reaction layers, while the low-wear regions near nozzle top showed reaction layers of 4~5mm in thickness. This is consistent with the model predictions of a total reaction layer thickness of ~5mm, with erosion removing portions of the reaction layer at different rates in different locations. Typical micrographs are shown in Fig. 9, and are arranged to illustrate these numbers.

Scanning electron microscope analysis of the reaction layer revealed elevated concentrations of Fe, Al and S, and depleted concentrations of Mg and Si. This provides evidence of a surface reaction layer containing infiltrated steel and alumina diffusion / capture that led to calcium aluminates / CaA_x (presumably liquid during casting), in addition to unreacted grains of magnesia from the original doloma. There is also evidence of CaS, presumably from reaction with S in the steel, and gas pores, presumably from graphite reactions. Beneath the reaction layer, the micrographs also reveal a 1-2.5 mm thick layer of carbon depletion before finally reaching the original unreacted doloma. Clearly, there are many phenomena yet to consider in the model.

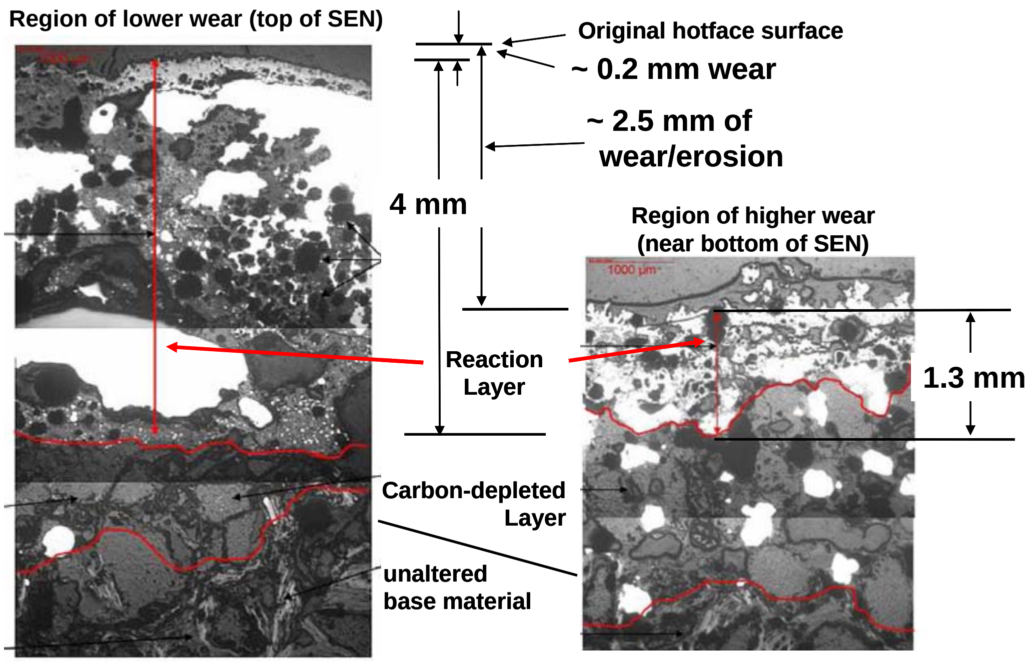

Fig. 9 - Microstructure near nozzle surface showing unaltered doloma refractory, carbon-depleted layer, and reaction layer, which is slightly eroded near SEN top (left) and greatly eroded near SEN bottom (right)

Conclusions

A detailed mechanistic 3-stage model has been developed to simulate diffusion, liquification, composition changes, and erosion of nozzle refractory walls. It is a macroscopic one-dimensional finite-element diffusion model, with different coefficients in each of three phase layers. The model has been validated with an analytical solution, and applied to simulate ~3 hours of service life of a typical doloma nozzle, where measurements were available. Finally, the model results can be interpreted to predict practical parameters such as erosion rate.

The doloma nozzles in the present study appear to have eroded at an average rate of ~1mm/hour and liquefied over 4ppm of alumina, which likely corresponds to clogging protection from ~40ppm total alumina inclusions in the flowing steel. The model predictions are roughly consistent with the measurements, considering the many crude assumptions. With much further work, this promising model could become a useful tool.

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