Client Report:

Obtaining better utilisation of UK grown small diameter oak & other hardwood stems using a novel sawing pattern for the production of structural members

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Obtaining better utilisation of UK grown small diameter oak and other hardwood stems using a novel sawing pattern for the production of structural members

Final Report and guidance

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Executive Summary

This report presents the final results from the project 'Obtaining better utilisation of small diameter, low value UK grown oak stems and other hardwood species to produce re-engineered components of standard dimensions using a novel cutting and jointing technique'. The project was funded by the Forestry Commission under contract number PPD24/02, and is due to finish at the end of June 2005.

This research programme complements work carried out under both Forestry Commission and Construction Directorate funded projects and forms part of the extensive BRE and UK sawmilling industry research programme. The project has primarily focused on the use of oak, although alternative hardwoods have also been assessed within the project.

The principle objective of the project was to better utilise low value small diameter oak stems. In order to achieve the objective, the concept was devised whereby small diameter oak stems would be cut into four quarters, the edges machined and the sections bonded back together in a reverse orientation using a moisture insensitive adhesive. This would result in a square beam with a void running up the centre.

The project has proven that the concept works very well. The process of constructing inside out beams in the 'green' state has been streamlined, and in theory, could easily be semi-automated.

It is recommended that the small oak stems be machine rounded to produce straight cylinders before any follow on process is attempted. This improves the process efficiency and allows the construction of standard beam dimensions from machine rounded stems. Four bonding edges are then planned on the stem prior to cutting into four sections, the sections are then spread with adhesive, turned inside out and pressed. The beams are then dried and planned to clean up any surface imperfections.

A number of work tasks were undertaken to assess various aspects of producing re-engineered oak stems and their physical properties. Assessments included:

- Structural tests to ascertain strength characteristics
- Assessments on suitable preservative or protective treatments to provide protection to the non-durable beam interior
- Investigation on the distortional characteristics of different orientations of re-engineered components
- Assessment of drying characteristics

Results from these assessments indicate that:

- Re-engineered beams constructed from small oak stems (using the correct timber to void ratio) are both stronger and stiffer than solid oak beams processed from similar dimension material, and are comparable in strength and stiffness to solid beams processed from large diameter material.
- Assessments on suitable preservative treatment indicate that it is possible to achieve complete preservative penetration of freshly constructed re-engineered beams using a boron diffusion process. Using the same process, it is also possible to provide a shallow envelope of protection on material which has already been partially dried.

- The incidence of twist, bow & spring (after drying) is significantly reduced in re-engineered oak beams when compared to solid oak beams processed from the same material.
- Drying assessments indicate that the re-engineered small oak stems exhibit significantly less surface checks and splits than solid material processed and dried at the same rate.

At the beginning of the project, there was a certain amount of scepticism whether the concept of bonding small diameter oak and other hardwood stems inside-out in the green state would be achievable. The project has been successful in proving the idea and the assessments on re-engineered beams has all been extremely encouraging. Considering the amount of interest in the product from the wood industry and manufacturers, it is hope that after further investigation and assessment, the beams will be produced commercially sometime in the future.

Contents

Introduction

This report presents the results from eight work tasks designed to utilise low value small oak stems and other hardwood species by using a novel cutting and jointing technique to produce re-engineered components. The work was funded by the Forestry commission and complements work being undertaken in a government funded Partners in Innovation project. This report represents the final milestone of the contract, due at the end of June 2005.

The UK Hardwood sawmilling industry produces approximately 130,000 m^3 of sawn timber per annum. Much of this timber is low grade and economic returns are often very small. The production and sale of beam oak is a thriving area of the hardwood market, although, much of the oak used for this purpose is imported from France and Germany. This is mainly due to the poor quality of home-grown material and the lack of sizeable stems available in the UK. The dimension and length of an oak beam is governed by the amount of sapwood surrounding the inner heartwood and the number of defects in the length of the stem. The paler outer sapwood of oak is non-durable so, a beam cut from the log must contain only the inner durable heartwood. This sawing process is very wasteful as the sapwood band may consist of up to a third of the main stem diameter.

'Green' gluing technology (bonding wood whilst the timber is 'wet') makes it possible to convert smaller diameter oak and other hardwood stems using a 'star' cutting pattern (stem cut into four equal quarters). Either before or after the log is cut into four quarters, both sharp edges of each section are machined flat. The quarters are inverted so that the outer face faces inwards, moisture insensitive adhesive is applied and the sections are pressed together to form a square. This process allows a much larger percentage of the main stem to be utilised, as the less durable sapwood is completely enclosed in a solid heartwood surround.

This report presents the final progress of the project and also provides guidance on constructing 'inside-out beams'.

Description of the project

The aim of the project was to improve the utilisation of a natural UK resource by using small diameter, low value, UK grown oak stems to produce re-engineered components of standard dimensions by using a novel cutting and jointing technique.

The project consisted of a number of work packages geared to the production of oak re-engineered components in a number of different dimensions and lengths. The main work areas investigated various aspects of producing re-engineered oak stems and their subsequent physical properties. These workpackages comprised:

1. The identification and selection of oak stems of adequate quality and dimension to produce relevant component sizes for structural use
2. The production of re-engineered oak components to assess customer reaction and provide test material for following tasks
3. Structural tests to ascertain strength characteristics
4. Tests on suitable preservative or protective treatments to provide protection to the non-durable beam interior
5. Investigation of the distortional characteristics of re-engineered components
6. Assessment of drying characteristics
7. Drying trials to assess drying potential
8. Production of a guidance document for re-engineering bonded hardwood components

It was hoped that the techniques investigated in this project could be used by the UK hardwood industry to utilise a low value material to produce a high value end product.

Findings and guidance

Task 1. The selection of oak stems

It was recognised early in the project that stem straightness would form an important part of the selection process when considering the production of re-engineered beams from small diameter oak stems. Rather than produce a standalone protocol for the process of measuring and assessing stem straightness, it was decided a Forestry Commission publication 'Protocol for stem straightness assessment in Sitka spruce[1,]' should be used. This document describes in some detail the process of visually assessing stem straightness on Sitka spruce stems in order to grade a stands mean straightness. The protocol is easily adopted for use on grading small diameter oak stems.

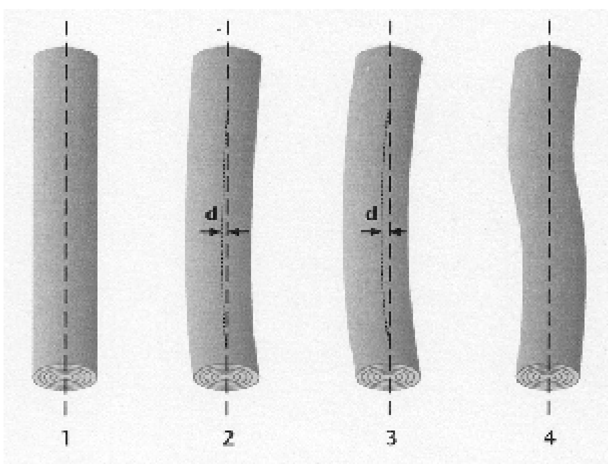

Figure 1. Stem straightness assessment of sample tress

Note: Log 1 and 2 qualify as straight logs; logs 3 and 4 are not straight. Maximum deviation (d) on log 2 does not exceed 1 cm over 1 m length. Maximum deviation (d) on log 3 exceeds 1 cm over 1 m length. Log 4 shows bow in more than one direction.

The stem straightness section of this document identifies four log definitions; straight logs, slightly bowed logs (less than 10 mm per metre length), excessively bowed logs (greater than 10 mm per metre length) and logs bent or bowed in more than one direction, figure 1. Figure 2 shows four small oak stems which cover the categories described in the protocol.

1. 2. 3. 4.

Figure 2. Stem straightness of oak logs categorised as per the Forestry Commission protocol

To maximise stem utilisation, it is recommended that stem straightness grade 1 and 2 logs are used, although this does not preclude the use of grades 3 and 4. The use of grade 3 or 4 logs would require extra machining which would result in a reduction in the overall utilisation of the log.

Upon close inspection of any small diameter oak stems, it is immediately obvious that the percentage of heartwood/sapwood varies considerably from log to log. It also varies between the butt and top end of the same log. The sapwood band may consist of between a third and a quarter of the log diameter (figure 3).

Figure 3. Variations in sapwood/heartwood percentages

This phenomenon has an influence on how each beam is constructed and whether the sapwood edges appear on the surface of a completed beam. A decision is required to include or exclude this feature. Reduction of the stem to ensure complete envelopment by the heartwood will reduce the utilisation of the log, although preservative treatment will provide a level of protection if the sapwood does appear on the surface.

Task 2. The production of re-engineered oak components

During the initial stages of the project, the production of re-engineered beams was undertaken on recently felled stems. It was apparent at the time that the process required extremely straight stems for the re-engineering to be carried out successfully. Any slight deviations present in the oak stem meant the machining requirements to produce the bonding faces in the quarter sections were increased substantially. This effectively reduced the utilisation of the stem and increased the working time required to construct a beam.

As the project progressed, a new system for the preparation of the stems was trialed. This system was instigated to speed-up the re-engineering process (both during preparation and bonding) and increase the utilisation of stems previously rejected due to slight stem deviations or excessive buttress flaring. Even so, the new process still requires relatively straight small diameter stems before re-engineering can be undertaken, if high utilisation of the stems is required.

The new system recommends that all stems be machine rounded to produce parallel-sided straight cylinders before planing, cutting and bonding. This process removes both bark and stem deviations (slight), and allows the construction of beams of standard dimensions. Machine rounding equipment is commercially available and is in use at a number UK sawmills, where different pole or stem diameters are machine rounded to produce fencing posts and constructional poles for use in playground equipment construction. This machine rounding process enables the system to be semi-automated; stems can be machine rounded to produce a range of standard pole diameters (figure 4) which in turn provide a uniform material from which a standard range of beams can be produced.

Figure 4. Machine rounded stems

An important point to note is that the machined stems should be sawn, bonded and pressed as soon after machine rounding as possible. Once the bark has been removed from a stem, it starts to dry very quickly, resulting in varying levels of movement as the stem dries.

Machining

As soon as the stems have been machine rounded, the poles should be passed through a four sided planer to create the bonding faces. This process can also be undertaken on a planer/thicknesser, although it is more difficult to machine the bonding faces accurately. After the four bonding faces have been planed onto the section, the pole can be sawn into quarters. As with the whole machining process, it is important to saw accurately to ensure that minimal planing is required after bonding and drying.

Figure 5. Pressing of cut quarter sections

On completion of the machining and sawing processes, the bonding faces are coated in adhesive, re-orientated inside out and placed in a pneumatic press to cure. It is essential at this stage to ensure that pressure is applied to both top and sides to reduce the chance of the four re-orientated sections sliding out of alignment. It is also crucial that a uniform pressure is applied along a beam's length while curing is taking place. This ensures no gaps appear in the bond lines. Although not trialed, it would also be possible to insert a fillet or machine a joint along the length of the bonding faces to increase the surface area and prevent sections slipping out of alignment whilst bonding.

The main experimental work was undertaken using a single plane press (figure 5), where only two quarter sections were bonded at a time. Once these sections were part cured, two of these sections were bonded together. In a higher capacity industrial process, a three way press would be recommended to allow the construction of complete beams at one pass.

Adhesive application and pressing pressure

The adhesive recommended for use in green gluing oak stems is Collano Purbond HB. This adhesive is available in five different pressing time grades, from 6 hours (HB 181) to 30 minutes (HB 222). Depending on the expected speed of production, the appropriate grade should be selected. Although full curing is achieved after 48 hours at ambient temperatures of 20ºC, bonded parts can be processed immediately after pressing. If re-engineering is undertaken at temperatures below 20ºC, extra time must be allowed for the pressing and curing stage.

To achieve good bond strength, approximately 200g/m^2 of adhesive should be applied to the bonding faces prior to pressing. If the correct amount of adhesive is used, a very small amount of excess adhesive should be visible at the surface of the bond line when pressed. If excessive squeeze-out is visible, reduce the amount of adhesive applied. If excess adhesive is not visible, increase the amount of adhesive applied.

The required pressing pressure should be in the region of 120 psi (0.8 N/mm^2). This pressure will vary depending on timber species.

Note: Polyurethane adhesives do not have gap filling capabilities, therefore, joints must be as thin as possible and incorrect machining or planing must be avoided.

Construction tolerances

In any industrial wood factory processing unit, it is important that there is a consistency in dimension and quality of the finished article. When undertaking the re-engineering of small oak stems, it is very important that each beam is constructed with the correct ratio of solid timber thickness to central void size.

To ensure adequate and consistent strength and stiffness of re-engineered beams, and for quality control purposes, a simple formula has been devised to aid the construction process. Based on the required final dimension of a beam, this formula can be used to calculate the diameter of the initial machine rounded stem and the amount of material to plane off the stem diameter to produce the four bonding faces. The formula takes into account the width of the kerf when the stem is sawn into quarters, shrinkage and planing of the re-engineered beam after drying. It accommodates parameter changes that may be necessary once a number of initial beams have been made. If excessive shrinkage occurs, or extra planing is required to produce the finished article, these can be taken into account.

Calculating initial stem diameters from final beam dimensions

The equation below is provided as guidance to estimating the machine rounded stem diameter for a given beam dimension. As wood is a natural product, the final dimensions may need to be adjusted slightly depending on the machining tolerances and/or the final moisture content of the beams. The equations have been produced in order that these changes can be done easily and simply. All input and output figures are in millimetres.

To calculate the initial stem diameter (machine rounded stem diameter), a number of input values are required:

- Select the final beam dimension
- Measure the kerf width of the saw being used to process the stem into four quarters
- Estimate the amount of material being planned from the finished beam after drying (each side)
- Using a relevant publication (Handbook of hardwoods[2]), look up the expected shrinkage of the species from green to 12% moisture content. This value is used to calculate the shrinkage factor.

Once these dimensions have been chosen or calculated, the value of the initial stem diameter (machine rounded dimension) can be used to calculate the depth of material that needs to be removed from each of the four outer faces to create the correct depth of bonding surface (eq. 2).

The following equations provide all the information required to construct beams with the correct depth of bonding surface and timber thickness to void size ratio.

Eq. 1. Calculating initial stem size from final beam dimension

$$S_d = \frac{S_h(F_d + 2p) + k}{0.82}$$

Where :

$S_d = Stem\ diameter\ (machine\ rounded\ stem)$

$F_d = final\ re-engineered\ beam\ dimension$

$p = planing\ dried\ beam\ to\ final\ dimension$

$k = saw\ kerf\ width$

$S_h = shrinkage\ factor$

$$S_h = \frac{100 + \%\ shrinkage}{100}$$

Example 1. To calculate initial machine rounded stem diameter for a final beam dimension of 100 mm, use eq. 1. as follows:

$$S_d = \frac{1.04 \times (100 + 2 \times 1) + 2}{0.82}$$

$$S_d = 132\ mm$$

$$Where:$$
$$F_d = 100\,mm$$
$$p = 1\,mm\ per\ side$$
$$k = 2\,mm$$
$$S_h = 1.04\ assuming\ 4\%\ shrinkage$$

Calculating bonding face depth

Equation 1 provides an indication of the size of stem required to construct a beam of a given dimension. One of the most important aspects of constructing a re-engineered (inside-out) beam from a small diameter stem is the requirement for adequate bonding surface dimensions on each of the quarters sections cut. The width of the bonding faces has a direct influence on the strength, stiffness and general integrity of the beam, and of course, regulates the dimension of the void running up the length of the beam. During the production of re-engineered beams, it is crucial that the correct ratio of timber to void size (two to one) remains constant throughout the production process. To calculate the correct ratio of bonding surface to void dimension, follow equation 2 shown below.

Eq. 2. Calculating bonding surface depth

$$B_s = S_d \times 0.09$$
$$Where:$$
$$B_s = bonding\ surface\ depth$$
$$S_d = stem\ diameter\ (machine\ rounded\ stem)$$

Example 2. To calculate the depth of bonding surface

$$Bs = 132 \times 0.09$$
$$B_s = 11.9\,mm$$

Equation 2 indicates the depth of planing required on **each** of the four surfaces (figure 8) of a machine rounded stem to ensure that the correct ratio of timber to internal void dimension is achieved prior to sawing the stems into four quarters and re-engineering.

During the machining process, the bonding surfaces must be machined accurately, and at right angles to one another. This ensures that when the mating surfaces of each quarter are brought together, they lay flat against one another to form a strong joint.

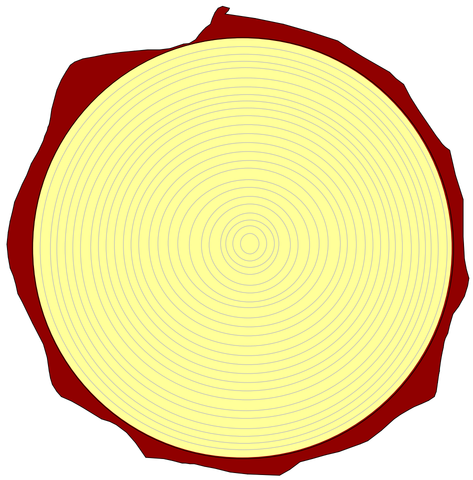

Figure 6. Stem with bark

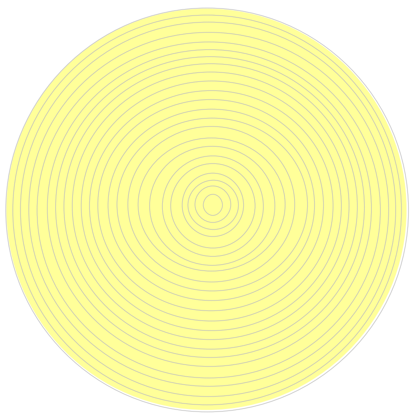

Figure 7. Machine rounded stem (S_d=132 mm diameter)

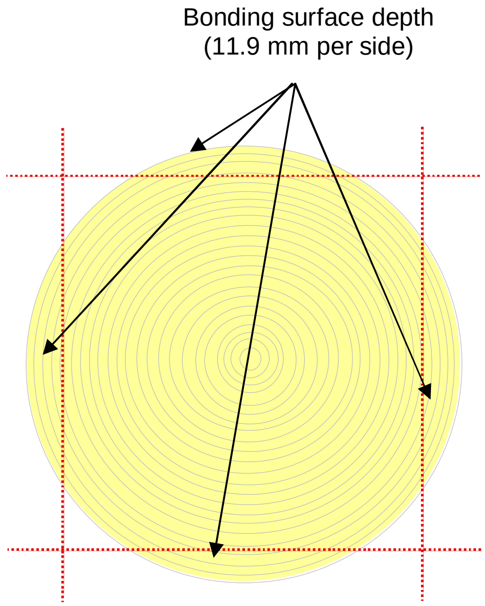

Figure 8. Machine bonding surfaces (B_s=11.9 mm for a stem diameter (S_d) of 132 mm)

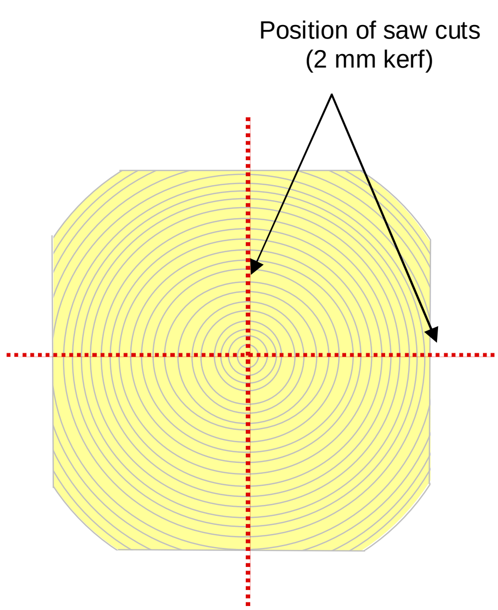

Figure 9. Cut stem into four sections

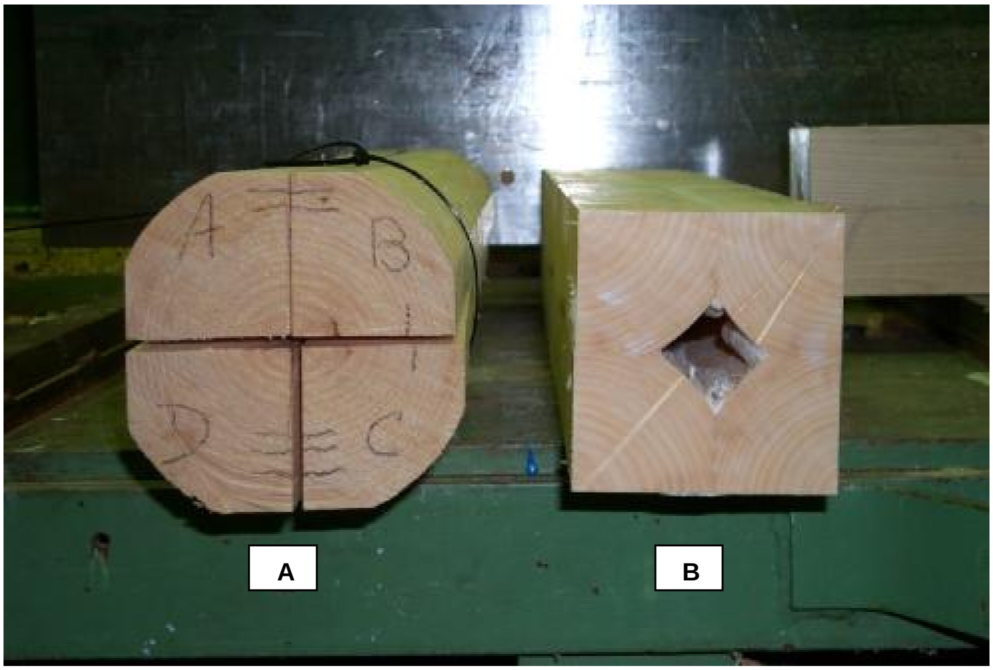

Figure 10. Quarter sections showing machine bonding surfaces prior to reversal (A). Quarter sections reversed, bonded and pressed to construct a re-engineered beam (B).

Figure 10a shows a machine rounded stem with the bonding faces created (B_s) and the stem cut into four quarters (2 mm saw kerf width). Figure 10b shows a re-engineered stem (F_d) with quarters reversed, bonded and pressed together after the beam was dried (4% shrinkage) and the faces squared by planing 1 mm off each face (*p*).

Figure 11 shows two finished beams, one constructed from ash (*Fraxinus excelsior*) and one from red oak (*Quercus rubra*). Beams have also been constructed from sweet chestnut (*Castanea sativa*) and birch (*Betula pendula*)

Figure 11. Re-engineered small diameter ash stem (left) and red oak stem (right)

Task 3. Strength characteristics

14 re-engineered beams (produced earlier in the project) and 14 solid oak reference samples were tested in four point bending in accordance with EN 408: 2000 (Timber structures-Structural timber and glued laminated timber-Determination of some physical and mechanical properties) and EN 384: 1995 (Structural timber-Determination of characteristic values of mechanical properties) for modulus of rupture (strength) and modulus of elasticity (stiffness).

The laminated beams were assessed using a medium capacity Avery strength testing machine located in the timber centre at BRE. Specimens were of varying width and depth, although all beams were the same length (2100 mm). The test set-up is shown in figure 12.

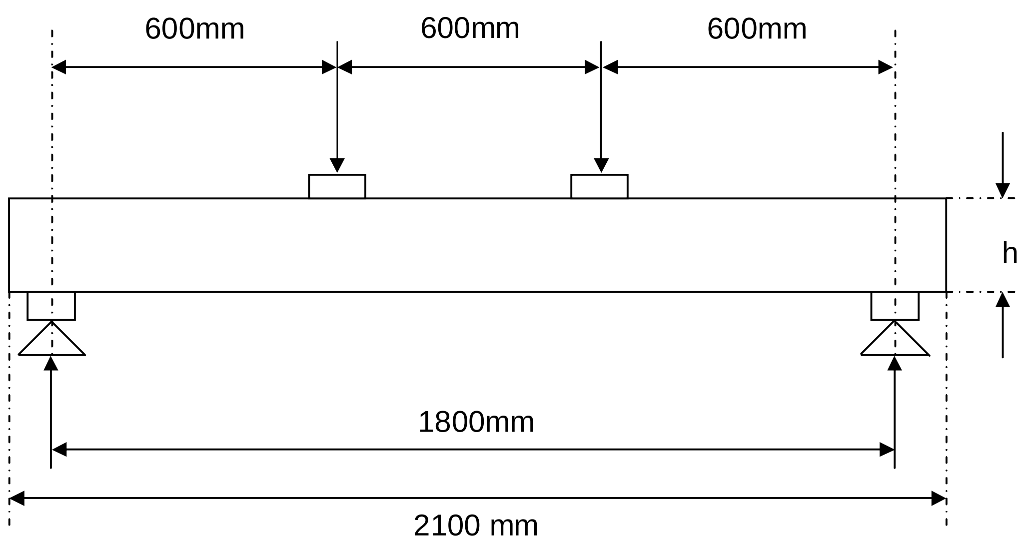

Figure 12. Set-up for four-point bending

A linear voltage displacement transducer (LVDT) was placed in a central position under each specimen to measure the deflection of the beam as the load was applied. Data from the LVDT and load cell were transferred to a PC via a data acquisition programme which recorded both the applied load and the specimen deflection at 1 second intervals up to a load of 10 KN. At this point, the LVDT was removed to prevent damage to the measuring device. The load was then re-applied until the beam failed. Both failure mode and maximum load were recorded.

Modulus of elasticity (MOE) was calculated using equation 3. from the data obtained from the data acquisition programme and in accordance with EN 408: 2000.

Eq. 3.

$$E_{m,g} = \frac{l^3}{bh^3} \times \frac{(F_2 - F_1)}{(w_1 - w_2)} \times \left[\left(\frac{3a}{4l} \right) - \left(\frac{a}{l} \right)^3 \right]$$

Where:
$\frac{(F_2 - F_1)}{(w_1 - w_2)}$ is calculated using the linear part of the load (F) over displacement (w) plot (gradient), generated by the data acquisition programme.
l = span width (1800 mm)
a = distance between a loading position and the nearest support,
b = specimen width
h = specimen height

All MOE results were standardised to a nominal 12% moisture content in accordance with EN 408: 2000.

Modulus of rupture (MOR) is the maximum load required to fracture the specimen. MOR was calculated using equation 4 shown below.

Eq. 4.

$$f_m = \left(\frac{aF_{\max}}{2W} \right)$$

Where:
f_m = modulus of rupture (N/mm^2)
$F_{\max}$ = breaking load (N)
W = section modulus (mm^3)
a = distance between a loading position and the nearest support

As the laminated beams were of various dimensions, the values were standardised to a 150mm depth, using equation 5 and then used to standardise values for span and depth using equation 6. This standardising process allowed direct comparisons to be made between specimens. Data standardising was not required when calculating modulus of elasticity as specimen dimensions were included in the equation and already taken into account

Eq. 5.

$$K_h = \left(\frac{150}{d}\right)^{0.2}$$

Where: K_h is the correction factor which is then multiplied by the maximum load to obtain comparable modulus of rupture values.
d is the depth of the specimen.

Eq. 6.

$$k_i \left(\frac{l_{es}}{l_{et}}\right)^{0.2}$$

Where:

K_i = correction factor which standardises the span length to 18x the diameter
l_{es} = effective length for the standard test procedure (mm)
l_{et} = effective length for the test (mm), and
l_{es} and l_{et} are calculated as follows
l_{es} or l_{et} = $l + 5a$ where a and l have respective values for the standard test procedure and test

Results from the assessment of strength characteristics of re-engineered oak beams

Table 1 shows the results from the strength and stiffness assessments of 14 re-engineered oak beams. Table 2 shows the same assessment results from 10 comparable solid oak beams obtained from large diameter oak sections where the beams have been sawn from the outer edges of the stem. $\mathbf{f_m}$ indicates the maximum strength of the beam (modulus of rupture) and *Ecen* the stiffness of the beam (modulus of elasticity).

Table 1. Strength & stiffness values of re-engineered oak beams

Specimen code	f_m (N/mm^2)	*Ecen* (N/mm^2)
102	38.2	11659.1
103	45.5	8074.2
104	65.5	9937.2
105	58.8	11413.1
106	55.2	10192.5
107	45.0	9764.9
108	80.4	11270.6
109	50.2	9602.7
110	53.1	10886.3
111	60.6	12172.3
114	54.5	8751.7
115	29.1	10157.6
116	48.1	6515.5
Average	**52.6**	**10030**
StDev	**12.7**	**1569**

Table 2. Strength & stiffness of comparable solid oak beams

Specimen code	f_m (N/mm^2)	*Ecen* (N/mm^2)
1	63.0	12917.6
2	38.6	9113.7
3	42.1	8456.2
4	62.6	10300.9
5	55.3	12218.1
6	59.3	12986.0
7	62.2	8319.7
8	59.1	11089.9
9	50.5	10684.0
10	44.1	8961.2
Average	**53.7**	**10504**
StDev	**9.3**	**1783**

Tables 1 and 2 show the strength and stiffness results obtained for the re-engineered oak sections and solid oak beams were very similar.

In a previous report (210-700), the re-engineered oak beams, as shown above, were compared to solid oak beams (boxed heart) cut from small diameter material. The results from that assessment indicated that the re-engineered oak stems were both stronger and stiffer than the comparable solid material obtained from similar sized stem material.

Previous results have also indicated that solid oak beams obtained from small diameter juvenile oak are weaker in strength and stiffness than beams obtained from the outer edges of mature oak stems. The latest results show that re-engineering small diameter oak stems, to produce structural beams, improves the strength and stiffness over the boxed heart beam significantly, with values closer to those obtained for beams cut from mature oak stems being achieved

Task 4. Preservative treatment

The sapwood band surrounding the durable heartwood on oak stems is known to be 'not-durable' and susceptible to insect and fungal attack, although decay generally occurs when the timber has a moisture content above approximately 23%. Once the stem is re-engineered, the sapwood band should only be exposed in the beam core, although this orientation is not always possible to achieve due to the fluctuations in the percentage of sapwood in each small oak stem. Due to the construction of the re-engineered beam, a hole will always be present through the length of the beam. Potential methods of protecting the inner core material include preservative treatment or a physical barrier. Protection from biological pathogens will be enhanced once the beam has dried to a moisture content below 23% but even so, all timbers are susceptible to woodworm at quite low moisture contents.

A set of tests was initiated to test the efficacy of a boron preservative treatment (Timbor) on re-engineered small oak stems according to BS 8417:2003 (Preservation of timber – recommendations, section 4.3.1.2). The boron diffusion process is well suited to the treatment of timber in the green state, before subsequent drying. Two sets of freshly re-engineered beam were treated in a vacuum/pressure impregnation vessel with a 2% boron wood preservative solution. Each section was end-sealed, weighed and placed in an impregnation vessel and a vacuum (660 mm/Hg) drawn for 30 minutes. At the beginning of this period, the tank was flooded with boron solution. The vessel was then pressurised (11.5 Kg/cm^2) for 60 minutes. When the treatment schedule was complete, the sections were re-weighed to provide information on the up-take of preservative and wrapped in polythene for seven days to assist the preservative diffusion process. The samples were then un-wrapped and placed in a conditioning chamber to dry.

After approximately 8 weeks, the sections had dried to a moisture content of 18%. To assess the extent of preservative impregnation, each section was cross-cut approximately a third of the way in from one end and a preservative indicator dye sprayed on the cut surface. The dye colour turns orange to indicate the presence of preservative and stays yellow if no preservative is present. Application of the dye provided an indication of the depth of penetration of the preservative and whether the treatment schedule was adequate for this type of material.

Figure 13 shows the results from the first set of sections assessed. These were preservative treated within two weeks of construction. Figure 14 shows the results from the second set of sections assessed. These were preservative treated within three months of construction. The presence of the orange dye indicates the depth of preservative in the sections. The section shown in the left hand corner of figure 13 (coloured yellow) was used as a control and left un-treated. Treated sections in figure 13 clearly show total preservative penetration has been achieved. As expected, sections shown in figure 14 (samples treated after 3 months) show a shallow envelope of preservative penetration.

Results from these assessments indicate that complete preservative penetration is possible on freshly treated material, even on timber that is difficult to treat, such as oak. The results also show that, if required, it is possible to provide a shallow envelope of protection on material which has already been partially dried.

In light of these excellent results, if a preservative treatment is required, it is recommended that the treatment schedule described in this section is followed. It must be highlighted that the treatment described is specifically for material destined for a protected location with possible moisture ingress, not for external use or for use in ground contact.

Figure 13. Preservative treated (within 2 weeks) re-engineered oak stems sprayed with an indicator to show treatment depth. Orange indicates preservative presence, yellow indicates preservative absence. The untreated control block is on the left.

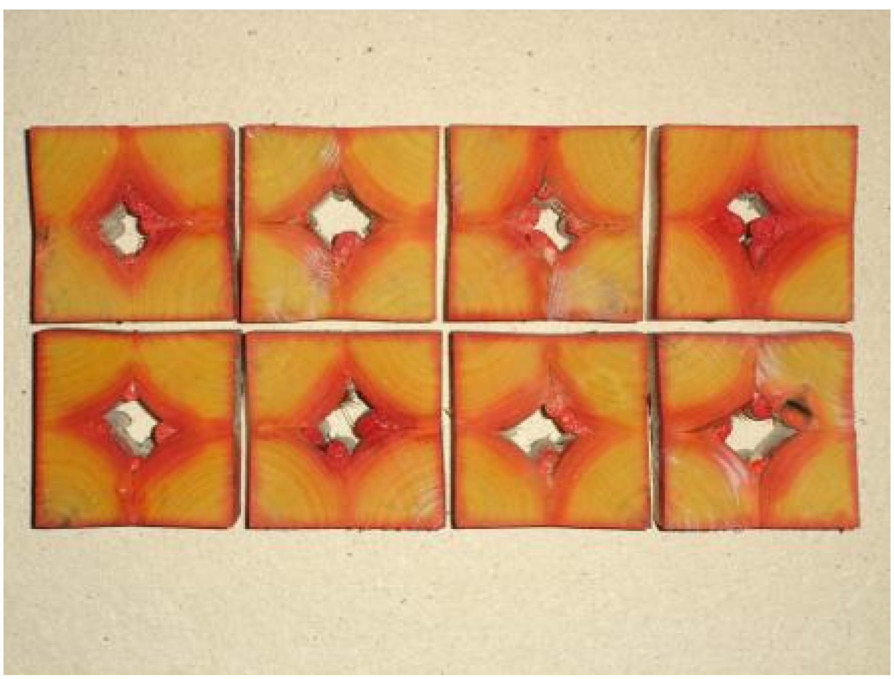

Figure 14. Preservative treated (after 3 months) re-engineered oak stems sprayed with an indicator to show treatment depth. Orange indicates preservative presence, yellow indicates preservative absence.

Task 5. Distortion Characteristics

As timber is a natural product, it will shrink and distort to varying degrees as it dries. Recent research undertaken at BRE has found that sawing and re-engineering solid material ‘prone to distortion’ can produce significant reductions in distortion values. This evidence led to an assessment being undertaken to assess the distortional characteristics of re-engineered oak beams against solid oak beams processed from similar material.

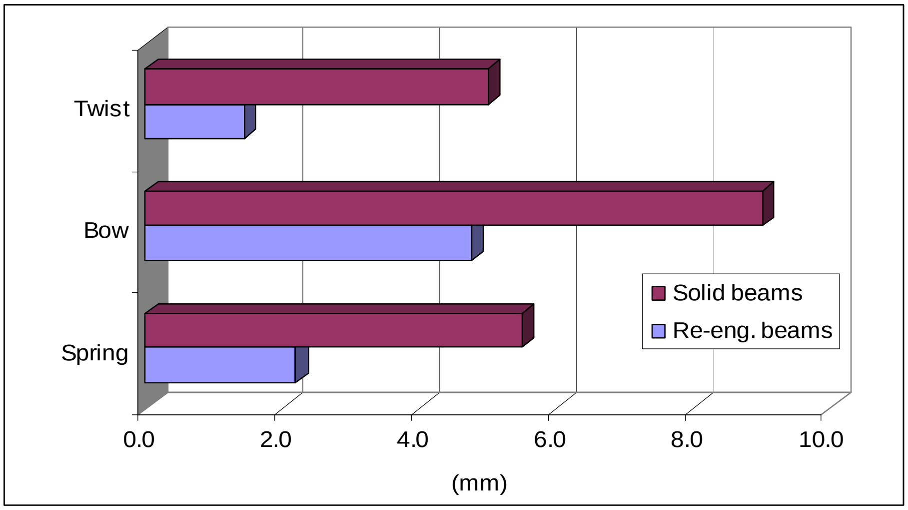

Figure 15. Mean distortion values for solid and re-engineered Oak

A number of re-engineered and solid oak beams were assessed for distortional characteristics using the distortion measurement method described in Appendix A. Both sets of beams were air-dried under cover and out of direct sunlight for approximately four months and had attained an average moisture content (depth of 25 mm) of 17%. To allow comparisons to be made, the distortion values obtained from the beams were normalised to a section dimension of 100 mm depth and 2000 mm length. Figure 15 shows the average results from the two sets of beams.

Initial results indicate that re-engineering small oak stems significantly reduces twist, bow and spring when compared with solid oak beams processed from similar material. Comparing the values measured on the re-engineered steam assessed to those on equivalent solid oak assessed, twist values were reduced by approximately two thirds, and bow and spring by approximately half.

Task 6. Assessment of drying characteristics

Oak is known to be difficult to dry in larger sections without some form of drying degrade. Dry beam oak normally exhibits varying degrees of surface checking and splits, some of which can be quite extensive. Two sets of re-engineered beams and two solid oak beams, cut fro small oak stems, were allowed to air-dry under cover and out of direct sunlight for approximately four months. The average moisture content of the re-engineered beams after this time was 17.2% and the solid beams 16.1%.

The two solid oak beams followed the normal trend of beam oak, their surfaces after drying showed a considerable number of splits and checks. In comparison, the re-engineered material, cut and re-engineered during the same period, dried with very few splits or checks occurring. This drying behaviour was unforeseen and the beams retained a very clean, almost machined quality surface finish (figure 16).

Figure 16. Air dried re-engineered oak beam above and comparable solid oak beam below

Since the initial work, many more beams, both solid and re-engineered have been assessed for drying characteristics. The initial results were confirmed, with re-engineered oak beams showing excellent results with regards to drying characteristics.

Task 7. Assessment of drying potential

Large section beam oak is traditionally air dried or used in its green state. Since the advent of wood drying kilns, large section oak is often air dried and then finally dried to the required moisture content in a wood drying kiln. The main reason for this practice is economics. Large section oak takes a long time to dry. To completely kiln dry it can be very expensive, in both time and energy. Beam oak is also difficult to dry without the development of surface checks and splits.

Air-drying and kiln drying assessments were undertaken on solid large section oak and re-engineered stems of a similar dimension.

Air drying

Two sets of re-engineered beams and two solid oak beams (approx. 120 x 120 x 2100 mm) were air-dried under cover, in an area of good air flow and out of direct sunlight from an approximate moisture content of 55% to approximately 17% in four months. This assessment was initiated in the spring and early summer when ambient temperature was on the increase. If air drying was undertaken in the winter months, drying would have taken considerably longer and the final moisture content would almost certainly be higher. After completion of the drying, the material was visually assessed. Following an established trend, and as reported in task 6, re-engineered beams dry with very little, if any, splits or checks, whereas solid beams develop significant numbers.

Depending on the quality requirements of the material being dried, the following air drying recommendations should be followed to obtain reasonable results:

- Coat the ends of the material with either a bituminous paint or water thinned PVA adhesive to reduce the incidence of end splitting during the drying period. This is especially important if drying short sections.
- Ensure the air-drying roof or cover has a suitable overhang to prevent or reduce the ingress of moisture from the sides
- Ensure the material is positioned out of direct sunlight and the cover provides adequate shade
- Ensure the stack of material is correctly stickered and is positioned to take advantage of any common air-flow direction

During the summer months, excessive splitting and checking of solid material should be expected.

Kiln drying

10 re-engineered and 10 solid oak beams (approx. 110 x 110 x 2100 mm) were kiln dried in BRE's experimental heat and vent kiln following the schedule shown in table 3. During the drying process, two solid and two re-engineered oak beams were monitored for moisture loss. Initial results indicate that re-engineered beams dry slightly quicker than solid material, although accurate final drying times are un-available due to a number of problems occurring during the schedule. After drying was complete, both solid and re-engineered material was visually assessed. The results again follow the same trend as those reported in task 6, re-engineered beams drying with very little, if any, splits or checks, whereas solid beams develop significant numbers.

It is obvious from this work, that specific schedules for drying re-engineered beams could be developed, and that these would be shorter in length than those used to dry solid material of the same dimension.

At the present time, a standard European oak kiln schedule is recommended to dry re-engineered oak beams (table 3). Due to the dimensions of timber being dried (>80 mm), a gentle drying schedule is required to reduce the chance of checks and splits developing and also to reduce the build up of excessive stresses within the material due to kiln drying. The schedule shown in table 3 is indicative only, changes to the schedule may be required depending upon the initial drying results in a commercial set-up.

Table 3. Indicative kiln drying schedule for oak with dimensions between 80 mm and 140 mm

Stage	Timber M/C (%)	Dry bulb (ºC)	Wet bulb (ºC)
1	Green	40	39
2	60	40	38.5
3	40	45	42.5
4	35	45	41.5
5	30	45	40.5
6	25	50	44
7	20	60	50
8	15	65	52

Conclusion and recommendations

This final progress and guidance report presents the findings from the investigation into the utilisation of small diameter, low value UK grown oak and other hardwood stems to produce re-engineered components of standard dimensions using a novel cutting and jointing technique.

The project has proven that the concept of using small diameter oak stems to produce re-engineered structural components is viable. Work has also been undertaken to assess strength, distortional and drying characteristics and preservative treatment on re-engineered beams constructed using the novel sawing and jointing technique.

Results from the completed project indicate that:

- Re-engineering small diameter oak stems using a novel sawing and jointing technique to construct structural components is a viable concept.
- Re-engineered beams constructed from small oak stems (using the correct timber to void ratio) are both stronger and stiffer than solid oak beams processed from material of the same dimensions, and are similar in strength and stiffness to beams processed from large diameter material.
- Drying assessments indicate that the re-engineered small oak stems exhibit significantly less surface checks and splits than solid material processed and dried at the same rate.
- The incidence of twist, bow & spring (after drying) is significantly reduced in re-engineered oak beams when compared to solid oak beams processed from material of the same dimensions.
- Assessments indicate that it is possible to achieve complete preservative penetration of freshly constructed re-engineered beams using a boron diffusion process. Using the same process, it is also possible to provide a shallow envelope of protection on material which has already been partially dried.

The re-engineering process has been improved progressively throughout the project, with the results continually exceeding expectations.

There is great expectation that a UK company will adopt the process and, with some additional work, it is anticipated that the product will become commercially available in the near future.

References

1. Macdonald, E, Mochan, S & Connolly T (2001) Protocol for stem straightness assessment in Sitka spruce. Forestry Commission information note.

2. Farmer, B. A. (1992) Handbook of hardwoods. Building Research Establishment. London: HMSO.

Appendix A – Distortion measurements

Twist

Twist was assessed by marking the central position of each beam; this was aligned with a central mark on a 2500 mm wide slate. The beam was then clamped against a vertical square 1000 mm from the central mark. Another square was placed against the batten 2000 mm from the clamped end and the top or bottom twist deviation measured to the nearest 0.5 mm

Bow

Bow was measured using a two metre straight edge and engineers rule. The central position and one metre either side of this point was marked on the broad face of each beam, and the straight edge placed against these marks. The amount of bow was the measured deflection (mm) of the piece away from the central portion of the straight edge to the nearest 0.5 mm (fig. 1).

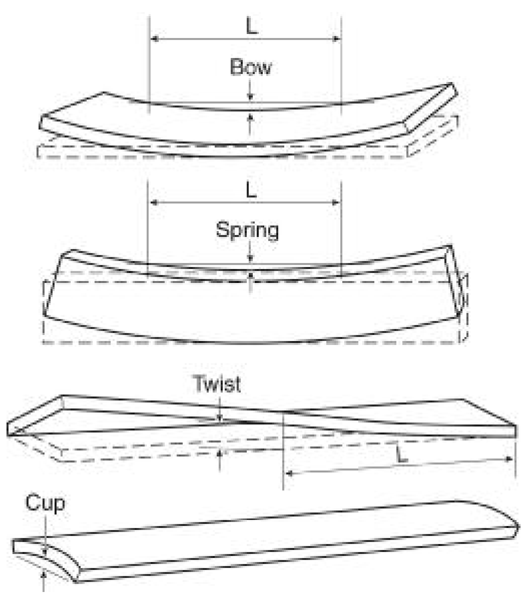

Figure 1. Distortion Types

Spring

The measurement of spring was similar to that of bow, except measurements were recorded on the narrow face only.

If the beams were of the same dimension, spring was measured on the adjacent face on which bow was measured.