



Full – Scale Evaluation of Creep Performance of Glued Solid Timber Beams for Sustainable Construction

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Abstract

Timber, as a sustainable and versatile building material, continues to play a key role in modern construction, while reducing reliance on large, old-growth timbers and other heavy materials. While numerous studies have focused on glued laminated timber beams (GLT), this research explores the potential of an innovative engineered product Glued Solid Timber (GST) beams as a durable, long-lasting alternative with broad application. This study presents a first series of experimental and numerical investigations conducted within the framework of Eurocode 5.

The models (beam samples) are full-scale and are produced from Spruce (*Picea Abies*) in accurate dimensions in the cross section 138mm x 170mm (EN 14080-2013), while the length of the beams is determined by referring to the procedures of the standard EN 408:2010+A1, which in this case is 3570mm.

Alongside the experiments, numerical simulations were carried out using the Finite Element Method (FEM) to model the performance of GST beams under long-term loading.

The creep of timber is taken into account when we calculate the serviceability limit state, i.e. the limit state of deflections, and it mostly affects the deflection from long-term loads usually from the action of permanent loads. The testing of creep of timber is needed to determine the deformation factor k_{def} (which represents the coefficient of creep) which, according to Eurocode 5, depends on the duration of the load and from service class of the timber. What is particularly important is that in Eurocode 5 there are no defined values for k_{def} for glued solid timber, and hence the great importance of the test of creep of timber of glued solid timber (GST).

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1. Introduction

Timber has long been recognized as a sustainable and versatile construction material. In recent years, its use has gained prominence in modern architectural and civil engineering projects due to its environmental benefits, aesthetic appeal, and structural performance [1]. Timber's anisotropic and hygroscopic nature necessitates careful selection and treatment, especially considering biological degradation and environmental variations [2]. Furthermore, timber structures offer good insulation properties, easy processing, and environmental benefits such as being a CO₂ reservoir, contributing to climate protection [3].

In these early decades of the 21st century, timber is enjoying a renaissance as a mainstream structural material [4]. As global efforts to reduce the reliance on traditional materials such as steel and concrete intensify, engineered wooden products have emerged as a promising solution. Various structural systems represented by light-frame timber structures, glued laminated timber structures, and hybrid timber structures have been formed worldwide [5]. Among these products, Glued Solid Timber (GST) beams stand out for their strength, durability, and adaptability in various construction applications [6]. On the other hand, compared to steel and concrete, timber exhibits a significantly lower carbon footprint, making it a key material in sustainable construction practices [7].

The research and development of GST beams are essential, especially in regions like the Western Balkans, where timber construction is increasingly popular but relies heavily on imports from countries like Germany, Austria, etc. By utilizing local resources, such as Spruce (*Picea Abies* PCAB), and adhering to European standards, the potential for producing high-performance structural timber elements locally can be explored and optimized. Different types of wood are used in construction, each with different characteristics that adapt to applications according to needs. There are species of wood from the coniferous (gymnosperm) and broadleaf (angiosperm) families that have different anisotropic properties, which serve to build large structures as vertical and horizontal supports [8]. One of the important aspects of using wood is choosing the right type for each assortment of the building, to ensure aesthetics, durability, functionality and structural safety.

To use wood in building constructions, it must go through a technological processing process that includes several necessary steps to be undertaken. Initially, the wood cut from the forest must go through a first stage (primary wood processing) before the mechanical process, namely the drying stage, to avoid its dimensional deformation in different environmental conditions [9].

Glulam is extensively used for its superior mechanical properties, design flexibility, and aesthetic appeal (EN14080:2013.) outlines the European requirements for glulam products, addressing mechanical resistance, bonding strength, and durability against biological attack (CEN, 2013). [11] noted the mechanical comparability of hybrid hardwood glulam beams to traditional homogeneous beams, suggesting potential weight savings. Reinforcement techniques, such as using CFRP sheets, significantly improve glulam beams' structural performance, allowing broader structural applications [2], [12].

Engineered materials used in construction, such as Glulam (glued laminated timber) and Glued Solid Timber (glued solid timber) are more advanced alternatives to natural wood and offer significant benefits in structural construction. These engineered materials are created using modern technology with the aim of improving the overall properties of wood [13].

Arguments for laminating by gluing together boards were to make the load bearing structure's formation independent of the dimensions of the growing trees and the possibility of manufacturing different shapes and suitable composite sections (The glulam handbook, volume I; edition 1:2024).

Glulam also offers architectural versatility, enabling the creation of large, curved, or complex structures, previously difficult to achieve with traditional timber products.

Source: The glulam handbook, volume I; edition 1:2024.

Glued solid timber (GST) refers to timber elements bonded in various configurations forming larger structural sections, often using interlocking joints rather than thin laminations as in glulam. A notable system is the Interlocking Glued Solid Timber (IGST), which employs overlapping patterns and diagonal cuts, offering mechanical properties comparable to solid timber without traditional finger joints [14]. Nowadays, extensive research has been conducted to explore the structural behavior of glulam beams and solid timber beams that are reinforced with FRP sheets or bars [15]; [16]; [17] [18]; [19]; [20].

Whereas for the research within the framework of this dissertation, the selected wood species is Spruce (*Picea abies*, PCAB), of high quality, Class I [11], inspected firstly and then selected mainly as radial wood (primarily) without natural defects, such as knots, twists, bending, etc. Quality control includes inspecting the wood for damage and assessing its strength and durability. The wood is chosen as treated (dried) to prevent damage from insects and various possible defects.

The performed experiments evaluated the structural performance of Glued Solid Timber (GST) beams through comprehensive experimental and analytical investigations.

The scope of this research encompasses the production and testing of three-layer GST beams manufactured with structural adhesive in accordance with EN standards. The investigation covers long-term behaviors, addressing critical aspects of mechanical performance and compliance with EN 408:2010+A1 and EN 14080:2013 standards.

In the long-term tests, sustained loads caused notable stiffness loss in the early loading stages, followed by a gradual stabilization. The model successfully replicated the creep trend and time dependent deflection, aligning closely with experimental measurements. This emphasizes the importance of accounting for creep effects in the long-term structural analysis of timber elements.

2. Materials and Methods

The experimental investigation involved two glued solid timber beams (GST) manufactured from Spruce (*Picea Abies*). In this context, Spruce refers to the family of softwood species, commonly employed in European structural glued laminated timber and glued solid timber beams. The GST beams tested had identical dimensions (138mm x 170 mm x 3570mm) and were subjected to a uniformly distributed load using full-steel billets (dimensions 140mm x 140mm x 500mm). The production of the beams was carried out based on the reference of standard EN14080 and the test set-up is done based on EN408:2010+A1:2012. Determination of wood characteristics and other criteria's regarding Eurocode standards, like moisture content of test pieces, drying the samples in oven and cutting and processing samples were done at the Faculty of Architecture, Design and Wood Technology, at University of Applied Sciences in Ferizaj. While, experimental tests of beams were performed at room temperature at the laboratory of the Faculty of Civil Engineering, Ss. Cyril and Methodius University in Skopje, North Macedonia. This series focused on investigating the long-term deflection behavior of beams under sustained loading conditions, specifically to evaluate creep development and determine the creep coefficient. Technical data monitored during the test are presented in tables 1 and 2.

Table 1. The data were recorded as presented in the following table report (Beam D11):

Long-term BEAM D11							
PHAS E	DAT E	HOU R	T[°C]	RH [%]	Dm1[m] m]	Dm2[m] m]	Weight kg
0	10.07	9:30	23.6	65	3.65	5.6	77.3+
1					4.35	5.76	79.4+
2					5.08	5.91	75.05+
3					5.55	6.04	76.45+
4					6.03	6.14	79.50+
5					6.75	6.27	76.85+
6					7.38	6.43	72.80+
7					7.78	6.52	76.45+
8					8.22	6.64	
G	11.07	10:00	23.7	64	8.39	6.64	
G	12.07	10:00	23.9	62	8.43	6.62	
G	13.07	10:30	24	60	8.46	6.62	
G	14.07	11:00	24.1	61	8.49	6.62	
G	15.07	10:15	24.2	62	8.53	6.62	
G	16.07	12:45	24.5	59	8.55	6.62	
G	17.07	8:45	24.5	54	8.52	6.57	
G	18.07	7:15	24.7	56	8.54	6.56	
G	19.07	15:05	25.2	64	8.62	6.58	
G	20.07	14:05	25.2	63	8.64	6.59	
G	21.07	10:35	25.1	62	8.64	6.59	
G	22.07	16:30	25.7	56	8.64	6.59	
G	29.07	9:50	24.6	52	8.67	6.47	
G	06.08	10:30	24.7	46	8.75	6.28	
G	12.08	10:50	25.3	50	8.83	6.27	
G	19.08	9:30	25.6	56	8.96	6.33	
G	26.08	8:20	25.2	50	8.96	6.36	
G	02.09	11:00	24.3	47	8.96	6.31	
G	09.09	9:40	24.5	57	9.06	6.35	
G	16.09	17:00	22.3	51	9.01	6.26	
							Total weight (sustained distributed load = 613.8 kg

G	23.09	16:30	22	51	9.02	6.3
G	01.10	8:20	20.5	30	8.9	6.14
G	07.10	15:00	20.3	55	9.09	6.34
G	14.10	17:15	19.8	54	9.08	6.35
G	21.10	19:15	18.6	52	9.06	6.32
G	29.10	16:30	18.1	58	9.09	6.35
G	04.11	8:20	20.5	50	9.06	6.32
G	11.11	13:30	22.8	47	9	6.16
G	19.11	19:10	22.1	40	9.04	6
G	26.11	17:15	20.8	27	8.96	5.73

Table 2. The data were recorded as presented in the following table report (Beam DI2):

Long-term BEAM DI2							
PHASE	DATE	HOUR	T[°C]	RH [%]	Dm1 [mm]	Dm2 [mm]	Weight kg
0	10.07.24	9:30	23.6	65	4.47	4.17	
1					5.1	4.28	74.9+
2					5.75	4.39	77.05+
3					6.2	4.44	80.75+
4					6.65	4.54	73.2+
5					7.26	4.65	73.9+
6					7.91	7.79	74.9+
7					8.33	4.87	78.05+
8					8.74	4.98	75.6+
G	11.07.2	10:00	23.7	64	8.89	4.98	
G	12.07.2	10:00	23.9	62	8.93	4.97	
G	13.07.2	10:30	24	60	8.97	4.97	
G	14.07.2	11:00	24.1	61	9	4.97	
G	15.07.2	10:15	24.2	62	9.02	4.97	
G	16.07.2	12:45	24.5	59	9.09	4.97	
G	17.07.2	8:45	24.5	54	9.05	4.98	
G	18.07.2	7:15	24.7	56	9.06	4.92	
G	19.07.2	15:05	25.2	64	9.12	4.93	
G	20.07.2	14:05	25.2	63	9.14	4.93	
G	21.07.2	10:35	25.1	62	9.14	4.93	
G	22.07.2	16:30	25.7	56	9.16	4.93	
G	29.07.2	9:50	24.6	52	9.24	4.82	
G	06.08.2	10:30	24.7	46	9.38	4.57	
G	12.08.2	10:50	25.3	50	9.47	4.57	
G	19.08.2	9:30	25.6	56	9.58	4.64	
G	26.08.2	8:20	25.2	50	9.6	4.68	
G	02.09.2	11:00	24.3	47	9.64	4.68	
G	09.09.2	9:40	24.5	57	9.69	4.67	
G	16.09.2	17:00	22.3	51	9.72	4.58	
G	23.09.2	16:30	22	51	9.71	4.62	Total weight (sustained distributed load = 608.35 kg
G	01.10.2	8:20	20.5	30	9.7	4.44	
G	07.10.2	15:00	20.3	55	9.76	4.66	

G	14.10.2	17:15	19.8	54	9.78	4.65
G	21.10.2	19:15	18.6	52	9.78	4.64
G	29.10.2	16:30	18.1	58	9.79	4.64
G	04.11.2	8:20	20.5	50	9.77	4.65
G	11.11.2	13:30	22.8	47	9.75	4.49
G	19.11.2	19:10	22.1	40	9.82	4.3
G	26.11.2	17:15	20.8	27	9.91	4

2.1. Material of Spruce wood

From the many investigations done for the timber in the local market of Kosovo, with the aim of finding wood from the first class, there were found two companies offering us material according to our request standard. The wood specie selected as wood type is defined Spruce wood family (*Picea Abies* PCAB). The lamellas were selected with initial thickness of 50mm, width of 200mm \pm 20mm and length of 4000mm. All were selected with extra care (checked and measured in thickness from stack) [21].

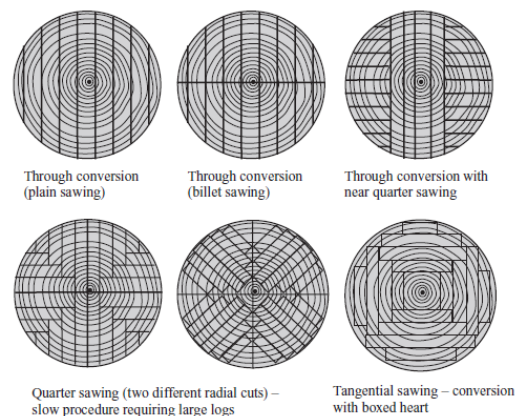


Figure 1. Selection of material based in Structural Timber Design to Eurocode 5

Source: J. Porteous and B. Kermani, Structural Timber Design to Eurocode 5

The class of these lamellas belongs to quality I (axial and central log boards, mainly radial), each lamella is individually measured in thickness due to the delicacy of twisting, bending, knots, resin and other possible defects

2.2. Determination of moisture content of test pieces

The moisture content of the test piece is determined in accordance with EN 13183-1 on the sections of the test pieces taken from 11 lamellas (boards) as described in standard.

Source: Standard EN 13183-1

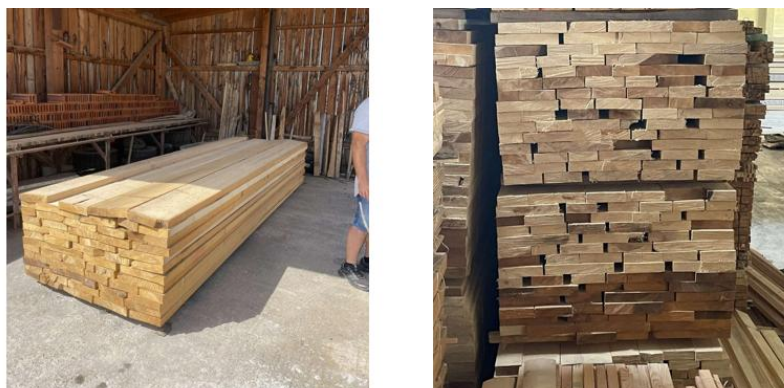


Figure 2. a & b view of the raw material deposited before transportation

2.3. Defining dimensions of the samples

The test slice was cut of full cross section and minimum 20 mm dimension in the direction of the grain, at a point by at 300 mm from either end of the test piece. The test slice was free from resin wood and features such as bark, knots and resin pockets

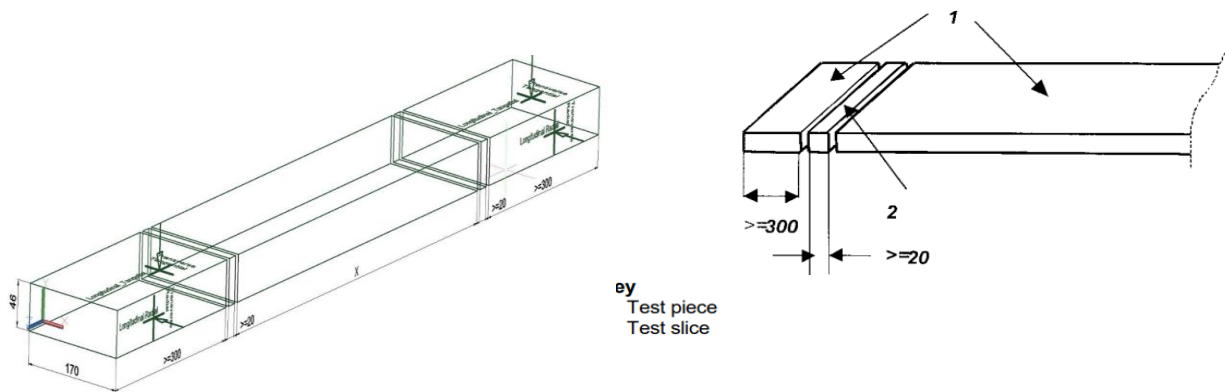


Figure 3. Source: Standard EN 13183-1

Source: Author, dimensions referred to EN 13183-1

2.3.1. Cutting slices

From each of the 11 test pieces, one test slice was cut, resulting in a total of 11 test slices. Each slice was extracted with its full cross-section preserved, measuring 170 mm in width and 20 mm in thickness, oriented in the direction parallel to the grain. This preparation ensured that the material properties could be evaluated under conditions representative of the original lamella configuration.

2.3.2. Measuring and scaling the test samples

Each test slice was marked and measured in longitudinal, radial and tangential directions (8 measurements were done per each piece with Nonius Caliper) and each piece has been scaled (accurate equip. to 0,01 g



Figure 4. Cutting the test pieces according to EN 13183-1 on the designated sections

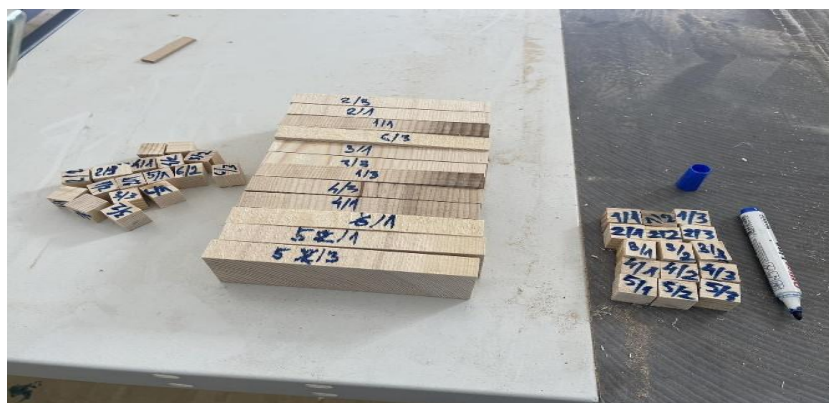


Figure 5. View of the cut and marked samples prepared for testing

Balance accurate scale was accurate to 0,01 g, because of the mass of the test slice were less than 100g in an oven dry state. Equipment for drying wood, ensuring free internal circulation of air and capable of maintaining a temperature of $(103 \pm 2) ^\circ\text{C}$.



Figure 6. a) Scaling of test samples for weight measurement and b) Measuring samples with caliper in three directions

2.3.3. Drying the samples in oven

First time each of the slices were scaled as a weight grain before drying in gram (Fig. 20);

Second time the slices were scaled after 5 hours dried in the special experimental oven;

Third time again three hours more were dried, until the difference between samples was not higher than 1 gram.

Calculation of the moisture content is done using the formula [22], [23]:



Figure 4. Adjustment of temperature in oven $103 \pm 2^\circ\text{C}$

$$\omega = \frac{m_1 - m_0}{m_0} \times 100 \dots (1)$$

Where:

- m_1 – is the mass of the test slice before drying, in grams;
- m_0 – is the mass of the oven dry test slice, in grams;
- ω - is the moisture content, in percent.

The average of the weight of cut slices (samples) was 70.25gr. and the average after 8 hours drying in the oven was 61.78gr. According to the formula written above, the moisture content is equal to 13.70%.

2.3.4. Determination of density of test samples

The density of wood is determined based on the ISO 13061-4:2014 standard.

Samples with proper dimensions (fig. 21) were measured before the drying process and were calculated using the formula [22]:

$$\rho_w = \frac{m_w}{a_w b_w l_w} = \frac{m_w}{V_w} [\text{kg}/\text{m}^3] \dots (2)$$

Where:

- m_w - mass in kilograms (or grams) of the test piece at moisture content W ,
- a_w , b_w and l_w - are the dimensions, in meters (or centimeters), of the test piece at moisture content W ,
- V_w – is the volume in m^3 (or cm^3) of the test piece at moisture content W .

Measuring Weight/Volume through the formula, the density of the test pieces is 438.33 kg/m^3 T30 (C50) characteristic strength, according to Class of boards (table 1) EN 14080.

Table 3. Characteristic strength and stiffness properties for T-classes in N/mm^2 and densities in kg/m^3 for boards or planks for GLT / Source: Class of boards from table 1, Standard EN14080

T - class of boards	ft,0,l,k	Et,0,l,mean	ρ ,k
T8 (C14)	8	7 000	290
T9	9	7 500	300
T10 (C16)	10	8 000	310
T11 (C18)	11	9 000	320
T12 (C20)	12	9 500	330
T13 (C22)	13	10 000	340
T14 (C24)	14	11 000	350
T14,5	14,5	11 000	350
T15	15	11 500	360
T16 (C27)	16	11 500	370
T18 (C30)	18	12 000	380
T21 (C35)	21	13 000	390
T22	22	13 000	390
T24 (C40)	24	13 500	400
T26	26	14 000	410
T27 (C45)	27	15 000	410
T28	28	15 000	420
T30 (C50)	30	15 500	430
^a The C-Classes according to EN 338:2009 meet at least the required values of the respective T-classes.			

Table 4. Recording and calculation of data, averaging dimension measurements (longitudinal, radial and tangential) and weights

Sample	Longitudinal					Tangential			Radial			Weight green	Weight after 5 hours	Final
	1	2	3	4	Average	1	2	Average	1	2	Average			
1	19.9	19.96	19.91	20.02	19.95	50.1	50.94	50.52	162.4	162.6	162.50	74.4	62.5	62.4
2	19.92	19.95	19.94	20.02	19.96	50.07	50.82	50.45	158.4	156.85	157.63	73.2	60.9	60
3	19.98	20.02	19.8	19.96	19.94	51.01	49.71	50.36	160.45	160.9	160.68	67.9	61.9	61.9
4	19.88	19.82	20.01	19.89	19.90	45.71	45.97	45.84	165.55	163.35	164.45	67.6	61.6	61.6
5	19.85	20.01	20.07	20.03	19.99	45.68	45.89	45.79	164.55	162.5	163.53	68	61.3	61.3
6	19.93	19.83	20.04	20.07	19.97	49.86	49.11	49.49	161.25	160.1	160.68	66.3	56.1	56.1
7	20.29	19.94	19.97	20.01	20.05	50.49	50.52	50.51	159.65	160.6	160.13	70.6	58	58
8	19.92	19.92	19.94	19.94	19.93	49.63	48.43	49.03	166.15	165.55	165.85	68.7	62.4	62.4
9	20.18	20.07	20.95	20.11	20.33	49.44	48.19	48.82	165.7	165.95	165.83	68.4	62.3	62.2
10	19.92	20	19.96	19.99	19.97	50.46	50.75	50.61	165.8	165.15	165.48	74.2	67.3	67.2
11	20.19	20.07	20.94	20	20.30	50.14	49.39	49.77	162.95	162.75	162.85	73.5	66.6	66.5

											Average:70.25	Average: 61.78
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2.4. Production and its stages

2.4.1. Processing of lamellas in machines

After the delivery of the wooden material to the workshop, the lamellas were allowed to rest for a period of three days to achieve moisture equilibrium with the ambient conditions of the work environment. This acclimatization step is essential to minimize dimensional changes and internal stress during subsequent processing. Once the material reached a stable moisture balance, the lamellas were cut to the desired length according to the specifications of the target plan.

A series of preparation steps were then carried out to shape and refine the samples for further testing and assembly. The following machining operations were performed:

Longitudinal and perpendicular cutting: Carried out using a circular saw machine to dimension the lamellas accurately in both length and width.

Planning (edge and face): A planer machine was used to smooth and straighten one edge and one face of each lamella, providing reference surfaces for further processing.

Thickness planning: The thickness planer machine was used to achieve uniform thickness across all lamellas, ensuring consistent cross-sectional dimensions.

Sanding: Final surface preparation was done using a sanding machine to remove any surface irregularities, improve surface quality, and prepare the lamellas for bonding or testing.

These operations were performed with care to preserve the integrity of the material and ensure high precision in sample preparation.



Figure 5. Initial stage of lamella preparation

The lamellas were passed through the planer machine one by one, on one face and on one edge. From 50mm the dimensions decreased to 46mm. The feed rate speed was around 3-6m/min. Surface preparation involved mechanical standing and thorough cleaning to remove contaminants and enhance adhesive penetration [24].

The next stage in the processing sequence involved the use of a thickness planer machine to achieve uniform thickness across all lamellas.

This machine was equipped with an automatic feed system, operating at a consistent feed rate of 7 meters per minute, which ensured efficient and continuous material flow during planning. The cutter head rotated at a speed of 4500 revolutions per minute (rpm), providing a smooth and accurate finish.

A high-quality four-edge cutting tool was used to guarantee precision and surface quality, contributing to consistent dimensions and improved bonding performance in later stages of fabrication.

2.4.2. Bonding process

The type of adhesive that is used for gluing the lamellas is for moisture curing one-component polyurethane adhesive, normative reference is made to EN 15425.

Having a variety of 4 different grades of Henkel Loctite HB S-adhesives available in bottles, I've chosen the type HB S709 (75 min OT /175 min PT):

- HB S049 (4 min open time / 10 min press time)
- HB S109 (10 min OT / 25min PT)
- HB S309 (30 min OT / 75 min PT)
- HB S709 (75 min OT /175 min PT)

During our bonding process is used type HB S709 is chosen because due to manual application and thought slower adhesive suits better to our needs.

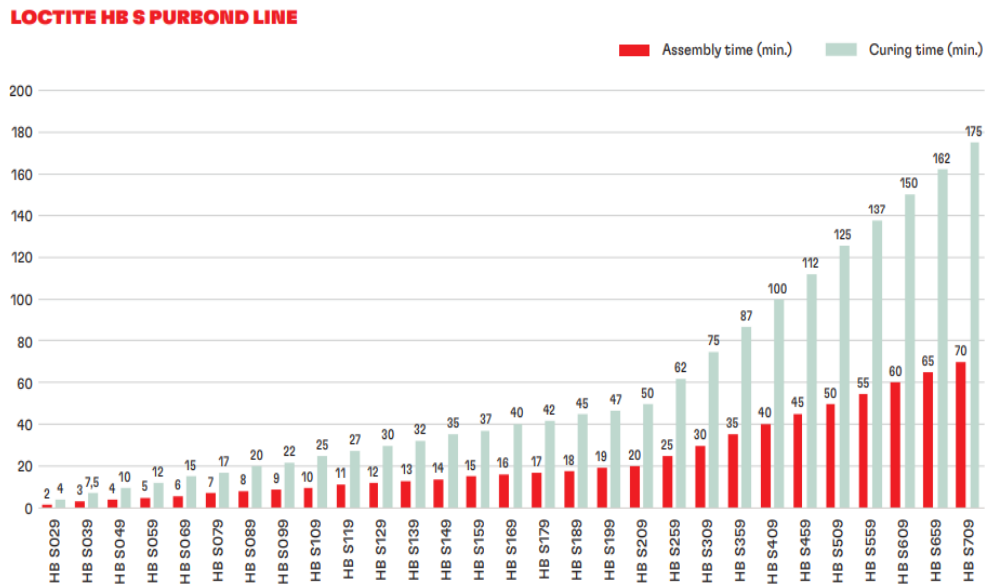


Figure 6. Graphic showing industrial Assembly time and curing time application for the beams

Source: Henkel adhesive technical data sheet



Figure 7. a) and b) Laying of glue with a thickness of more than 0.1 mm with the density of adhesive at around 1,16 g/cm³

2.4.3. The press time application

According to the Technical Data Sheet, the glue line thickness should be around 0,1 mm. This is to be expected, as the density of the adhesive is 1,16 g/cm³. But we made the pouring by manual application (spatula), and as foreseen the glue line thickness increased, which resulted in a longer press time to at least keep the timber lamellas double the press time (around 5 hours).

Industrial adhesive application systems apply 125-150 g/m². By manual application of the adhesive with a spatula was better to be applied from 150-200 g/m² (recommended from the producer). While for the pressure is taken in consideration the size of lamella starting from 0.6 N/mm² and not exceeding 1.0 N/mm².

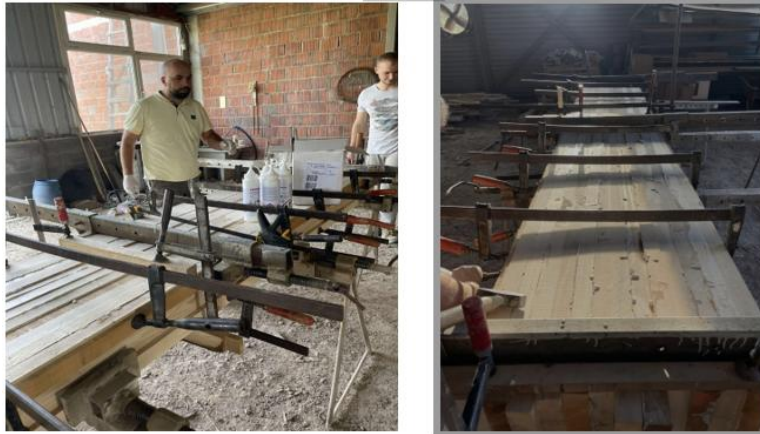


Figure 8. a & b Tightening lamellas by mechanical clamps and vices



Figure 9. GST beams produced from the author

The class of these lamellas belongs to quality I (axial and central log boards, mainly radial), each lamella is individually measured in thickness due to the delicacy of twisting, bending, k

2.5. Experimental procedures

This series focused on investigating the long-term deflection behavior of beams under sustained loading conditions, specifically to evaluate creep development and determine the creep coefficient. The beams (2) tested had identical dimensions (138mm x 170 mm x 3570mm) and were subjected to a uniformly distributed load using full-steel billets (dimensions 140mm x 140mm x 500mm).

Two loading configurations were used: DI1 with a total mass of 613.8 kg and DI-2 with 608.35 kg.

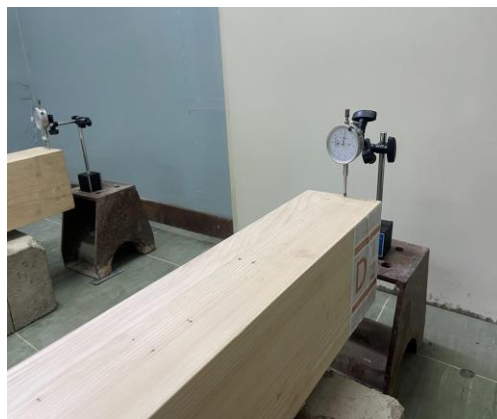


Figure 10. a & b view of the raw material deposited before transportation

The testing period lasted for 139 days (3336 hours), during which relative humidity (RH) and temperature (T) were kept constant to ensure consistent environmental conditions and minimize external influences on deformation behavior.

Throughout the testing period, the ambient relative humidity (RH) and temperature were continuously monitored to ensure stable conditions and minimize the influence of external factors on the mechanical behavior of the specimens.

The initial recorded values were approximately 23.6°C for temperature and 64% for relative humidity. These data were documented at each measurement phase and serve as a basis for evaluating the impact of environmental conditions on long-term deformation (creep) development.

Each individual full - steel billet was carefully weighed on the scale to determine the total load applied to the beam.



Figure 15. Long-term effect and creep coefficient under sustained load for DI1 and DI2

3. Results and Discussion

The long-term behavior of the beams was monitored through Test DI1 and Test DI2 over a period of 139 days. Throughout the testing period, the environmental conditions were maintained relatively stable, with an average relative humidity (RH) of equal to 53% and an average temperature of 23.3°C. These controlled conditions help ensure the reliability of the observed time-dependent deformations and provide a consistent basis for evaluating creep and shrinkage effects on the beam specimens.



Figure 16. Weighing each of the steel billets

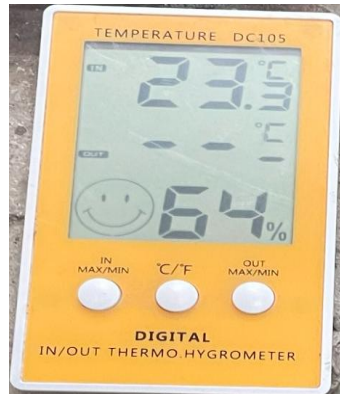


Figure 17. Equipment for temperature and relative humidity monitoring

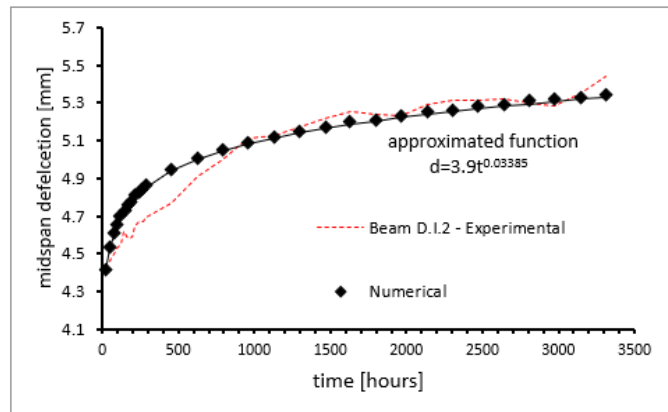


Figure 18. Mid-span deflection depending on hours (DI1)

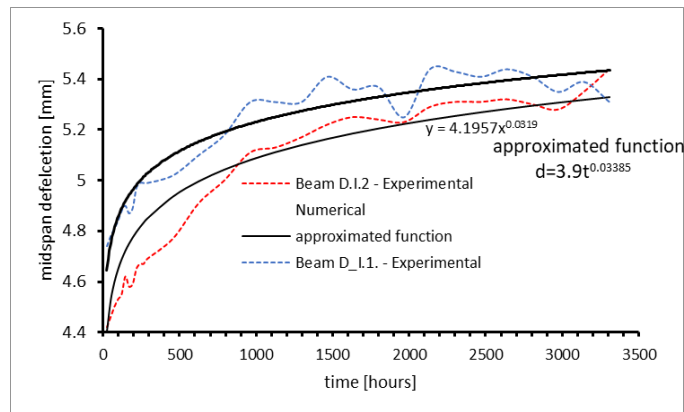


Figure 11. Comparison of experimental results between DI1 and DI2, including approximated function

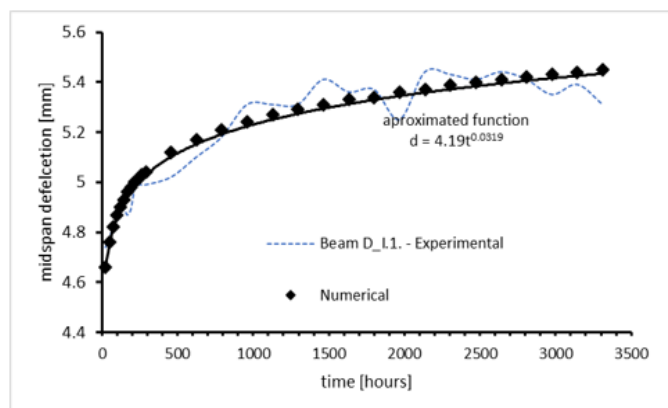


Figure 20. Mid-span deflection depending on hours (DI1)

The initial mid span deflection under sustained load was recorded as 4.4 mm for DI1 and 4.65 mm for DI2, marking the beginning of the long-term loading phase.

The graphs above (fig. 20 and 21) present the midspan deflection of two beams (DI2 and DI1) under sustained load over approximately 3300 hours. It compares experimental results, a numerical model, and an approximated function.

Deflection increases over time for all curves, indicating time-dependent deformation typical of creep behavior in timber.

The approximated (solid black line) lies between the experimental results, suggesting a good calibration with physical behavior.

This matches the long-term creep trend well, especially after ~500 hours.

The approximated power - law function provides a reasonable prediction of long - term deflection behavior. The numerical model effectively captures the overall creep trend

The graph below (fig. 22) shows how the effective elastic modulus of two beams (DI1 and DI2) decreases over time under sustained load due to creep. Beam DI2 retains a higher modulus than DI1, indicating better resistance to long-term deformation.

Most of the stiffness loss happens early, then levels off, with a noticeable drop over (~15–18%). This highlights the importance of considering creep in long-term structural performance.

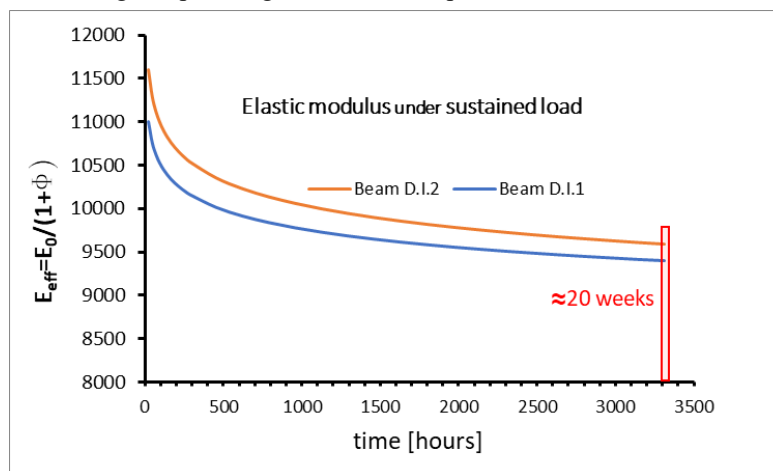


Figure 121. Creep trend and the elastic modulus of DI1 and DI2 under sustained load

This graph shows (fig. 22) how the mid-span deflection of Beam DI2 increases over time under sustained loading due to creep. The red line represents experimental measurements, while the black segments show numerical results.

The close match between the indicators show that the numerical model accurately captures the beam's behavior. Deflection rises more rapidly at the beginning and then slows down the rhythm, which is random for creep.

Overall, the graph highlights the importance of accounting for time-dependent deformation in long-term structural analysis.

4. Conclusions

The findings presented in this paper, regarding Glued Solid Timber (GST) beams clearly demonstrate that this structural material represents a reliable and sustainable alternative for use in modern construction. The controlled values of physical parameters, such as moisture and density, indicate a well-managed production process ensuring repeatability and industrial scalability for industrial applications.

The creep of timber is taken into account when is calculated the serviceability limit state, i.e. the limit state of deflections, and it mostly affects the deflection from long-term loads usually from the action of permanent loads. The testing of creep of timber is needed to determine the deformation factor k_{def} (which represents the coefficient of creep) which, according to Eurocode 5, depends on the duration of the load and from service class of the timber. What is particularly important is that in Eurocode 5 there are no defined values for k_{def} for glued solid timber (GST), and hence the great importance of the test of creep of timber of glued solid timber.

By measuring the instantaneous deflection immediately after applying the load and subsequent deflection over time there are results obtained from the creep of timber understanding that the values range around $k_{def} = 0.5-0.6$, which indicates that the behavior of glued solid timber is closer to solid timber for service class 1.

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