

## A time-based corrosion model for ammunition at the Paardenmarkt

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Ammunition at the Paardenmarkt has been corroding in a marine environment, without any known protection against corrosion. This corrosion started immediately when the ammunition was dumped (1919-1920) and continues to this day, 105 years later. In order to estimate the current condition of the shells, constructed with brass cartridge, steel shell and zamak fuse, an extensive three-year experiment was conducted, in which metal coupons representing the materials used in the construction of these shells, in various configurations (buried, on top of the sand, half upright) and in different salinities (seawater, fresh water, brackish water). Based on the outcomes of those experiments, predictive modeling of corrosion was undertaken, using the power-law equation:

$$D(t) = k \cdot t^n$$

where  $D(t)$  represents the damage (e.g., mass loss or pit depth) in mm at time  $t$  in years,  $k$  is a material- and environment-specific constant, and  $n$  reflects the rate of corrosion progression. Fitting of these parameters was performed with the `scipy` module in python, and these fitted parameters subsequently used in Monte Carlo simulations to estimate the accumulated corrosion loss for 105 years.

Accumulated metal loss due to corrosion of the different metals was estimated at  $(0.544 \pm 0.048)$  mm for zamak when combined with steel, versus  $(15.2 \pm 3.2)$  mm for zamak alone, and at  $(5.78 \pm 0.79)$  mm for steel versus  $(2.5 \pm 1.2)$  mm for steel when combined with zamak. The accumulated material loss for zamak is the only averaged value that exceeds the assumed thickness at construction.

Leakage of the most part of the munition at the Paardenmarkt is therefore very probable. Based on the simulations, 95% of ammunition is already leaking. The cause of the leakage for this type of munition would be the corrosion of the zamak fuse in 98% of penetrated munition. If ammunition is not yet leaking, penetration is expected in the coming 30 years. These findings are in line with observations from the traces of TNT and chemical warfare agents in the water column and from the leakages seen by experts at the dismantling facility at Poelkapelle.

### Keywords

Corrosion; Paardenmarkt; Power Law Modelling