Thermal and Atmospheric Effects on Femur Fragment Microstructure

Background

- Challenge: The analysis of burned skeletal remains is a significant hurdle in forensic investigations due to heat-induced microstructural alterations.
- Aim: To systematically quantify these microstructural changes in human femur fragments subjected to controlled heating under aerobic and anaerobic conditions.
- Goal: To establish clear, temperature-dependent deterioration patterns, creating a robust methodology to estimate temperature exposure in forensic cases.

Figure 1: Photos of unburnt femoral segment (left), after aerobic burning (middle), and after anaerobic burning (right).

Methodology

- Sample Preparation: 2 human femur fragments were heated from 400 ◦ C to 1000 ◦ C in 50 ◦ C increments, under both aerobic (AE) and anaerobic (AN) conditions.
- High-Resolution Imaging: Each fragment was scanned using high-resolution CT to capture its detailed internal microstructure.
- Image Processing & Analysis: The image processing workflow involved reconstruction, filtering, segmentation of bone and pores, followed by pore network analysis, performed in Avizo 3D software.

Results

- Porosity Trends: The pore/bone volume ratio increases with temperature, indicating progressive bone material loss and void space growth.
- Atmospheric Effect: The presence of oxygen (aerobic condition) accelerates the degradation of organic components, resulting in greater porosity at higher temperatures.

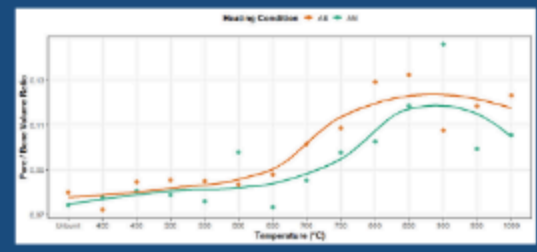

Figure 2: Effect of Temperature on Pore/Bone Ratio.

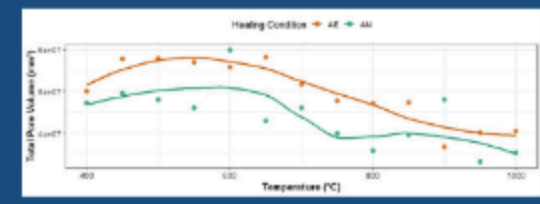

Figure 3: Effect of Temperature on Total Pore Volume.

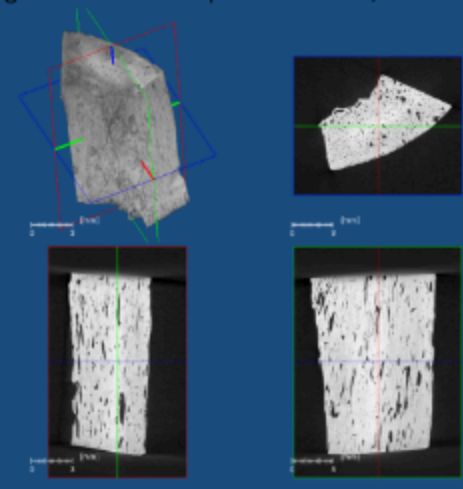

Figure 4: Volume rendering of aerobic sample before burning.

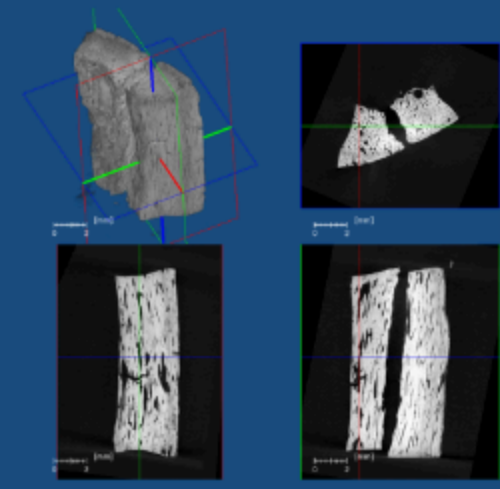

Figure 5: Volume rendering of aerobic sample at 1000 ◦ C.

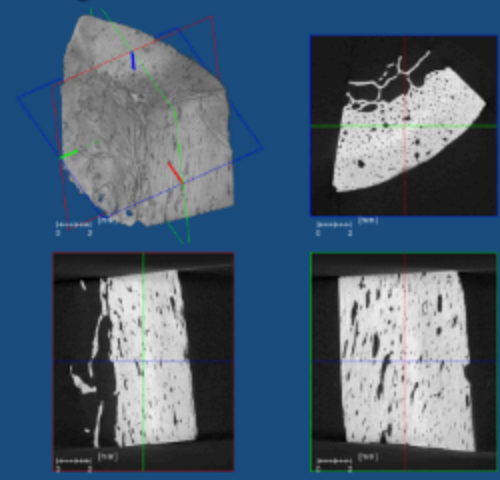

Figure 6: Volume rendering of anaerobic sample before burning.

Note: The views (clock-wise from the top-left) are arranged as: full rendering, XY, XZ, and YZ.

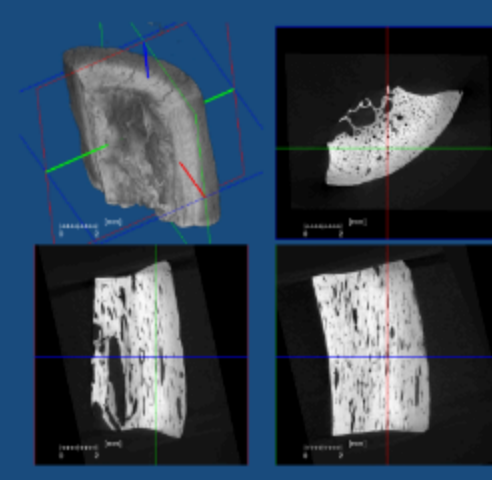

Figure 7: Volume rendering of anaerobic sample at 1000 ◦ C.

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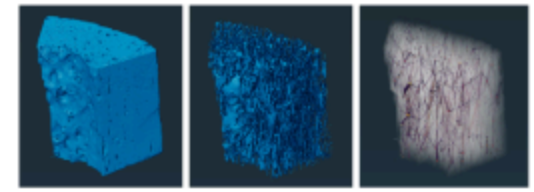

Figure 8: Volume renderings of parts of the image analysis workflow for unburnt femur fragment. Segmented bone label (left), segmented pores (middle), and pore network (right).

- Bone Volume: A clear negative association was observed between temperature and total pore volume.
- Critical Point: Significant changes in the pore network, likely from microfractures, become particularly pronounced around the 650 ◦ C mark. This aligns with findings by Marques et al. (2021) that identified 600 ◦ C-700 ◦ C as a critical threshold.

Discussion

- Core Finding: The results demonstrate a clear, temperature-dependent relationship between heat exposure and the degradation of bone microstructure.
- Mechanism: The critical threshold of 650 ◦ C likely corresponds to the point where the combustion of the bone's organic collagen matrix accelerates dramatically.
- Oxygen's Role: Differences between AE and AN conditions highlight oxygen's crucial role as a primary driver of structural decay (Festa et al., 2023).
- Forensic Utility: The strong, quantifiable correlations form the basis for a promising new tool for objectively estimating fire intensity in forensic analysis.

References

1. Festa, G. et al. (2023) 'In-situ anaerobic heating of human bones probed by Neutron diffraction', Analytical Chemistry, 95(4), pp. 2469–2477. doi:10.1021/acs.analchem.2c04721.
2. Marques, M.P. et al. (2021) 'Profiling of human burned bones: Oxidising versus reducing conditions', Scientific Reports, 11(1). doi:10.1038/s41598-020-80462-3.