- *Improved dimensional stability*
- *Improved resistance to fungal decay*
- *Non-toxic*
- *Reduced fracture resistance*
- *Not for in-ground contact applications*

Heat treatment of softwoods to improve stability and durability

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Background

The use of softwoods in exterior applications has to address the related problems of stability and durability, and historically this has been done through surface coating and by impregnation with fungicidal materials. The cost implications of painting, with ongoing maintenance, are obvious, and the increasing environmental objections to all types of chemical fungicides are equally well known. In recent years research work in Europe has focused on two alternative and complimentary technologies to address these problems. The more sophisticated of these processes is chemical modification, with methods such as acetylation and fufurylation yielding timber of very high durability and considerably improved stability. This is an expensive process requiring high quality feedstock, and will be the subject of a future COFORD Connects Note. A simpler and cheaper process, considered in this Note, is heat treatment in which the timber is taken to temperatures considerably above those used for conventional drying, leading to chemical changes which reduce moisture induced dimensional change and give improved exterior durability. Using native softwoods, both laboratory and field trials have been carried out, and it is now possible to quantify the potential advantages and disadvantages of heat treatment in the Irish context.

The Process

There is no single standard heat treatment process; rather there are a number of similar approaches, all of which involve heating the wood in an inert atmosphere to temperatures around 190 °C. Commercial timber from these processes goes under various names, for example Thermowood from Finland, Retiwood from France, Westwood from the USA and Platowood from the Netherlands. Although processes differ in detail the Platowood process can be taken as typical.

This process combines an initial hydrothermolysis step with a dry curing step. The presence of abundant moisture in the woody cell wall during this hydrothermolysis phase results is the occurrence of chemical transformations and provokes increased reactivity of the cell wall components. In order to reach a selective degree of depolymerisation of the hemicellulose during hydrothermolysis, relative mild conditions can be applied to limit unwanted side reactions which can influence the mechanical properties negatively. In the hydrothermolysis step wood is treated at temperatures typically between 160 -190 °C under increased pressure. A conventional wood drying process is then used to dry the treated wood to a moisture content of 10%. In the third step (curing) the dry intermediate product is heated again to temperatures typically between 170-190 °C. Figure 1, taken from the Plato handbook, illustrates the process flowpath.

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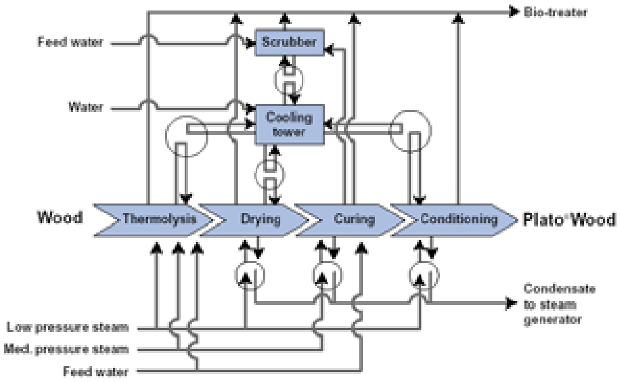

Figure 1: Schematic of the PLATO process.

The process time depends on the wood species used, the thickness and form of the wood, but typically is as follows:

1. Thermolysis 4-5 hours,
2. Drying step 3-5 days,
3. Curing step 14-16 hours,
4. Conditioning 2-3 days.

The total energy requirement for heat treatment is around two to three times that for a conventional drying cycle and the need for atmospheric control means that heat treatment kilns are more complex pieces of engineering than standard drying kilns.

The key changes resulting from the process are:

- reduced equilibrium moisture content,
- durability class 2-3 can be achieved,
- reduction of 15-40 % in shrinking and swelling,
- bending strength reduced by 5-18 %.

As the timber is evenly treated throughout the section it is usual to machine to final profile after heat treatment. Depending upon the severity of the treatment colour change moves towards a deeper brown and importantly the heat treated timber is non-toxic and so there are no application restrictions. The degree of improvement in durability class, from 5 to 3 or even 2, is a function of the severity of the treatment, but such improvement comes at the expense of loss of mechanical properties. This will be explained later.

Mechanism of Action

During heat treatment changes occur within the cellulose, hemicellulose and lignin components of the wood. Cellulose undergoes some reduction in molecular weight, but cellulose crystallinity can increase. Hemicelluloses are the most thermally reactive cell wall constituents having lower thermal stability due to their lack of crystallinity, and during thermal treatment carbonic acids, mainly acetic acid, will be formed as a result of cleavage of the acetyl groups. The formation of acetic acid further catalyses carbohydrates cleavage, causing a reduction of the degree of polymerisation. Acid catalysed degradation results in the formation of formaldehyde, furfural and other aldehydes as well as some lignin cleavage. The decomposition of hemicellluloses results in the reduction of the number of available hydroxyl groups and a lower concentration of reactive sites will therefore decrease the equilibrium moisture content of heat-treated wood and thus improve the dimensional stability. In addition, the acetic acid that has formed depolymerises the cellulose microfibrils in the amorphous area.

Changes within the lignin are equally complex. During the treatment bonds between phenylpropane units are partly broken but condensation reactions occur also. The longer the autohydrolysis time is, the more condensation reactions occur. Auto-condensation of lignin is believed to occur through the formation of methylene bridges connecting aromatic rings. The extent of these reactions is mild but they lead to an increase in cross-linking with consequent improvement in its dimensional stability and decreased hygroscopicity of wood.

In summary heat-treated wood has reduced hygroscopicity and improved dimensional stability because the cellulose microfibrils are surrounded by a more firm and inelastic network due to cross-linking within the lignin complex. The microfibrils have decreased expansion possibility and less capacity to absorb water between cellulose chains. This results in a lower fibre saturation point and a higher resistance to biological decay. The cell wall hemicellulose is transformed into a more hydrophobic network.

Timber species and applications

Northern European softwoods including Scots pine, maritime pine, the spruces and white fir have been the predominant species used in the process and have found applications in cladding, decking, flooring, door and window frames and garden furniture. In many of these applications the warm brown colour, imparted by the process is seen as an initial aesthetic advantage. Poplar is probably the most important hardwood to receive attention and has found application as cladding/siding. Other hardwoods with a history of treatment are beech, which it is claimed will match the durability of teak after treatment, and ash and birch. Juvenile teak has also been heat treated to improve stability for furniture applications, thereby improving the utility of small diameter plantation grown materials. In the Coford HEATREAT project the focus was on the main Irish commercial timbers, Sitka spruce (picea sitchensis), lodgepole pine (pinus contorta) and Japanese larch (larix kaempferi).

HEATREAT Project

Investigations into heat treatment processes started in 2007 with the COFORD HEATREAT project involving the University of Limerick and facilitated by the cooperation of several European treatment companies. Sitka spruce, lodgepole pine and Japanese larch were subject to three different treatment regimes, differing in severity, followed by mechanical testing and laboratory evaluation of durability using fungal exposure. Primary interests were dimensional stability during the process, improvement in stability and durability following the process.

An early and important observation was that in order to get the best through-process stability it is important to use good quality feedstock. Heat treatment imposes much greater stresses on the timber than those experienced in conventional kiln drying and exacerbates any existing flaws. On this point alone Japanese larch was disqualified as a suitable material for treatment due to the large numbers of knots and irregular grain. Good quality Sitka performed much better.

Physical property change results are broadly comparable with those obtained by the European processors. Figure 2 compares the moisture absorption isotherms of heat treated Sitka and an unmodified control, and considerable improvement in apparent.

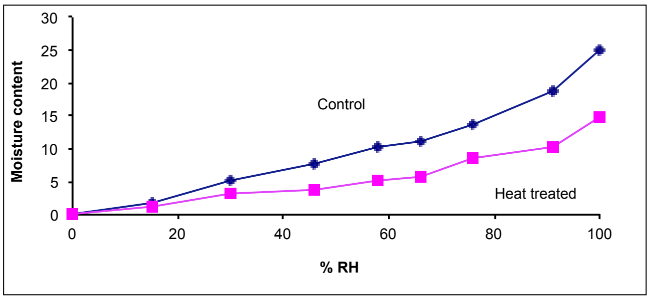

Figure 2: Comparison of equilibrium moisture content for heat treated Sitka spruce and untreated control.

As stated earlier there is some loss in mechanical properties associated with the process. In general timber becomes harder and more brittle. Figure 3 shows an electron micrograph of a heat treated timber fracture surface and demonstrates that failure occurs through fragmentation of the cell wall and separation of the middle lamella. Compared with an unmodified timber work to fracture is very considerably reduced and there is no great evidence of fibril pullout in the heat treated material. These differences in micro-fracture mechanisms explain the loss in toughness.

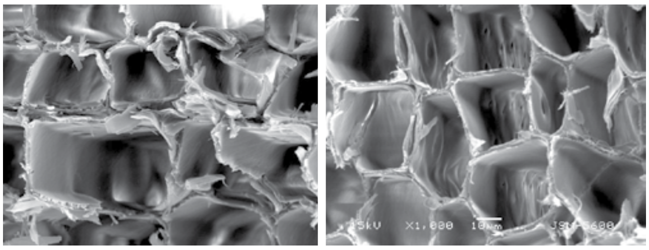

Figure 3: Fracture surface of heat treated Sitka spruce left and control right.

Following the initial laboratory work larger amounts of the treated materials were machined and used to manufacture representative cladding panels, using different profiles and using nail gun fixing. These panels, which are approximately one metre square, have now received almost nine years of exposure and have periodically been examined and scored on colour retention, durability, freedom from distortion and general appearance. Figure 3 shows the exposure site and situation and Figure 4 an individual panel.

Untreated softwood controls, exposed simultaneously, are now showing decay, whereas all of the heat treated panels remain free from decay and also show less dimensional distortion, with the best appearance being presented by the Sitka subject to the mildest heat treatment. Again it is apparent that the better the quality of the timber going into the process, the better the ultimate outcome.

Figure 4: Panel exposure test site near Clonmel, County Tipperary. Also showing the different profiles used to construct the panels.

Figure 5: A heat treated Sitka spruce panel after six years of exposure.

Some words of caution

Like many relatively new technologies awareness of the process limitations is important. First, the heat treatment process imposes significant stresses on the timber and this will exacerbate any existing flaws, and so quality selected timber should be used to reduce in-process losses. This cannot be over emphasised. Secondly, although durability class improvements from 4-5 up to 2-3 can be obtained, thus allowing use of heat treated softwoods in more exposed applications such as cladding, use of the timber in ground contact is not recommended. Thirdly the user should be aware of the mechanical changes that occur, with the wood becoming somewhat harder and more brittle, particularly with the more severe treatment procedures associated with maximum durability. However in normal, non-structural or low load, applications these property changes should not be a problem, and as mentioned, research has demonstrated that there is no need to pre-drill before nail fixing.

Conclusions

All mainland European countries now possess heat treatment plants and the process in its various forms is well established across the world, although so far no processor exists in Ireland or the UK. The market for these materials lies in those applications where improved stability, durability and paintability are needed, without the expense and toxic hazard of pressure impregnation. As architects and engineers become more familiar with the advantages and also the limitations of heat treated timber it is to be expected that it will be increasingly referred to in European standards and seen in project specifications.