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Irish Timber – Characterisation, Potential and Innovation

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ABSTRACT:
In order to increase the utilisation of Irish timber in construction and novel engineered wood products, the mechanical and physical properties of the material must be established. For timber products used for structural applications, the fundamental properties are the modulus of elasticity, bending strength, density and dimensional stability as these define the structural grade of the material. In order to develop engineering design models for applications such as reinforced timber, knowledge of the nonlinear stress-strain behaviour in compression is also required.

The paper presents the programme and results of an ongoing research project 'Innovation in Irish Timber Usage' which focuses on the characterisation of Sitka spruce as it is the most widely grown species in Ireland. In the past, a number of studies have been conducted to determine the properties of Irish-grown Sitka spruce. Nevertheless, due to the changes that have taken place in silvicultural practices since the publication of these studies, there is a need to determine how these properties have changed. This paper presents the data gathered from historical studies together with the results of an extensive test programme undertaken to characterise the properties of the present resource.

Moreover, the paper examines the potential use of Irish grown Sitka spruce in novel timber products. Construction applications, such as fibre-reinforced polymer reinforced timber elements and connections, and cross-laminated timber are investigated.

KEY WORDS: Sitka spruce, timber properties, reinforced timber, Cross-laminated timber

1 INTRODUCTION

Due to the increasing focus on the use of sustainable construction materials to meet environmental targets related to efficient energy use and emissions, a significant opportunity exists for the Irish wood products sector. In 2012, the Irish forestry and forest products sector generated €2.2 billion in annual output, representing 1.3% GDP, and employed approximately 12,000 people [1]. Moreover, there exists a substantial potential to expand production. According to COFORD [2] half of the forest estate is less than 25 years old and further expansion of forest cover is planned by policymakers. Forest products to a value of €303 million were exported: including €73 million worth of sawn softwood and €179 million worth of wood-based panels. In general, 89% of the wood-based panels were exported [1]. The supply of roundwood from Irish forests is projected to increase from 3903 million m^3 in 2011 to 7110 million m^3 in 2028. These figures show the potential of Irish forests to provide increased and sustainable supplies of wood products [3]. Increased sales of existing products and the development of new markets at home and abroad for new added-value wood products will lead to job creation across the sector.

In order to increase the utilisation of Irish timber in construction, the mechanical and physical properties of the material must be established. For timber products used for structural applications, the fundamental properties are the bending modulus of elasticity (MOE), the modulus of rupture (MOR), the density and the dimensional stability as these define the structural grade of the material. In order to develop engineering design models for reinforced timber, knowledge of the nonlinear stress-strain behaviour in compression is also required.

As part of the project 'Innovation in Irish Timber Usage', funded by the Department of Agriculture, Food and Marine of the Republic of Ireland under FIRM/RSF/COFORD scheme, all of the available historical data on the properties of Irish Sitka spruce, from published and unpublished sources, is being collated. Moreover, testing of a large number of samples is being carried out to establish the mechanical and physical properties of the current resource. Furthermore, in order to investigate the potential for new add-value timber construction products, the two key research areas are addressed, namely, Fibre-Reinforced Polymer (FRP) reinforced timber and Cross-Laminated Timber (CLT).

2 CHARACTERISATION OF IRISH TIMBER

2.1 *Introduction*

The focus of this paper will be on timber from Sitka spruce as it is the most widely grown species in Ireland. Irish-grown Sitka spruce is characterised as a fast growing, low density species due to the rapid growth condition in Ireland and short rotation length. As a result of these growth conditions, the most common structural grade achieved by Irish-grown Sitka spruce is C16 grade.

In the past, a number of studies have been conducted on the properties of Irish-grown Sitka spruce [4-16]. This species is native to a narrow belt of the Pacific North West coast of

North America, along Alaska in the north, down through British Columbia, Washington and Oregon to California. Due to similarities in climate between this region and Ireland, it was first introduced to Ireland in 1831. The wide ranging site types suited to growing Sitka spruce vary from very fertile mineral to impoverished peaty soils [17].

A large study (the SIRT project) on Scottish Sitka spruce was undertaken in Scotland in recent years [18]. This has resulted in the publication of a report by the Forestry Commission entitled ‘Wood properties and uses of Sitka spruce in Britain’ [19]. This report is important for Ireland as the growing conditions in Scotland are similar to those in Ireland and the likelihood is that the physical and mechanical properties of the timber produced in both countries will be comparable.

In the following sections, properties of Irish Sitka spruce from selected studies are presented.

2.2 Mechanical properties

Investigations and grading results carried out by sawmills confirm that Irish Sitka spruce meets predominantly the requirements of strength class of C16. Table 1 presents the main strength requirements for C16 according to EN 338 [20]

Table 1. EN 338 [20] main characteristic values for C16.

Bending strength ($f_{m,k}$)	Compressive strength parallel to grain ($f_{c,0,k}$)	Mean modulus of elasticity parallel ($E_{0,mean}$)	Mean density (ρ_{mean})
16 N/mm^2	17 N/mm^2	8 kN/mm^2	370 kg/m^3

Picardo [4] undertook a large-scale testing programme to evaluate the influence of a number of classifying variables such as yield class (mean of cubic metres of solid stem wood added to an area of woodland per hectare per year [m^3/ha/yr]) , section size and forest on the strength and stiffness of Irish Sitka spruce. From tests on 1487 planks, he found that only section size had a practical influence on the MOR.

Ní Dhubháin et al. [5] examined the influence of compression wood on the bending MOE and MOR properties. This study had a relatively small sample size of 100 specimens of single cross-sectional size. They found that increased percentages of compression wood resulted in a decrease in MOE but appeared to have no effect on MOR.

Picardo [6] conducted another large study involving the machine grading of about 5000 pieces of timber into different strength classes. This study found that the yields for C14 and C16 were very high and the thickness has a significant impact on the yield. He did not undertake destructive mechanical tests.

Lucey et al. [7] investigated the utilisation of Irish grown Sitka Spruce timber (from forests in County Galway) in I-joists. It was reported that the stiffness of the I-joist has a high correlation to the stiffness of both tension and compression flanges. There was only a low level correlation between the strength of the web material and the strength of I-joist. Therefore, extensive testing programme was carried out on specimens used for the flanges. The MOR of the flange materials, presented in Table 2, was measured as described in EN 408 [21]. The average MOR results ranged from 22.2 N/mm^2 to 25.4 N/mm^2 for all cross-sectional sizes. However, the dimensions had an influence on the standard deviation of and 5-percentile of the MOR, which was lower for the smaller cross-sections.

Table 2. MOR parallel to grain results for square beams [7].

Specimen type & size	No. of specimens	Mean MOR [N/mm^2]	S. D. [N/mm^2]	5-percen. [N/mm^2]
compression flanges: 44 x 44 mm^2	31	22.2	4.6	13.5
tension flanges: 44 x 44 mm^2	31	22.3	3.9	15.5
compression flanges: 65 x 65 mm^2	11	24.8	2.0	21.9
tension flanges: 65 x 65 mm^2	11	24.4	4.0	18.1
compression flanges: 65 x 65 mm^2	10	25.5	2.1	22.9
tension flanges: 65 x 65 mm^2	10	25.4	2.8	20.9

The MOE parallel to grain was also measured in specimens stressed in both tension and compression. The results differed depending on cross-section size, and reached almost 8 MPa for the bigger sizes and 7 MPa for the smaller ones. These results for MOE testing are shown in Table 3.

Table 3. MOE parallel to grain results for square beams [7].

Specimen type & size	No. of specimens	Mean MOE [N/mm^2]	S. D. [N/mm^2]	5-percen. [N/mm^2]
compression flanges: 44 x 44 mm^2	29	7027	1026	5148
tension flanges: 44 x 44 mm^2	29	7106	945	5610
compression flanges: 65 x 65 mm^2	11	7533	627	6770
tension flanges: 65 x 65 mm^2	11	7531	1319	5573
compression flanges: 65 x 65 mm^2	10	7997	606	7180
tension flanges: 65 x 65 mm^2	10	7999	885	6696

In addition to bending properties, Lucey et al. [7] examined compression parallel to grain and tension strengths for various sizes of samples using Irish Sitka spruce. The results of these mechanical properties are summarised in: Table 4 – compression strength parallel to grain and Table 5 – Tension strength.

Table 4. Compressive strength parallel to grain results [7].

Specimen size [mm x mm x mm]	No. of specimens	Compressive Strength [N/mm^2]	S. D. [N/mm^2]	5-percen. [N/mm^2]
44 x 19 x 19	31	24.9	4.8	17.2
65 x 40 x 39	11	24.4	1.8	22.4

Table 5. Tensile strength parallel to grain results [7].

Specimen size [mm x mm x mm]	No. of specimens	Mean tensile strength [N/mm^2]	S. D. [N/mm^2]	5-percen. [N/mm^2]
44 x 19 x 10	31	23.9	4.3	16.3
65 x 40 x 20	11	24.6	2.9	20.2
65 x 40 x 20	10	25.1	2.1	22.2

Raftery and Harte [8] undertook a comprehensive study in order to assess the relationship between mechanical properties and physical characteristics in the longitudinal direction on clear and in-grade samples. Parameters, which were studied, included density, knot area ratio, MOE and ultimate strength. The results of this investigation might be essential in terms on the future development, design and optimisation of engineered wood products from Irish Sitka Spruce. It was concluded that MOE was the most highly correlated parameter to the tensile strength for both clear and in-grade specimens. Furthermore, the knot area ratio had a considerable influence on the strength of the timber both in compression and tension. Density was more highly correlated to ultimate compressive strength than ultimate tensile strength in clear wood specimens. In addition, the authors reported that MOE in tension had a poor correlation to the density of clear wood and was also poorly correlated to the knot area ratio and the density of in-grade specimens.

Moreover, testing of Irish timber has been undertaken in Irish third level institutions as part of the research for MSc and PhD theses. Not all of this data has been published in the available literature. Nevertheless, some of these results are shown in the following paragraphs.

The quality of Irish Sitka spruce was extensively investigated by Evertsen [9] using destructive and non-destructive methods. In order to determine the MOE and MOR, static four point bending tests were carried out on over 200 planed planks of different sizes taken from woodlands of yield classes 16 and 20. The moisture content of the samples during test was generally at 15 ± 2%. The mean, maximum, and minimum MOE and MOE results, including standard deviation, for different yield classes are presented in Tables 6 and 7.

Table 6. MOE parallel to grain from destructive tests [9].

Yield class	No. of specimens	Mean MOE [N/mm^2]	S. D. [N/mm^2]	Min. [N/mm^2]	Max. [N/mm^2]
16	64	8623	2757	1044	18424
20	116	9291	2511	3707	15772
16&20	180	9053	2601	1044	15772

Table 7. MOR parallel to grain from destructive tests [9].

Yield class	No. of specimens	Mean MOR [N/mm^2]	S. D. [N/mm^2]	Min. [N/mm^2]	Max. [N/mm^2]
16	64	24.4	9.4	0.4	44.5
20	116	26.3	7.5	7.2	47.8
16&20	180	25.6	8.2	0.4	47.8

For the non-destructive determination of the mechanical strength properties, an ultrasonic testing method was used by Evertsen [9]. This technique was developed by Bucur [10, 11], who had found that the MOE for small clear specimens had a high correlation with the ultrasound propagation speed in increment core sized samples. 300 small clear specimens were tested including 240 of yield class 16 and 60 of yield class 20. The obtained average MOE values were 8639 N/mm^2 and 7677 N/mm^2 for the first and second batch, respectively, and the average MOR values were 73.8 N/mm^2 and 67.2 N/mm^2, respectively.

Subsequently, tests results published by Patrick [12] confirmed that Sitka spruce has a brittle mode of failure in axial tension influenced by larger knot occurrence. The characteristic in-grade strength of 14.4 N/mm^2 was obtained in comparison to mean in-grade strength of 27.1 N/mm^2. These values were approximately half of the characteristic and mean strengths for clear timber, respectively. On the other hand, the mean and characteristic compressive strengths showed less variability reaching 30.6 N/mm^2 and 21.0 N/mm^2, respectively, for in-grade samples. The value of MOE in compression of 9125 N/mm^2 was found.

For the purpose of the studies carried out by Bourke [13, 14] a substantial number of pieces were selected in order to represent a typical forestry region and divided into three batches. Bending MOE tests were carried out in accordance to EN 408 [21] and the results are shown in Table 8.

Table 8. Mean MOE results [13,14].

Batch ID	No. of specimens	Mean MOE [N/mm^2]	S. D. [N/mm^2]
A	85	9367	1492
B	85	7475	1335
C	64	9036	-

In addition to these studies, Treacy et al. [15, 16] examined the influence of density and microfibril angle on the bending MOE and MOR of clear wood specimens from Sitka spruce of four different provenances. This study was confined to small clear samples and only 96 samples were subjected to bending tests. A linear relationship, the same for all examined provenances, was found between microfibril angle and strength.

2.3 *Physical properities*

Evertsen [9] undertook an extensive testing programme to determine the physical properties of Irish Sitka spruce. Densities were examined by different testing procedures, including oven drying, infra-density and microdensitometry (optical density). The mean density (oven dry) of 273 specimens was 370 kg/m^3 with standard deviation of 46.2 kg/m^3. The average of basic density (wood dry mass over wood fresh volume) of 480 samples was 366 kg/m^3. X-ray microdensitometry was used to determine the density of specimens cut at different radial distances from the core. Specimens were conditioned to a moisture content of 15 %, prior to testing. These results for microdensitometry are summarised in Table 9.

Table 9. Microdensitometry results [9].

Wood type	Mean [kg/m^3]	Max. [kg/m^3]	Min. [kg/m^3]
Juvenile wood	472	864	306
Adult wood	451	812	259
Yield class 16	462	838	283
Yield class 20	424	781	242

Other timber properties determined by Evertsen [9] include values of twists and shrinkage. Mean values of twist and shrinkage for samples of yield classes 16 and 20, are shown in Tables 10 and 11, respectively.

Table 10. Twist results [9].

Yield classes	Samples no.	Mean twist [mm/3m]	S. D. [mm/3m]
16	80	6.38	4.81
20	159	7.17	4.49
16&20	239	6.90	4.60

Table 11. Dimensional shrinkage values [9].

Yield class	No. of specimens	Length [%]		Width [%]		Depth [%]	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
16	78	0.055	0.037	2.17	0.76	1.88	0.62
20	157	0.041	0.030	1.52	0.75	1.37	0.52
16&20	235	0.045	0.033	1.73	0.81	1.54	0.60

Mean values of shrinkage for 960 specimens of yield class 20 were 4.21% with standard deviation of 0.94% for the tangential direction and 2.15% with standard deviation of 0.69% for the radial direction.

Bourke [13, 14] investigated distortion in timber from fast-grown Irish Sitka spruce, dried to 12% moisture content. The results demonstrated that the dominant mode of distortion was twist, which results in significant reduction of load bearing capacity. It was found that almost all the planks were within specification for both bow and crook, even for stricter limits for special structural (SS) material. An analysis of the location in the logs from which each board was sawn shows significant variation with respect to radial position. A strong negative correlation was demonstrated between distance from the pith and the degree of twist that developed during drying.

Currently, as a part of the project ‘Innovation in Irish Timber Usage’, the MOE and MOR are being determined from flexural testing. Physical properties including moisture content and density of each specimen are also being verified. These tests are being carried out in order to establish the variability in the mechanical properties including an assessment of the in-board and between board variability in the MOE, and to investigate the relationship between board MOE, density and the timber origin.

3 POTENTIAL & INNOVATION

3.1 *Introduction*

The capacity of lower grade timber can be enhanced by its utilisation in novel engineered wood products. The properties of timber elements can be greatly improved through the reinforcement by various materials. This strategy has been successfully implemented within the construction industry and has grown in recent years. The methodologies, with large potential for Irish timber, are presented in the following paragraphs.

3.2 *FRP Reinforced Timber*

Fibre reinforced polymer (FRP) is a composite consisting of reinforcing fibres bound together in a polymer matrix. The most common reinforcing fibre materials are glass, carbon and aramid. These FRP materials are commonly used in the aerospace, automotive and marine sectors due to their high strength to weight ratio [22]. Timber has been reinforced using FRP material in various configurations such as plates or near surface mounted rods. Although FRP has been largely used for retrofitting and repairing old timber structures there is potential for the development of design codes to incorporate the use of FRP material into new composite timber engineering design.

Along with more commonly used FRP materials, increasing focus on environmental issues has promoted the use of natural fibres within FRP materials. Basalt fibre reinforced polymer (BFRP) is a lesser known fibre which has the potential to rival and surpass more commonly used fibres. BFRP is formed similarly to many other reinforcing fibres. The basalt rock is pre-treated and melted and the filaments are created as the molten rock passes through hundreds of small orifices. Lopresto et al. [23] compared basalt and glass fibre reinforcement. The results showed a high tensile modulus, compressive strength and bending strength for BFRP material. The BFRP reinforcement also showed a 35 - 42 % higher elastic modulus when compared to that of glass fibre reinforced polymer (GFRP) reinforcement. This material shows promising results both structurally when comparing material properties and economically when looking at a cost comparison with more expensive fibres such as carbon and aramid fibres.

Many researchers have shown that the addition of FRP reinforcement to solid timber beams results in an increase in strength and stiffness [24, 25]. These enhancements are also experienced in glued laminated beams. Glulam beams reinforced with modest percentage reinforcement ratios (0.4

% - 2.9 %) of FRP material have been shown to demonstrate superior strength, stiffness and ultimate moment capacity when compared to glulam beams in their unreinforced state [26, 27]. Hansson and Kristoffer [27], observed an increase in bending stiffness of 85 % with a percentage reinforced area of 2 % using carbon fibre reinforced polymer (CFRP) reinforcement plates. Raftery et al. [29], examined the effect of GFRP rods on the structural properties of Irish-grown Sitka spruce glued laminated beams. With a modest percentage reinforcement of 1.4 %, a mean stiffness enhancement of 13.9 % and a mean improvement in the ultimate moment capacity of 68 % was achieved when compared to beams in their unreinforced state. Kelly [30] examined the effect of BFRP rod reinforcement on low grade timber beams. The results indicated an increase in bending stiffness of 12 %, with a percentage reinforcement of 1.2 %, when compared to the timber beams in their unreinforced state. These results show great potential for such a low percentage reinforcement.

Much of the studies undertaken to date in the field of reinforced timber have highlighted the positive effect of the reinforcement on the short-term behaviour in bending. I. The research being carried out as part of the project 'Innovation in Irish Timber Usage' aims to determine the long-term performance of such reinforced timber beams with respect to load duration and variable climate and to develop appropriate modification factors for design purposes.

3.3 *Reinforced Timber joints*

In timber engineering the critical elements in the design of a structure are generally the joints. The most prevalent type of joints found in timber structures are pinned joints. Moment connections, however, are more versatile but these are less common as they are perceived to be more expensive. Moment connections can be achieved by using bolted plates, dowels positioned in a circular arrangement or glued-in rods [31, 32].

Glued-in rod connections, as shown in Figure 1, can be extremely efficient and possess many desirable attributes in terms of manufacture, performance, aesthetics and cost compared to the cumbersome conventional steel moment connections that are often encountered in timber construction. Not only do connections with glued-in rods look better than conventional connections, they also have enhanced fire protection as the rods which transfer moment are embedded inside, and are therefore protected by, the timber.

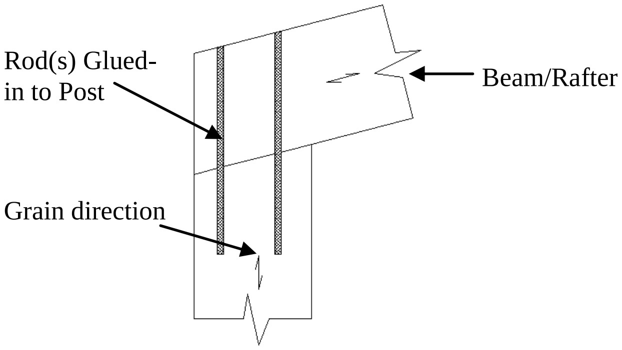

Figure 1. Sketch of Glued-in Rod Connection

With regards to new-build construction, Gehri [33] identified five areas where glued-in rods may be used for connections: frame corner, beam-post connection, beam-beam joint, supports and hinged joints.

Over the past two decades there have been many national and international research projects commissioned on the use of glued-in rods in timber joints e.g. GIROD, LICONS [34] and Bainbridge and Mettem [35]. In spite of this, no universal standard exists for their design. There had been an informative annex in prBS ENV 1995-2 [36] which provided limited coverage of the design of glued-in rods using steel bars however this document was replaced by BS EN 1995-2:2004 [37] and no guidance is included in the current document. The three main elements to be considered when designing glued-in rod connections are: the timber, rod and adhesive. The most significant challenge in the development of a standard design method is the many varying approaches to defining these joint properties as each of these elements can be expanded further, thus making the definition of design rules more complicated.

The majority of research done in this area to date comprises steel rods glued-in to glued laminated (glulam) elements with lamellae of a high strength class timber. The investigation on the use of locally sourced Irish Sitka Spruce is a part of the project 'Innovation in Irish Timber Usage'.

3.4 *Cross-laminated timber (CLT)*

Cross-laminated timber (CLT) is a prefabricated multi-layer engineered wood product made of at least three orthogonally bonded layers of timber. In order to increase rigidity and stability, successive layers of boards are placed cross-wise to form a solid timber panel, as show in Figure 2.

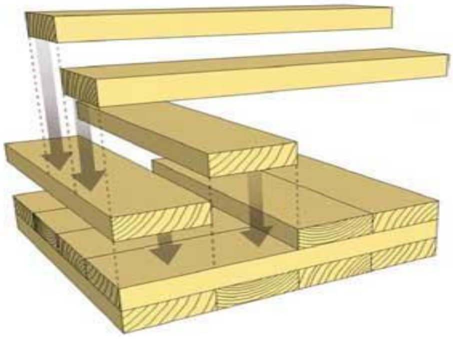

Figure 2. CLT panel schema [38].

Load-bearing CLT wall and floor panels are easily assembled on site to form multi-storey buildings. This improves construction and project delivery time, reduces costs, and maximises efficiency on all levels [39-41]. In this project, the feasibility of using Irish Sitka spruce to produce commercial CLT panels is being investigated.

4 CONCLUSIONS

In the past, a number of studies has been conducted to determine the properties of Irish-grown Sitka spruce. Nevertheless, due to the changes in that have taken place in silvicultural practices since the publication of these studies, there is a need to determine how these properties have changed.

As a part of ‘Innovation in Irish Timber Usage’ ongoing project testing of a large number of samples will be undertaken to establish the properties of the current resource. Comparative analysis will be undertaken with the data produced for Scottish Sitka spruce in the SIRT project and with historical data.

Other objectives of the project include determination of the durability of reinforced timber beams with respect to load duration and variable climate and to develop appropriate strength modification factors.

The next aim of the research programme is to investigate and develop a sustainable means of creating moment resistant connections within timber frames using bonded-in FRP rods, with a specific emphasis on the portal frame.

Moreover, the suitability of Irish-grown Sitka Spruce for the manufacture of cross-laminated timber panels (CLT) is investigated. This is vital in order to develop the necessary engineering data to support the commercialisation of Irish-made CLT.

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