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Determination of the manufacturing methods of Indian swords through neutron diffraction

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Abstract

The analysis of the micro-structural features of ancient Indian swords has been carried out by neutron diffraction as well as by metallography. The results provide a clear identification of the different materials used to produce those weapons. Only a small proportion of the large number of swords produced in India historically were made of hypereutectoid textured steel, namely *wootz* steel also (misleadingly) known as "Damascus steel". Diffraction analysis was applied to a group of four swords and the micro-structural and compositional characteristics were identified for all of them revealing a strongly differentiated construction method and the peculiar micro-structural features of at least one kind of *wootz* steel. This kind of results is a further proof of the validity of the use of neutron scattering techniques for authentication and characterization of ancient metal artifacts.

1. **Introduction**

During the early Middle Ages in Europe, steel for swords was obtained via the bloomery process. In this process, iron ore was heated with charcoal and reduced to form a solid product, a bloom of iron (parts of which might be steel) together with a slag, which became a liquid at around 1200°C. The steely parts had then to be somehow separated from the rest of the bloom. In contrast an entirely different process, known as crucible steel, developed in the Middle East [1]. Pieces of bloomery iron were heated for days in sealed crucibles with a carbon-containing material until enough carbon had been absorbed for the steel to be formed as a liquid, at 1300 °C - 1400 °C, and so separated entirely from the slag. A special application of crucible steelmaking was the production of 'Damascus steel' [2]. It may be that much of the crucible steel made did not undergo the extremely slow cooling which leads to the "watered-silk" pattern visible on the surface of the most highly prized 'Damascus' blades, and therefore it has not been recognised. If this is so, the quantity of crucible steel employed may well have been considerably underestimated in the past [3, 4].These were famous blades which had a watered-silk or damask pattern on their surfaces, and were made from a very high-carbon crucible steel (*wootz*) which was allowed to cool extremely slowly after liquefaction, so that the cementite (iron carbide, Fe_3C) crystals were large enough to form a visible pattern on the surface. These cakes were exported to centres of arms manufacture such as Damascus