these, scholars working with ceramics are mostly concerned with the identification of manufacturing methods and characterization of the fabric.

It was Rye (1977, 1981) who recognized that different primary forming techniques leave characteristic fingerprints in the clay body that can be made visible through X-rays. Pinching, drawing, coil-building, slab-building, molding, and wheel-throwing differ in the alignment and distribution of inclusions, shape and orientation of voids, evenness and thickness of vessel walls, and the visibility of seams where sections of a pot were joined together. Pinching can be recognized by an alignment of inclusions parallel to the surface, but without a recognizable horizontal or vertical orientation. Drawing orients inclusions weakly vertically when viewed in cross-section and voids appear flattened and

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circular when viewed normally. Coiling results in a preferred horizontal orientation of inclusions and elongated, horizontal voids. Inclusions aligned parallel to the surface but without a predominant orientation is a characteristic pattern of slab-building. Molding produces a parallel but random alignment to the surface. Lastly, inclusions aligned parallel to the surface but set at a diagonal orientation when seen from the front are characteristic of wheel-thrown pots (Rye 1981).

Secondary forming techniques, such as scraping, trimming, smoothing, and adding sections, do not normally interfere with the radiographic visibility of the primary techniques (Berg 2008; Carr 1990). The exceptions are the paddle-and-anvil technique because it applies so much pressure that it obliterates all primary features and results in extreme thinning of vessels which removes all extant features. Secondary forming techniques and surface treatments are therefore best understood through macroscopic analysis.

Investigating forming techniques can lead to exciting discoveries, such as the existence of two distinct manufacturing traditions (Attic and Rhodian) for Aegean Bronze Age transport stirrup jars. Used to transport olive oil, the main distinction lay in the forming of the "fake" spout as either a hollow or solid part of the vessel (Leonard et al. 1993). Vandiver (1987), using the no longer supported xeroradiography, was able to reconstruct the slab-building technique used in the Zagros region of modern-day Iran in around 3000 BCE. By using so-called thick sections (whereby a vessel is cut into vertical slices whose cross-sections are then X-rayed), Vandiver was able to reconstruct the precise shape, size, and sequence with which each slab was applied to form a vessel. Nowadays, this kind of analysis can be undertaken using computed tomography (CT). A major study of Cretan Bronze Age pottery by Berg (2009) illustrated the great variety of forming techniques utilized by ancient potters. It also showed that potters often combined multiple forming techniques on the same vessel, such as a Minoan amphora which was constructed by wheel-throwing, coiling, and drawing. The power of this tool is not limited to pottery. Analysis of clay figurines, for example, has proven very effective in understanding step-by-step how they were constructed.

X-radiographs may be helpful in characterizing ceramic fabrics by determining the size, proportion, type, and general mineralogy of inclusions and/or tempering materials. The technique can only do so when the inclusions or temper have different radio-densities from the clay body which makes them stand out. Based on these differences, scholars have been able to distinguish between classes of minerals, though specific attribution is often problematic when inclusions have similar chemical composition, morphology, and radio-densities. In contrast, organic inclusions often burn out during the kiln firing and leave a recognizable void behind (Carr and Komorowski 1991).

Using X-radiography, Blakeley, Brinkmann, and Vitaliano (1989) were able to divide their sherd assemblage of Pompeian Red Ware successfully into two major fabric groups. The validity of these groups was subsequently confirmed using petrology and chemical analysis. Carr (1990, 1993), in contrast, was interested in understanding whether X-radiography could be used to determine whether body sherds found in close proximity to each other during excavation belonged to the same fabric group and hence possibly the same vessel. X-radiography has the ability also to detect unusual tempering practices or combinations of different clays on the same vessel. Despite its great potential, it is always recommended that petrography and chemical analysis are undertaken alongside.

X-radiography can be used to discover structures hidden inside a complete vessel. One of the very earliest applications of this technique discovered that Peruvian water jugs contained an internally hidden whistling mechanism. Repairs—ancient and modern—are often clearly visible macroscopically. However, where there is doubt, X-radiography will be able to detect them easily if they were undertaken with materials of a different atomic density. An example of a known repair is the insertion of a metal pin into the fake spout of a Bronze Age stirrup jar. Damage incurred during the life history of a ceramic object, such as firing cracks, temperature cracks, or stress breakages, will also be clearly visible in an X-ray.

New technologies such as CT have the potential to supersede X-radiography in archaeology in time because they can offer a 2D and 3D view of the object at macro- and nanoscale, allowing for quantitative and qualitative analysis of temper and pores/voids. However, the disadvantages are currently too great to establish them as a viable alternative. X-radiography is now almost exclusively digital and much improved in quality. Taking X-rays is quick, inexpensive, and nondestructive, and industrial, medical, or veterinary facilities are abundantly available in most locations across the world or can be brought into museums. The resulting images can be viewed immediately and enhanced quickly, if required, using commonly available software packages requiring minimal training. In contrast, CT scanning necessitates for objects to be brought to the facility (portable machines are available, but prohibitively expensive and large), scanning time is measured in minutes and hours rather than seconds, imaging software is highly specialized, thus requiring extensive training, and processing a single image can take hours.

SEE ALSO: Petrography and Ceramics; Raman Spectroscopy; Raman Spectroscopy and Material Analysis; Terahertz Imaging in Conservation; X-Ray Radiography and Material Analysis; X-Ray Radiography; X-Ray Tomography

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