Client Report :

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

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Executive Summary

This report presents the results to date from the project 'Obtaining better utilisation of UK grown small diameter Oak stems and other hardwood species using a novel sawing pattern for the production of structural members'. The project was funded by the Forestry Commission under contract number PPD 24/02, and is due to finish in September 2004.

This research programme complements work previously carried out under both Forestry Commission and European Commission 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 will be assessed later in the project.

This first five tasks in the work programme consisted of;

- The identification and selection of oak stems of adequate quality and dimension to produce relevant component sizes for structural use
- The production of re-engineered oak components to assess customer reaction and provide test materials for following tasks
- Undertake structural tests to ascertain strength characteristics
- An assessment of distortional characteristics
- An assessment of drying characteristics

Results from these work tasks have been very encouraging:

- A number of oak beams have been produced using the novel sawing and bonding techniques outlined in the project proposal
- During the initial production of the beams, a number of problems were highlighted, mainly due to log shape. The presence of excessive taper, butt flair or stem ovality all result in a reduction of the finished beam diameter.
- Results from tests indicate that re-engineered oak beams constructed from small oak stems are both stronger and stiffer than solid oak beams processed from the same material.

- The incidence of twist, bow & spring (after drying) was significantly reduced in the 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 considerably less surface checks and splits than solid material processed and dried at the same rate.

Although the project was slightly slow to start it is now well underway and further production is being planned. The re-engineering process will be altered to overcome the problems encountered and also streamlined to speed up the overall production. It is hoped that several alternative hardwood species can be obtained very soon and these will be re-engineered following the same process as those undertaken on oak.

Contents

Introduction

This report presents the progress and results from the first of four work tasks in a series of eight, 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 is represents milestone 1 of this contract, due at the end of March 2004.

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 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.

By using 'Green' gluing technology (bonding wood whilst the timber is 'wet') it is possible to convert small diameter oak and other hardwood stems using a 'star' cutting pattern (cut into four equal quarters). After the log is cut into four quarters, each section has both sharp edges machined flat and the quarters are then re-engineered with the outer face facing inwards using the 'green' bonding process. This process allows a much larger percentage of the main stem to be utilised.

Further work will also be undertaken on a number of alternative hardwoods following a similar work program.

Description of the project

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

The project consists of a number of work packages geared mainly to the production of hardwood re-engineered components in a number of different dimensions and lengths. The main work areas will investigate various aspects of producing re-engineered oak and other hardwood stems and assessing their physical properties. These will comprise of:

- The identification and selection of stems of adequate quality and dimension to produce relevant component sizes
- Production of re-engineered oak and other hardwood components to assess customer reaction and provide test materials for following tasks
- Undertake structural tests to ascertain strength characteristics
- Undertake tests on suitable preservative or protective treatments to provide protection to the non-durable material
- Investigate the distortional characteristics of different orientations of re-engineered components
- An assessment of drying characteristics
- Undertake drying trials to assess drying potential
- Production of a comprehensive guidance document

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

Project Progress

Task 1. The identification and selection of hardwood stems

The first task in this project concentrated on locating suitable material to undertake the re-engineering of oak stems into beam components. After some discussion within the timber centre at BRE, it was decided to request the delivery of oak stems in a range of dimensions in 2000 mm lengths. The processing and re-engineering could then be monitored and streamlined as the project progressed and any problems identified could be rectified as they occurred.

The proviso placed on the order was that the stems should be as straight as possible, have very little taper and if possible no buttress flare. The proviso was given to ensure that all the initial effort could be concentrated on processing and re-engineering the oak components. Expected problems with buttress flare and excessive taper would be investigated later in the project. It was also decided at this stage that no effort would be made to ensure the elimination of the sapwood band in the newly re-engineered components. All efforts would be channelled into streamlining the re-engineering process. The first batch of fresh oak logs varied between 130 to 195 mm in diameter (top-diameter under bark) and were 2000 mm in length (figure 1)

Figure 1. Small Oak logs

Stem straightness

It was recognised early in the proposal stage, that stem straightness would form an important part of the selection criteria 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 of the oak stems it was decided to utilise a Forestry Commission publication 'Protocol for stem straightness assessment in Sitka spruce[1]'. This document describes in some detail the process of visually assessing stem straightness on Sitka spruce stems to grade a stands mean straightness.

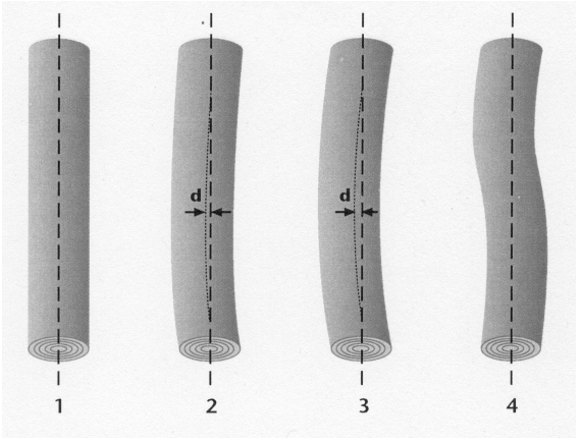

Figure 2. Stem straightness assessment of sample tress

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 stems straightness section of this document (figure 2) 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 3 shows four of the delivered logs which cover the categories described in the protocol.

1. 2. 3. 4.

Figure 3. Stem straightness of oak logs categorised as per the Forestry Commission protocol

Each log used for the re-engineering process will undergo assessment as per the protocol in order to identify the type of log required to produce suitable hardwood components.

Other log quality issues

Stem straightness was found to be the main problem associated with processing the oak stems into four sections and re-engineering the sections inside out.

During initial processing, two other log quality issues affecting the re-engineering process became apparent.

- Excessive stem taper
- Stem ovality

Both these factors increased the amount of machining required on the bonding faces, causing a significant reduction in the final dimension of the finished beam.

Task 2. Processing and re-engineering of small hardwood stems

Before processing and re-engineering, each log was measured for top and butt diameter (under bark) and the diameter of the heartwood core. The log was then marked into four sections, each section being numbered with a plastic tag in an outwards orientation (figure 4). This helped in the identification of the sections during machining and re-engineering process and ensured the cut sections were bonded together in a similar orientation from which the sections were first processed.

Figure 4. Log tagged and ready for processing

The logs were then cut into four equal sections using the bandmill located in the timber centre at BRE. Each log was passed through the wide band saw to form two halves. The cut half sections were then re-positioned on the reciprocating table (one behind the other) and re-sawn into quarters.

During the sawing process, it was noticed that both the half sections and quarter sections were very prone to spring after passing through the saw. Due to the excessive spring exhibited by the cut sections, the main faces required more extensive planing to allow ‘bonding edges’ to be machined prior to re-engineering.

Subsequent to the initial processing, the quartered oak sections were transferred to the wood machine shop here the main face of each section was planed flat and the bonding faces machined using a planer thicknesser.

When machining the bonding faces using the planer thicknesser, it became apparent that any slight deviations along the main stem increased the amount of material which required removal in order to form a minimum bonding face for re-engineering.

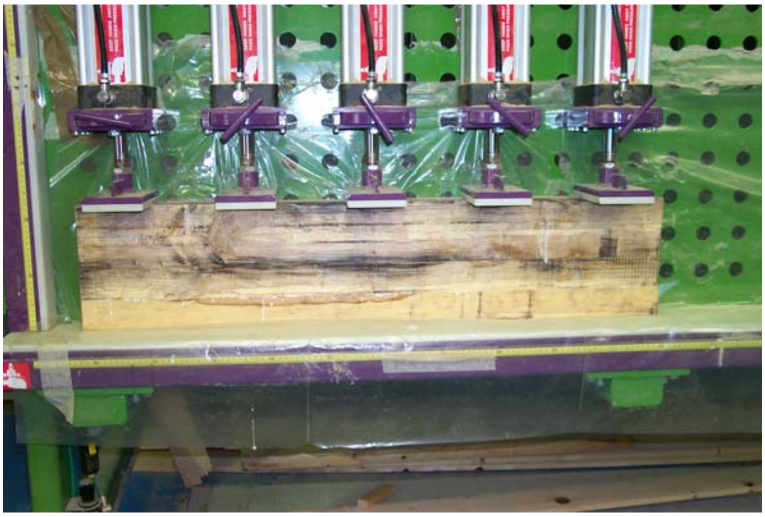

Figure 5. Cut quarter sections being pressed

On completion of the machining process the sections were coated in polyurethane adhesive, re-orientated inside out and placed in a pneumatic press to cure (figure 5).

During the first stage of the bonding process only two quarter sections were bonded at a time. Once these sections were part cured, the two bonded quarter sections were then bonded together. Figure 5 shows the pneumatic press used in applying pressure to the sections to obtain a tight face joint. Later in the project, a strap clamping system will also be tested.

The polyurethane adhesive utilised in this project has undergone extensive investigation in several previous BRE projects in regard to bonding ‘green’ timber. The results from these investigations indicate that the bond obtained when bonding ‘green’ timber has adequate strength for a variety of end uses.

The polyurethane adhesive used to bond the sections requires the presence of moisture to aid curing. As the curing commences, the adhesive foams actively, forming a raised white bead along the bonded joints. Once dry, the cured adhesive is easily removed by machining or by scraper and has no detrimental effect on planer blades or associated equipment.

Figure 6 shows one of the larger beams assembled after initial processing and re-engineering. The final diameter of the beam is 138 mm. The beam was processed from a log with a top diameter of 195 mm.

Figure 6. Re-engineered oak beam

The initial processing and re-engineering of small oak logs indicates that between 35 mm and 45 mm was lost from the overall log diameter in production of each re-engineered beam. These figures do not include producing a beam with only heartwood surrounds. This aspect of the will be investigated as the project progresses.

Task 3. Strength characteristics

14 of the re-engineered beams produced in task 2 along with two solid Oak reference samples (cut during the same period) 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). Test set-up is shown in figure 7.

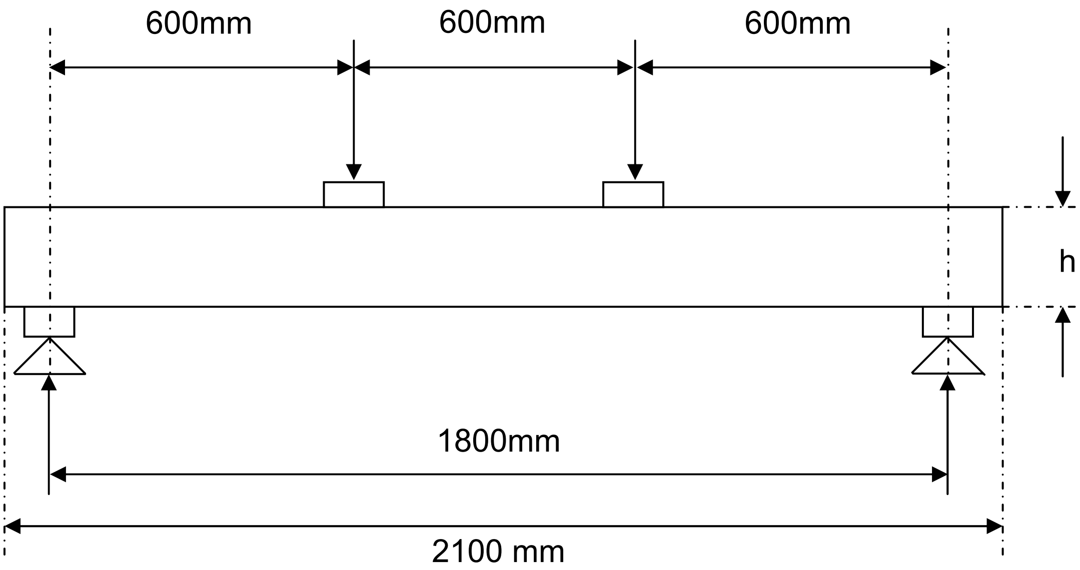

Figure 7. Set-up for four-point bending

A linear voltage displacement transducer (LVDT) was placed in a central position under each specimen. This allowed the deflection of the beam to be measured as the load was applied. Data from the LVDT and load cell was transferred to a PC via a data acquisition programme. This recorded both the applied load and the specimen deflection at 1 second intervals up to a load of 10 KN (ten kilonewtons). 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 then recorded.

Modulus of elasticity (MOE) was calculated using equation 1. by utilising the data obtained from the data acquisition programme and in accordance with EN 408: 2000.

Eq. 1.

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

Where:

$\frac{(F_2 - F_1)}{(w_1 - w_2)}$ is calculated using the linear part of the load over displacement plot (gradient), generated by the data acquisition programme.

L - is the span width (1800mm),

a - is the distance between a loading position and the nearest support,

b - is the specimens width

h - is the specimens height

All MOE results were then 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 2 shown below.

Eq. 2.

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

Where:

f_m is the modulus of rupture (N/mm^2)

$F_{\max}$ is the breaking force (N)

W is the section modulus (mm^3)

As all the laminated beams were of various dimensions, the values were standardised to a 150mm depth, using equation 3. These values were then used to standardise values for span and depth using equation 4. This allowed direct comparisons to be made between specimens. This standardising method was not required for calculating modulus of elasticity as the specimen dimensions were included in the equation.

Eq. 3.

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

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. 4.

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

Where:
K_i is the correction factor which standardises the span length to 18d,
l_{es} is the effective length for the standard test procedure (mm),
l_{et} is the 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

Strength characteristics of re-engineered oak beams

Table 1 shows the results from 14 of the re-engineered oak beams and table 2, the results from the two comparable solid oak beams processed from the same batch of material as the re-engineered sections. *fm* indicates the beams maximum strength (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	*fm* (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**	**10030.6**
StDev	**12.7**	**1569.1**

Table 2. Strength & stiffness of comparable solid oak beams

Specimen	*fm* (N/mm^2)	*Ecen* (N/mm^2)
9631	36.0	8394.5
9634	46.6	8144.7
Average	**41.3**	**8269.6**
StDev	**7.5**	**176.6**

A Comparison between the mean values obtained from the solid oak beams and the re-engineered oak sections indicates that the re-engineered beams were both stronger and stiffer than the comparable solid material. Figure 7 shows one of the solid sections under test.

When the values from the re-engineered material was compared to values obtained from solid oak beams previously tested at BRE (from larger diameter material), the results were very favourable. The re-engineered beams showed greater strength (MOR) although stiffness (MOE) was slightly less than the oak beams previously tested.

Further tests are being planned in order to verify these promising results.

Figure 7. Solid oak beam under test

Task 5. Distortion Characteristics

Because timber is a natural product, as it dries, will shrink and often distort to varying degrees. In recent research undertaken at BRE, it was found that sawing and re-engineering solid material 'prone to distortion' can produce significant reductions in distortion values. In the light of this evidence, an evaluation was undertaken to assess the distortional characteristics of the re-engineered oak beams against solid oak beams processed from the same material.

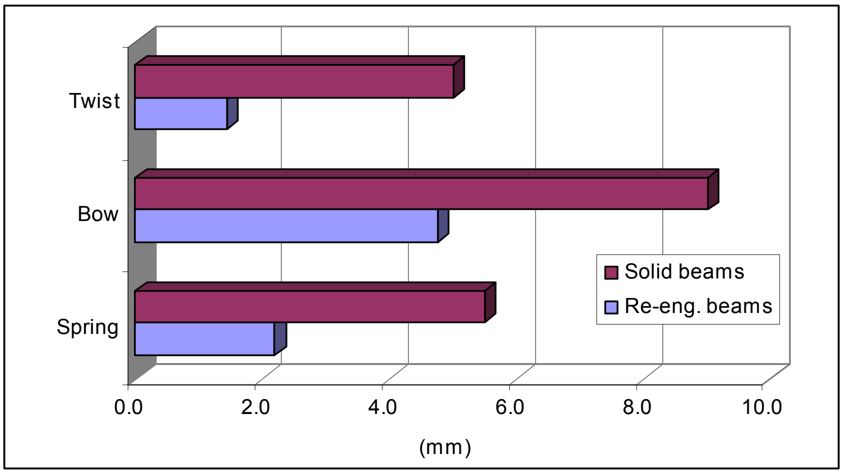

Figure 8. Mean distortion values for solid and re-engineered Oak

14 re-engineered beams and 2 solid oak beams were assessed for distortional characteristics using the distortion measurement method described in annex 1. The beams had been 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 easy comparison, the distortion values obtained from the beams were normalised to a section dimension of 100 mm depth and 2000 mm length. Figure 8 shows the average results from the two sets of beams. These results indicate that re-engineering small oak stems significantly reduces twist, bow and spring when compared with solid oak beams processed from similar material. Twist values were reduced by approximately two thirds and bow and spring by approximately half, when compared to values exhibited by the solid beams.

As new re-engineered beams are produced, further distortion assessments will be undertaken, to again verify the initial results.

Task 6. Assessment of drying characteristics

The two sets of re-engineered beams and two solid oak beams 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%.

Oak is known to be quite difficult to dry in larger sections without some form of drying degrade. Partially dried beam oak normally exhibits varying degrees of surface checking and splits, some of which can be quite extensive. The two solid oak beams cut from the small oak stems followed the normal trend and their surface (after drying) showed a considerable number of splits and checks. In comparison, the re-engineered material (cut and re-engineered during the same period) has dried with very few splits or checks occurring. This drying behaviour was quite unforeseen and the beams retain a very clean, almost machined surface finish (figure 9).

Figure 9. Surface finish after drying

Conclusions

This progress report presents the results from the first phase of the work programme to investigate the utilisation of small diameter, low value UK grown oak stems and other hardwoods to produce re-engineered components of standard dimensions using a novel cutting and jointing technique.

Results from these work tasks have been very encouraging:

- 30 oak stems of adequate quality and dimension were acquired
- A number of re-engineered oak beams have been made up to assess customer reaction and provide test materials for following tasks
- Tests reveal that re-engineered oak beams constructed from small oak stems are both stronger and stiffer than solid oak beams processed from the same material.
- The incidence of twist, bow & spring (after drying) was significantly reduced in the 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 considerably less surface checks and splits than solid material processed and dried at the same rate.

Overall, the results from this phase of the work programme have been much better than anticipated. A further batch of small hardwood stems is expected in the New Year and these will be re-engineered for further test work.

References

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

Annex 1. Distortion measurement methods

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).

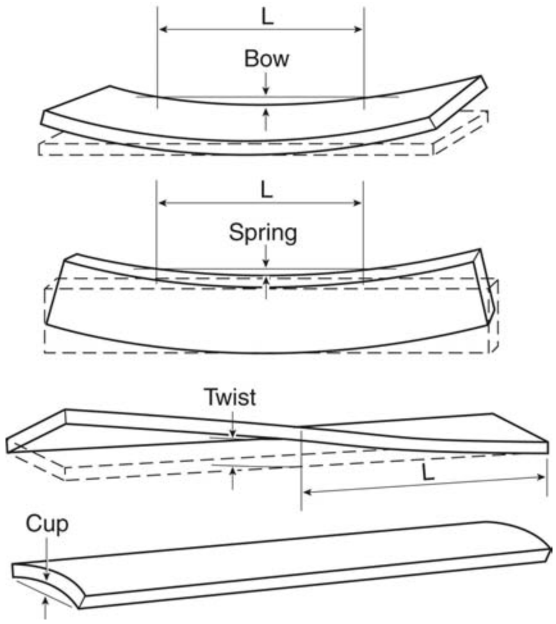

Figure 1. Distortion Types

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.