Timber structures in aggressive environments

STEP lecture E26
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Objective

To present information about timber structures under the influence of aggressive environments.

Summary

A brief explanation is given of the behaviour of timber and wood-based materials when exposed to chemical actions, high temperatures and the influences of ultraviolet rays and weathering. The material properties and the resistance to these actions are described. The use of timber in practice in aggressive environments is shown with examples of projects carried out.

Introduction

The material properties of timber are mainly determined by its structural composition. As a natural product wood shows great deviations in respect of these properties, not only between different species of wood but also in the same species. A certain homogeneity of material properties can be achieved by chipping the wood or cutting into bits and subsequently putting then panels together again to form glued laminated timber or wood-based materials. Glued laminated timber displays the same anisotropic characteristics of solid timber with significant differences between properties in the direction of grain and perpendicular to it but reduces the significant defects.

With the use of wood-based materials or glued laminated timber material final properties can be varied by changing the properties of the constituents and their shape and assembly. Of significant importance is the choice of the glue used. Factors to be considered in choosing an adhesive for structural timber include behaviour on exposure to the environment and durability, ease of use during production and the nature of the joint to be made. For more information concerning material properties see lectures A4 and A12.

A number of chemical processes and other similar events may give rise to chemically polluted atmospheres often associated with the presence of high-temperature moisture-laden air. Swimming-pools will also seem an obvious situation for such exposure risks, although the equilibrium moisture content of timber structures can be quite low due to the heated environment.

On account of their high resistance to the effects of aggressive environment, timber and wood-based materials are often used for structures where such conditions prevail. This natural resistance of timber is not a fixed value, but the behaviour under different negative influences varies greatly and also changes with the course of time.

Resistance to chemical actions

In comparison with other materials, such as steel, timber offers remarkable resistance to the effects of chemical actions. Damage or destruction of timber, starting from its surface as a result of physical and chemical interaction, is called corrosion. It must be realised that aggressive media mainly attack the hemicelluloses and lignin and not the cellulose. For this reason coniferous timber, with its higher percentage of lignin, displays in general a higher corrosion resistance than deciduous timber. Corrosion phenomena are mostly associated with a brown or dark colouring of the timber, which spreads from the marginal zones to the central sections. All these effects depend on the strength of the chemical and the period of exposure. The manner of destruction is similar to the behaviour of timber under the influence of fire. The decrease in strength effects only the first 10 *mm* to 20 *mm* depth, while for the rest of the section the natural properties remain unchanged. In designing timber structures it is usual to allow for these effects by increasing the cross-section.

Timber is very resistant to acids and also to salt solutions. Alkalies lead more quickly to a destruction of timber, especially if high temperatures occur at the same time. At a pH-value of between 3 and 10 it may be assumed that no damage will occur, however certain types of timber react differently and the time and temperature of influence play an important part. For a short time higher or lower pH-values will cause no damage, but higher temperatures accelerate the speed of destruction.

The influence of aggressive gases, for example ammonia and formaldehyde, have no negative effects on either solid timber or glued laminated timber. Sulphur dioxide causes certain damage only in combination with high temperatures and high moisture content.

To determine the real characteristics of the resistance to chemical actions it is often necessary to carry out tests. Such tests are normally conducted in two parts, first of all using small pieces of timber exposed to highly concentrated attacks, in order to obtain qualitative statements, and later with full scale tests to quantify these values. This method is of special importance for glued laminated timber and wood-based materials, where the choice of glue or binding material is also significant in increasing the resistance to chemical actions.

Glued laminated timber pieces have been treated with highly concentrated sulphuric acid to measure its effect on the timber and to determine the most suitable type of adhesive. From these tests it was found that only certain adhesives of the phenol-formaldehyde and resorcinol-formaldehyde type and their combinations satisfy this particular requirement. With such adhesives no seeping of acid into gluelines was seen, which would have led to the same dark colouring of the timber alongside the gluelines.

A special form of chemical action may occur where timber is in immediate contact with metals, for example with mechanical fasteners. Depending on the type of timber and the moisture content, corrosion of the metal surface leads to colouring of timber and also changes its mechanical properties. Iron, when in contact with wood of high tannic acid content, like oak, causes a black colouring. The tensile strength decreases with long contact, the compressive strength is not affected. On small contact areas the attack occurs very slowly and is limited in extent. For trussed rafter roofs in stables or similar buildings, with nail-plate connections, special corrosion protection have to be provided. In such cases the metal parts have to be galvanised or coated with plastics.

A secondary effect of corrosion appears if the decomposition products of corrosion are washed out by water or other fluids. The consequence is dark coloured traces on other parts of the timber, which can be unsightly.

In most cases where timber is exposed to chemical actions no special conservation measures are necessary, because the natural resistance is adequate. In fact it is better if the planed surfaces of timber beams are not coated with wood preservatives, since the paint forms grooves in which sedimentation of aggressive chemicals is facilitated.

Examples of projects carried out

For the reconstruction of a storage battery manufacturing plant (see Figure 1) glued laminated timber was used in order to resist the attacks of sulphuric acid vapours, and to guarantee the durability of the structure for at least twenty years. Tests have determined the amount of weakening to be expected over a period of twenty years. These results formed the basis for the calculation of the cross-section.

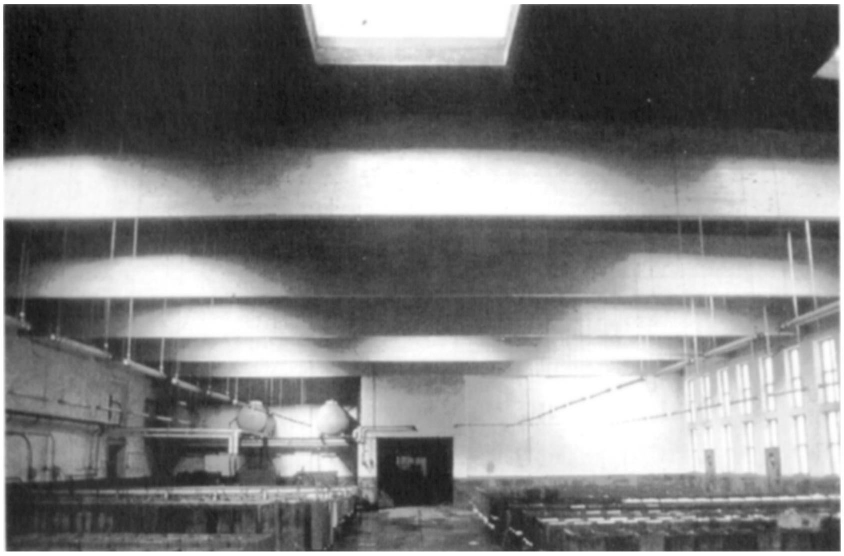

Figure 1 *Timber roof structure of a storage battery manufacturing plant.*

As described before, these tests were performed in two steps. The first was to choose the right adhesive with small-scale tests, and the second to observe the behaviour of a girder made with this adhesive under operating conditions in the manufacturing plant over a period of several weeks.

The roof of a central storehouse of a cheese production firm was also built using glued laminated timber. Timber being able to resist the expected formation of lactic acid during fermentation better than other materials, for example steel.

To solve the corrosion problems occurring during the storage of de-icing salt in storehouses or silos, many such buildings have been erected using glued laminated timber, see Figure 2. Metal components were in general of stainless steel.

Because of the formation of condensation water and ammonia vapours, set free during the production of fresh ice, glued laminated timber girders and stainless steel connectors were chosen, for a roof construction over an ice skating stadium, see Figure 3.

The roof over a thermal spa, which is exposed to thermal spring vapours, has been built with glued laminated timber, see Figure 4. The timber girders used were produced using water-proof and boil-proof glues. The quality of the metal fasteners was chosen to withstand the thermal spring vapours.

Figure 2 Silo from glulam for salt storage.

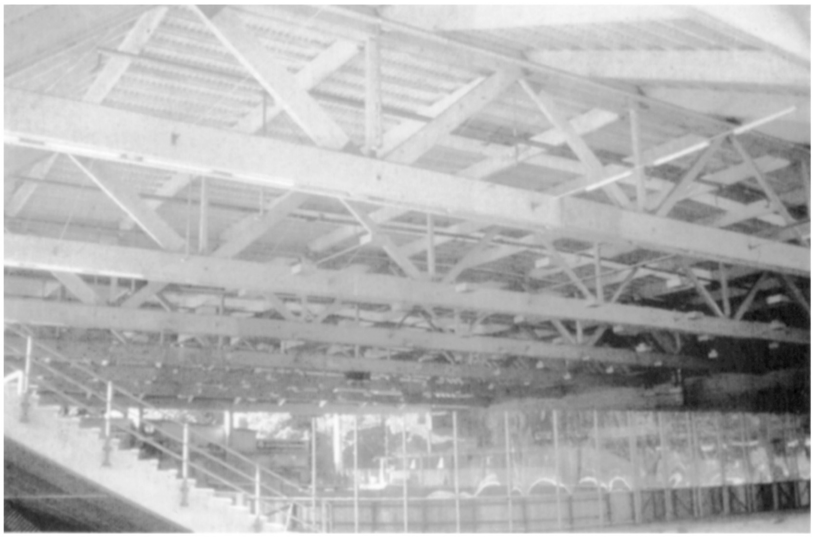

Figure 3 Timber roof structure of an ice skating arena.

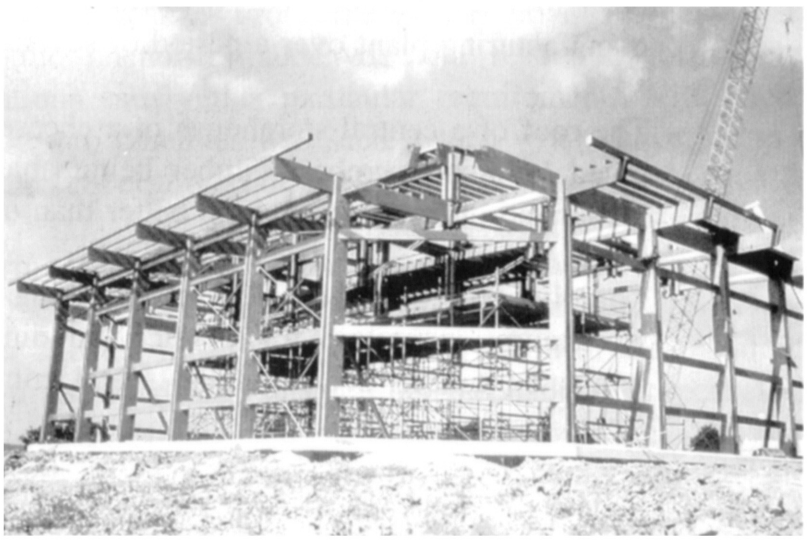

Figure 4 Timber roof structure of a heated swimming pool.

Resistance to high temperatures

The thermal properties of timber are extremely important. The specific heat of timber is comparatively high, in relation to its density, but of minor importance compared with its thermal conductivity. The thermal conductivity of timber is approximately 0,4% of steel. It varies, approximately in proportion to density, being lowest for low density softwood and highest for high density hardwood. The thermal conductivity also increases significantly with moisture content, by perhaps a third for a moisture content increase of 40%.

High temperatures affect material properties of timber only if the time of exposure is long enough. The degree of destruction also depends on the level of these temperatures. Temperatures around 100 °C lead to a brown colouring of timber but the weakening of strength can hardly be detected. At temperatures up to 150 °C, the first decrease of strength occurs within a couple of weeks. Higher temperatures accelerate the destruction and above 250 °C unprotected timber, depending on its density and environmental conditions, is rather quickly destroyed. In general, it can be said that the higher the density the greater the resistance to high temperatures.

On account of the low thermal conductivity of timber the thermal destruction is transmitted slowly from the outer parts to the central section, so that appropriately designed elements have a sufficient resistance to high temperatures. The simultaneous influence of high temperatures and increased humidity causes significant changes in the material properties of timber; both the strength and the stiffness decrease.

Example of projects carried out

Figure 5 shows the roof over an enamel smelting house. Timber has been used successfully to resist the continuous high temperatures inside the building augmented by the changing climatic conditions on the outside.

Figure 5 Timber roof structure of an enamel smelting house.

Resistance to the influences of ultraviolet radiation and rain

Resistance to the effects of weathering depends mainly on the structure of the timber. Bulk density, thickness of cell walls and constituent substances are highly significant. When estimating degree of resistance a distinction has to be made between the effects of ultraviolet radiation alone and conditions where timber can also be reached by rain.

Timber exposed to UV-radiation, suffers from discolouring, which can be irregular for different radiation intensities. In this way timber yellows and in course of time takes on an intensive brown colour, resulting from little dark decomposition products of the corroding surface. Translucent varnish is not suitable for protecting timber from these effects. Instead, paints available in a large variety of colours should be used.

With the additional influence of fluids or high humidity these decomposition products are washed out, leading to a grey colouring of the wood. The surface thus created is rough and full of corrugations, which reduce the cross-sectional area. Besides this direct reduction of area or quality reduction of performance, secondary destructive processes caused by fungi are likely, and therefore further destruction of timber can take place, and which is usually of more significance.

The resistance of wood-based materials is not only determined by the structure of the timber used; it is also influenced by the adhesive or binding material used. Urea resin based glues are rather quickly destroyed by swelling and shrinking of adjacent timber parts, which decreases the overall strength. For full exposure to weather, water-proof and boil-proof adhesives should be chosen; these can be obtained by using certain adhesives of the phenol-formaldehyde or resorcinol-formaldehyde type. Only these types can provide resistance to the weathering of wood-based materials. Besides the proper choice of adhesives improved surface treatments also increase the resistance to the effects of ultraviolet radiation and weathering.

Although it is normal to dry timber to a moisture content equivalent to the average relative atmospheric humidity anticipated movement problems are often also encountered: shrinkage with drying and swelling with wetting. Faults such as cracks or fissures appear, in other situations cross-sectional movement may become apparent as warping through the effects of twisted grain. The obvious solution to all these problems is to use only timber with low movement but this is not always realistic. The alternative is to impregnate timber with chemicals which induce stabilisation, although processes of this type are also frequently unrealistic because of the difficulty of achieving deep penetration.

One approach is to enclose timber within a protective film in order to stabilise the moisture content. Paint and varnish coatings will act in this way, provided they completely cover the timber and are not damaged in any way. Unfortunately whilst these coatings give good protection against rainfall, they are unable to prevent moisture content changes resulting from slow seasonal fluctuations in atmospheric humidity. As a result the painted timbers shrink or swell with changes in relative humidity, causing the surface coating to fracture. Rain is absorbed into the crack by capillary action and the remaining paint coating restricts evaporation, so that the moisture content increases and thus causes the dampness to accumulate. Therefore in any case the paints to be used should be micro-porous, that water may evaporate.

The most widely used conservation system is to ensure that timber remains dry by taking appropriate structural precautions. Thus buildings have to be designed to protect the structure from the penetration of dampness, especially in the form of dripping water, e.g. rain but also as condensation water. For example, walls should be designed to resist penetrating rain, perhaps as cavity constructions, which have to be built with the possibility of adequate ventilation. In some cases where timber girders are exposed directly to the weather it is often more useful to protect them with a cheap cladding, which can be replaced from time to time, than to preserve the whole girder by chemical treatments.

Concluding remarks

Timber offers a high resistance against aggressive environments and can be successfully used under such conditions. The maintenance cost for steel or concrete structures in identical environments are much higher than for comparative timber structures. Steel structures need a regular coating with corrosion protection and concrete buildings a permanent observation of the concrete surface in order to detect cracks which can lead to corrosion of the reinforcement bars. Timber, however, needs very little maintenance in most aggressive environments although, unless stainless steel is used, the corrosion protection of the steel fasteners has to be checked in regular intervals.