Fig. 1 - The fleet of king Richard II leaves Ireland (M 19). Jean Creton: Histoire du Roy d'Angleterre Richard II. France, 1401-1405. British Library, Harley 1319, fol. 18 (from [1])

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THE BREMEN COG PROJECT THE CONSERVATION OF A BIG MEDIEVAL SHIP

The Bremen Cog from AD 1380 is one of the world's largest ship finds. It is 23.27 m long, 7.62 m wide and 7.02 m high to the top of the capstan on the castle deck. Its conservation took 19 years.
A specially developed two-step PEG-treatment was employed at an extraordinary scale: the conservation tank held 800 m^3 PEG-solution. The achieved stabilisation of the once waterlogged timbers is good, residual shrinkages average 3.1%, corresponding to an anti-shrinkage-efficiency (ASE) of 80%. The novel conservation method was a success, and the concept of rebuilding the ship before conservation proved to be valid.

Cogs were the ships of merchants and kings along the coasts of Northern Europe. They were high and sturdy ships built to take bulk cargo, merchandise or troops of warriors. The cogs ruled the Northern European seas in the 13th and 14th centuries. They gave prestige and power to kings and wealth to the coastal towns from England to Novgorod. Cogs were depicted on town seals, on walls and vaults of churches, and in illuminated manuscripts [1] (Fig. 1).

But no one in our time knew what a cog really looked like until 1962, when a dredge in the River Weser in Bremen hit upon a strange wooden hull (Fig. 2). Art historian Siegfried Fliedner from the town museum was called in, and from several construction features he dared to identify the ship as a big medieval cog. The extremely wide clinker-laid hull planks, the straight stem und stern posts, and the castle deck all resembled the pictures on certain seals from Hanseatic towns. Fliedner decided to salvage the unique wreck [2, 3].

The salvage

The iron nails holding the hull together had corroded away, so there was no way to lift the ship as a whole. There was neither

Fig. 2 - A strange hull in the river Weser: very wide clinker-laid planks fastened to each other with big, clenched iron nails run into straight stem posts fore and aft. These are features of a cog (Photo: K. Schierholz, Focke-Museum)

money nor time, with winter ice threatening, to arrange an excavation in a caisson, as was done for the Viking ships in Roskilde Fiord in Denmark. The cog had to be taken up timber by timber, with the help of a helmet diver groping his way in the dark brown water of the river (Fig. 3).

About 2,000 pieces of waterlogged wood were lifted and placed in water-filled tanks and shipped to a warehouse in the harbour. Rosemarie Pohl-Weber, Fliedner's new colleague, spent many weeks in a diving bell, searching the riverbed with probes and a metal detector for any possible pieces from the cog that were not found in the first campaign [4].

The reconstruction

The federal government of Germany, the government of Bremen, and the town of Bremerhaven established a foundation and built the Deutsches Schiffahrtsmuseum in Bremerhaven. In 1972 the ship's timbers could be transferred to the new museum. Master shipwright Werner Lahn and a few helping hands reconstructed the cog from the 2,000 wet timbers. She is 23.27 m long, 7.62 m wide and 7.02 m high from the keel to the top of the capstan on the castle deck [5]. A technique for gluing wet wood with a resorcinol resin had to be developed [6], and the traditional method of joining timbers with wooden dowels and nails had to be modified. A spraying system kept timbers and the ship wet all the time, for seven years, to avoid any drying damage prior to conservation (Fig. 4).

The conservation problem

Waterlogged archaeological wood is a strange and delicate material. When it dries, it shrinks cracks and warps. During its long burial in a wet environment, micro-organisms, mainly bacteria, have consumed parts of the wood substance of the cell walls, or have broken them down to low molecular weight fragments. Cavities have developed and have been filled with water. The water supports the degraded cell walls and damaged cells; the wet wood does not show its weakness.

But on drying, water evaporates from the cells. Water surfaces develop in the cell lumina, and with their surface tension they pull at the cell walls. If the cell walls are degraded, they cannot withstand the tension, they collapse, and so does the whole cell. The water surfaces sink deeper and deeper into the wood during the drying process, and collapse affects the whole piece of wood. To avoid heavy shrinkage, splits and warping, one has to strengthen the structure of the wet wood before it is allowed to dry.

Polyethylene glycol (PEG), which was used to stabilise such fresh wood as veneers and gun stocks, was the choice substance also for the treatment of the ship. PEG is a colourless and water soluble artificial wax. It is chemically stable, cheap and easy to handle. When a piece of waterlogged wood is placed in a PEG-solution, PEG molecules will diffuse into the wood and substitute part of the water. When the wood is allowed to dry, the residual water evaporates and the PEG precipitates in and on the cell walls. It solidifies and reinforces the degraded wood structure against shrinkage and

Fig. 3 - Feeling his way in near-zero visibility, a hard-hat diver tries to understand and to describe to the archaeologists on board the barge the structure of timbers he is going to attach to the crane (Photo: L. Kull, Bremen)

Fig. 4 - The 4th strake. Reconstructing the cog from waterlogged timbers called for 100% relative humidity - fog - in the cog hall and for constant spraying of the wood. Wooden dowels and treenails proved to be the best choice for assembling the wet timbers (Photo: G. Meierdierks, DSM)

Fig. 5 - Building the stainless-steel conservation tank around the reconstructed cog (Photo: P. Hoffmann, DSM)

collapse. The question is, however, which PEG is the best and which molecular size is suitable?

High molecular weight PEG 3000 or 4000 (MW 3,000 or 4,000) is solid, like stearin, at room temperature, and gives a good stability to the wood. But it permeates less degraded wood only very poorly, if at all. Low molecular weight PEG 200 or 400 permeates much better. But these PEGs are hygroscopic, and wood impregnated with them tends to absorb moisture from the air; it never really dries. Apart from that, low molecular PEG is liquid at room temperature, so it cannot strengthen heavily degraded wood. In 1981, the largest ever conservation tank was built around the cog (Fig. 5).

My co-workers in the museum filled the tank around the cog with 800 m^3 of water, and we started to add PEG 200. Our budget was good for 40 tonnes per year, for a 5% increase of the concentration. The final PEG concentration would be 70%.

The two-step PEG-treatment

Over a couple of years I had been looking closer at the stabilising capacities of a wide range of PEGs for oak woods of various degrees of degradation. Penetration of PEG into cell walls was investigated, as was the hygroscopicity of impregnated wood. In the end I could design a novel two-step PEG-treatment which would stabilise timbers of all states of preservation, even timbers consisting of tissue of different degrees of degradation at the same time [7]: in a first bath containing low molecular PEG 200, this PEG diffuses into the wood and into the cell walls of the only slightly degraded parts of the wood. The PEG 200 replaces the water in the cell walls. When the wood dries after treatment, the PEG 200 remains there, held absorbed by physical forces. It keeps the cell walls in a permanently swollen state, and prevents the wood from shrinking.

In a second bath with high molecular PEG 3000, this PEG diffuses into the areas of highly degraded wood only. It cannot penetrate into non-degraded cell walls. But in the degraded tissue the PEG 3000 fills the cell wall remnants, and also the cell lumina to a certain degree. In this bath non-absorbed superfluous PEG 200 from the heavily degraded areas diffuses out of the wood again. As a result, after the second bath the stabilised wood is not very hygroscopic any more. The chosen PEG-concentration for the first bath was 40%, and 70% for the second. The second bath had to be heated to 40 °C to keep the solution of PEG 3000 liquid.

On drying, laboratory samples showed residual shrinkages between 0 and 5%; without stabilisation comparable samples shrunk 15% to 25%. If all wood qualities were stabilised to the same degree, presumably no tensions would build up in larger, multiquality timbers, i.e. tensions that normally lead to distortions and cracks.

This two-step impregnation method was the right procedure for the cog.

The board of the museum invited the leading waterlogged wood conservators of the world to Bremerhaven. The specialists examined the laboratory results, the two-step PEG-method, and the conservation scheme. They approved. The large-scale experiment began.

The conservation of the cog

During the first treatment step we added 5% PEG 200 per annum to the bath. Two times a year a tank lorry came with 20 tonnes of liquid PEG, and pumped it into the tank. In the preceding days we had evaporated the corresponding volume of water from the tank in a large evaporator installed in the basement. In all, 320 tonnes of PEG 200 were needed for the first bath.

Visitors to the museum could watch the cog through large windows from a gallery. Floodlights hung in the water, and in a green and mysterious twilight the visitors saw dark beams and parts of the hull planking. The divers working on the Mary Rose, the sunken battleship of King Henry VIII, once came to see the cog. They said it reminded them of how their ship had looked on the bottom of the sea on days with good visibility.

Two times a year we took 5 mm-thick core samples from representative timbers and analysed them for PEG-content and PEG-distribution. The PEG profiles told us how far the timbers still were from the desired degree of impregnation [8].

The cog sat in the bath for 15 years. We were limited by our annual budget and could not buy as much PEG as we would have liked. Otherwise, the impregnation with PEG 200 could have been finished in about five years.

Large volumes of conservation solutions can only be disposed of with the consent of the authorities. It took several years and a series of limnological and wastewater treatment investigations, and of expert's opinions to demonstrate that both PEG 200 and PEG 3000 are completely biodegradable in a normal wastewater treatment plant. The authorities then permitted us to pump off the solutions down the drains very slowly, so that the microbes in the treatment plant could adapt themselves to the PEG macromolecules. It took three months to pump off the first bath.

After 15 years, in the summer 1995, we stood in the cog again. The warm dark brown wood gleamed and the cog looked beautiful. Many visitors came, including journalists from newspapers, radio and television stations, as well as numerous conservators and archaeologists. They all wanted to see the cog and to creep into her and around her in the tank.

We laid out 250 metres of warm water tubes under the ship and connected them to the central heating of the museum. The second bath had to be heated to 40 °C to keep the solution of PEG 3000 liquid.

In November 1995 we began to fill the tank again. We arranged with the producers of the PEG to synthesise it on demand, to fill the 100 °C melt directly into heated tankers, and to ship it overnight from the factory to the museum 800 km away. Here the melt, together with water from a fire hydrant, was pumped through a mixing station, and the resulting 60% solution was piped into the tank. The tankers came two days a week.

The days between the deliveries were devoted to work in the tank. We laid layer after layer of 5x1 m elastomer coated textile balloons under the ship and into its hold, and filled them with brine. The balloons were a means of reducing the active volume in the tank in order to save on expensive PEG. The heavy 18%-saltwater solution kept the balloons submerged in the PEG solution (Fig. 6). The balloons reduced the active volume by about 50%. Eighty tonnes of salt were used to produce brine. Thirteen tankers brought 270 tonnes of PEG 3000.These exciting weeks have been described in greater detail elsewhere [9].

A year later some balloons were removed, and more PEG 3000-melt was mixed into the solution to increase its concentration to the final 70%. Again we monitored the progress of the impregnation. The PEG-profiles confirmed my expectations: PEG 3000 filled the outer, more degraded portions of the timbers; nearly no PEG 200 was found there anymore. But in the less degraded inner parts of the timbers sufficient PEG 200 remained for a good stabilisation (Fig. 7). When no more PEG 3000 accumulated in the wood, we terminated the impregnation, in March 1999. The second bath had lasted for three years.

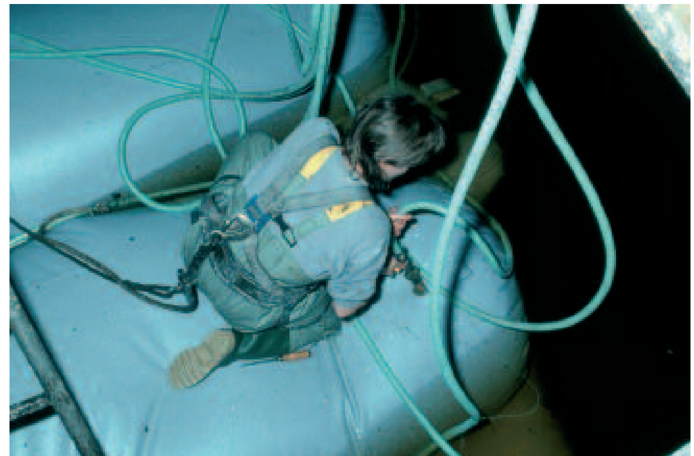

Fig. 6 - Filling displacement balloons in the tank with brine in a tropical climate. The PEG solution had to be kept at 40 °C (Photo: P. Hoffmann, DSM)

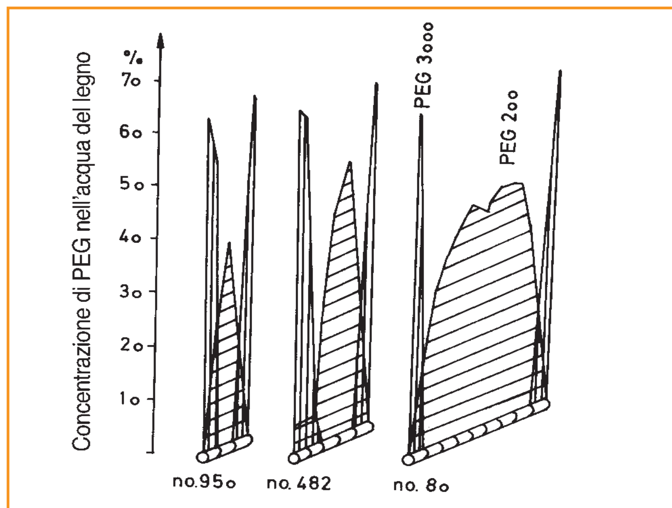

Fig. 7 - At the end of the second treatment step the PEG-profiles show PEG 200 in the inner parts of planks and ribs, and PEG 3000 in their surface layers

Fig. 8 - Turning the huge conservation tank into 130 tons of scrap iron. The starboard side of the castle deck is cleared in the foreground (Photo: P. Hoffmann, DSM)

Fig. 9 - Due to the slow pumping-off, the concentrated PEG 3000 solution has solidified on the timbers of the hull (Photo: E. Laska, DSM)

Fig. 10 - A view into the Cog. The port side has eroded away down to below the huge cross-beams. The asymmetric steel-rod-system transfers most of the hull's weight to the ceiling (Photo: E. Laska, DSM)

The steelworkers from a nearby shipyard found it a rather intricate job to dismantle the tank. No pieces of steel, nor any droplets of liquid steel from their plasma torches, could be allowed to fall onto the ship in the tank. But once they had found out how to ensure that, it did not take long to cut the largest conservation tank in the world down to a heap of scrap iron (Fig. 8).

Results and discussion

By Christmas 1999, the cog stood free once again in the cog hall of the museum. She looked like a ship on an arctic expedition, encrusted in white, solidified PEG-solution (Fig. 9). Cleaning was tedious. But with a carefully applied steam jet, and with brushes, sponges, and spatulas, we could remove the PEG without washing too much of it out of the wood surface.

Today the timbers have a nice dark grey-brown colour. Just enough PEG has been washed out of the surfaces to render them naturally looking and dry. After 600 years we still see charred patches on the planks: the medieval shipwrights heated the planks over a fire to make them soft and pliable, so that they could bend them in place onto the hull. We will not apply any surface treatment to the wood; it looks very attractive as it is. But we have worked over the dry timbers with a hot-air blower. We just melted the PEG in the surface, and that gave a deeper and more transparent colour to the wood.

After 5 years of drying, the residual cross-grain shrinkage of planks and beams measures 3,1% on average, and the longitudinal shrinkage is zero. Comparing these values to the average shrinkage of 15% of non-treated wood from the cog, the anti-shrinkage-efficiency (ASE) of the treatment is 80%. The full-size two-step PEG-treatment has rendered the same good results as the laboratory experiments. We feel very relieved that the scaling-up of the method has not reduced its efficiency.

Only a few heavy beams have warped. They were cut from the centre of the tree. Such centre-beams, when made of fresh wood, are extremely difficult to dry without damage. This limited warping, however, has not influenced the integrity of the hull structure. It is only a slight aesthetic irritation.

Planks and beams have become hard and stiff through conservation. The extravagant decision to rebuild the cog from the wet and soft timbers before conservation was right.

The cog is a nearly complete ship: only the upper part of the port side has eroded away in the riverbed. Visitors standing at the foot of the stem, or at the stern, are amazed at the impact of the bulky and high hull, and at the same time delight in the elegant strakes of the enormously wide planks. The cog seems to be ready to move at any moment (Fig. 10 to 12).

ABSTRACT

Il progetto per il recupero e la conservazione della Cocca di Brema

La Cocca di Brema, risalente al 1380 d.C., è una delle più grandi navi antiche mai rinvenute. È lunga 23,27 m, larga 7,62 m e alta 7,02 alla sommità dell'alberino sul ponte di castello. La sua conservazione ha richiesto 19 anni. È stato sviluppato e utilizzato un trattamento in due stadi a base di PEG, impiegando circa 800 m^3 di soluzione. La stabilizzazione è stata conseguita con grande successo e la procedura di ricostruzione della nave dopo l'intervento di conservazione si è dimostrata ottimale.

Fig. 11 - The Bremen Cog as she stands in the Deutsches Schiffahrtsmuseum (Photo: E. Laska, DSM)

Fig. 12 - Werner Lahn's drawings of the Bremen Cog were the basis for the construction of several full-size replicas. Here the Hansekogge from Kiel sails in a light breeze (Photo: U. Dahl, Flensburg)

Conclusions

The Bremen cog project has taken 38 years, from the salvage to the presentation of the stabilised ship in the museum. Two major decisions characterise this project, and they were both successful. First, we rebuilt the ship from its waterlogged timbers before conservation, as the planks would have become stiff and unpliable in conservation. And second, we stabilised the ship's timbers with a specially developed two-step treatment using low molecular PEG and high molecular PEG. This two-step PEG-treatment has meanwhile been adopted for the conservation of other archaeological ships, such as the Kinneret boat in Israel, the Shinan Treasure Ship in Korea, and the Mary Rose in Britain. The treatment is expensive, but it gives excellent results with multi-quality timbers.

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