DOES METEORITIC METAL CHANGE WITH FORGING? AN EXPERIMENTAL STUDY

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Introduction: Metal working has played a pivotal role in human history, and the use of meteoritic iron in the manufacture of artifacts from the Bronze Age has been well documented [1-4]; perhaps the most famous is the iron blade of Tutankhamun's dagger [1]. The details of the manufacturing process for these artifacts are largely unknown, although they appear to have involved relatively low temperatures (<750 °C), based on, e.g., the preservation of kamacite and taenite lamellae within some artifacts [3]. An important unknown is the extent to which the working of meteoritic iron gives rise to changes in the bulk composition during the forging process.

The manual process of forging iron introduces many variables such as actual peak and hold temperatures, amount of time in the forge and the possible introduction of external contaminants such as flux. Through analysis of representative samples of Gebel Kamil metal obtained in the course of the forging of a set of knife blades, this initial study attempts to determine whether forging temperatures (sub-solidus, 1440 °C [5]) are high enough and long enough to cause fractionation of elements. The results of our study have implications for the linking of specific artifacts to known meteorite sources, including in ruling out or linking Gebel Kamil to Tutankhamun's dagger.

Methods: A set of knife blades was forged by Randy Haas of HHH Custom Knives, using 2.3 kg of Gebel Kamil meteoritic iron as starting material. The process is best described as diffusion forge welding, in which the metal pieces are heated below the melting temperature (in this case 1200-1300 °C, for a few minutes at each stage) and pressed together. A flux (20 Mule Team brand Borax) was used to assist in homogenizing the meteorite's composition. The forging process ensured that meteoritic inclusions such as phosphides (e.g, schreibersite) and sulfides (e.g., troilite) would not create faults (initiation sites) in the final blade.

Four samples ranging in mass from 40 to 50 g each, representing progressive stages in the forging process, were subsampled for bulk analysis. Herein we refer to these as Stage 1 through 4. Analyses were done on ~0.5 g subsamples dissolved and analyzed via solution ICP-MS using typical methods, using a Thermo Scientific iCAP RQ inductively couple plasma mass spectrometer at UAlberta, with a sample of the North Chile (Filomena) meteorite as an internal standard. Also analyzed was a 0.6 g subsample of unprocessed Gebel Kamil; this analysis served as an additional check on the analytical method, as well as the starting composition with which processed samples could be compared. Elements analyzed include Co, Ni, Cu, Ga, Ge, As, Ru, Rh, Pd, W, Re, Os, Pt, and Au. Processed samples were also characterized using backscattered electron imaging with a Zeiss Sigma 300 VP-FESEM secondary electron microscope at UAlberta, operating at 15 kV and 7.2-11.3 mm working distance.

Results: Our analyses reproduced the composition of Gebel Kamil as reported in [6] within 20% for all elements with the exception of W, which differed by ~30% (0.5 ppm vs. 0.66 ppm reported in [6]). Results of analysis of the Stage 1 through 4 samples show that the composition of the meteoritic metal did not change significantly through the forging process, with the majority of elements remaining within 10% of the concentration obtained in unprocessed Gebel Kamil. No changes in Ni/Co or Ni/Fe (e.g., [2]) were observed. Two notable exceptions are W and As. The concentration of W increases to 1.1 ppm in Stage 1, decreasing to unprocessed levels (0.6 ppm) in Stages 3 and 4. We attribute this to contaminaton imparted by the forging process: a spot weld is used to attach the billets together, and additional flux was used to ensure the billets would successfully weld together. Although samples were taken from inside the processed material, it is most likely that W was contributed by the spot weld; the source of As may be similar. Further analyses of other elements including additional siderophile, chalcophile, and lithophile elements are in progress. Textural observations (SEM) reveal numerous inclusions resulting from the heating and working of the metal and the action of the borax flux; the abundance of inclusions decreases from Stages 1 through 4. The original plessitic structure of Gebel Kamil [6] is not preserved, even though the bulk composition remained the same.

Implications: The main conclusion of our study is that the composition of an artifact made with meteoritic iron should be a relatively faithful representation of the original meteoritic material, even at the higher temperatures afforded by modern forging methods. Therefore it is unlikely that the methods used in the past would result in significant fractionation of elements. The Gebel Kamil meteorite (19.8 wt% Ni, 0.75 wt% Co [6]) could not have been the source of Tutankhamun's blade (10.8 wt% Ni, 0.58 wt% Co [1]) unless the latter had been significantly admixed with other iron – although examples of this are documented from the Iron Age [2], it was unlikely in this case. Our study provides insights into the degree to which meteoritic metal is modified through human activity, with implications for the interpretation of historically significant meteoritic metal artifacts.

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