ISPITIVANJE DRVENIH LAMELIRANIH NOSAČA

TESTING WOOD LAMINATED BEAMS

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Apstrakt

Za kreiranje različitih drvenih konstrukcija sve više se primenjuju lamelirani drveni nosači. Njihovom upotrebom se postiže gotovo neograničena sloboda i dizajniranju konstrukcije, istovremeno osiguravajući potrebnu čvrstoću, stabilnost i upotrebljivost konstrukcije jer svaki nosač ima precizno određene (testirane) vrednosti mehaničkih i fizičkih osobina.

U radu se daje kratak pregled primene lameliranih drvenih nosača, neke karakteristične vrednosti osobine nosača, standardi i testna opreme za ispitivanje čvrstoće smicanja u liniji lepka lameliranih nosača.

Ključne reči: *laminirani drveni nosači; osobine nosača; testiranje performansi nosača; oprema za ispitivanje*

Abstract

To create different wooden structures are increasingly being applied laminated wooden beams. Their use is achieved almost non-limitation in the freedom of designing the structure, while ensuring the necessary strength, stability and usability of the structure because each beam has a precisely determined (tested) value characteristics of mechanical and physical property.

The paper gives a brief overview of the application of the wooden laminated beam, some characteristic values of features of beam, standards and test equipments for shear testing of glue lines of laminated beams.

Key words: *laminated timber beams; properties of beams; testing the performance of beam; test equipment;*

I. Introduction

Wood has been used for thousands of years, since the dawn of the World. It has been valued for its light weight, strength and the ease of processing and shaping. The modern world still finds wood to be an important element for construction and design. Wood 'feels good', it is a piece of nature that makes part of your home. As for any product we use, the wood underwent some serious improvements over the years. Today's manufacturers process wood and not produce only typical 'sawn' lumber, already they also processing scrap material and wood waste – that originally could not be used for construction, to make to produced an artificial material, typically referred to as "Engineered Wood Products" or EWP giving lumber super powers. These are the most common EWP types:

- Plywood – is a panel created by cross-laminating continuous sheets of wood veneer in alternating directions, each layer perpendicular to the next. This cross-orienting gives plywood its strength.
- Oriented strand board (OSB) – is a panel created by bonding strands of wood in layers with adhesives. Again, the layers are cross-oriented to improve strength and stiffness.
- Glued laminated timber (glulam) – is a structural member, a beam consisting of layers of solid-sawn lumber stacked on top of each other and oriented in a way that eliminates or greatly reduces bending and twisting that typically occurs in solid sawn lumber members (if used individually). Glulams can be shaped in curves or custom shapes.
- Laminated veneer lumber (LVL) – is a structural beam made by bonding thin veneers of wood. The veneers are oriented in the direction of the span of the beam.
- Cross-Laminated Timber (CLT) – is an areal analog of glulam: it is made of several layers of wood, each layer perpendicular to next – giving the material strength and rigidity.
- Parallel strand lumber (PSL) – as the name suggests, it is made of strands of lumber – typically long strands that are bonded with adhesive to create a strong material resistant to shape changes
- Laminated strand lumber (LSL) – is material manufactured from wood strands of rather long and thin shape. The strands are pressed together and bonded with adhesive to create strong material.
- I-joists and wood I-beams – are wood versions of steel I beams – i.e. they are I shaped structural members – with top and bottom flange and a web connecting the two. I joists are used for floor and roof framing and they use less lumber than solid sawn construction members – while carrying the same load.

II. Glued timber beam

Timber, one of the longest-serving traditional engineering materials, has been widely applied in construction. In general, timber possesses a high strength to weight ratio, good insulating properties, and good durability when properly treated. Also, it is capable of good load transferring in both tension and compression (Porteous and Kermani 2007). Timber can also easily be shaped, reshaped and joined using various types of connections and connectors. However, timber acquired naturally does have its limitation. At present, engineered wood products (EWPs) have been developed to overcome some of major limits in available timber dimension and natural defect found in sawn wood. Typically, EWPs are formed by mechanical manipulation together with chemical bonding which is applied to the original sawn wood or plank to enhance better efficiency in structural performances and mechanical properties. Glued laminated (glulam) timber, one type of a variety of engineered wood timbers, can provide high quality and uniform products in any shape, size, and form. Glulam is fabricated from dried thin wood planks bonded together into laminates with grains of the laminate arranged parallel to the longitudinal axis of the member (Porteous and Kermani 2007).

In recent years, fiber reinforced polymer (FRP) materials have been used for external reinforcement of glulam timber beams (Plevris and Triantafillou 1992; Fiorelli and Dias 2006; Dempsey and Scott 2006). However, the use of FRP materials for reinforcement is still very much limited due to the relatively high cost and rather complicated fabrication processes (Lopez and Xu 2002). For civil engineering infrastructure applications, glulam panels reinforced with hybrid FRP had been experimentally and analytically evaluated for bridge deck construction (Lopez and Xu 2002). Several computational models of glulam timber beams have been developed and reported in a number of researches (Lindenberg 2000; Romani and Blab 2001; Lopez and Xu 2002; Fiorelli and Dias 2003, 2006). A semiprobabilistic model based on the Monte Carlo approach to determine the strength and stiffness of glulam beams was developed by Lindenberg (2000). A simple beam analyzed linearly and non-linearly based on a moment-curvature model had been proposed to respectively compute structural properties and to predict ultimate load (Lopez and Xu 2002). Design models for moment of rupture had been developed and compared with experimental results (Romani and Blab 2001; Fiorelli and Dias 2003, 2006). Furthermore, various approaches to improve post elastic responses of glulam timber beams under bending had been experimentally investigated by Tomasi et al. (2009).

Figure 1. Glued laminated beams construction which need very high quality of beams

Figure 2. Special roof construction which include different types of glued laminated beams in certain parts

Figure 3. Big sport hall with a roof from glued laminated beams produced based on certain design

Figure 4. Very special construction from glued laminated beams

Figure 5. Special construction of a bridge from glued laminated beams

Certain past studies (Beng 2004; Ngamcharoen et al. 2007) presented the use of PW (Para-rubber wood) planks in glulam beams which had been intensely under attention over the past years. Currently, the plantation area for Para-rubber tree (Hevea brasiliensis), cultivated in more than 30 countries particularly in South East Asia and China, has been rapidly expanding. Para-rubber wood is very well suited as a raw material for various wood products such as wood based panel, plywood, particleboard, medium density fiberboard (MDF), and oriented strand board (OSB). However most PW has been utilized in industries concerning furniture, furniture components and wood panels. Their applications in civil engineering infrastructures still have not been widely investigated and accepted due to the lack of data and understanding in structural performance and responses. Past researches on PW glulam structural members are scarcely available and/or are not yet too well understood. In addition, structural performances and behaviors of structural FRP reinforced PW glulam beams are also not yet comprehensively studied and established still.

To overcome this concern, further researches are deemed necessary to evaluate the performance and behavior of FRP reinforced PW glulam members. Based principally on experimental and analytical investigations, the primary objectives of this research focus on structural properties and responses of FRP reinforced PW glulam beams under various bending test conditions. Moreover, analytical methodologies have been proposed to predict the momentcapacity, reduction factor, and ductility. Results from this research are anticipated to contribute to a further knowledge and understanding of the structural performance and behaviors of FRP reinforced PW glulam beams prior to actual practical utilization.

III. PROPERTIES GLUED LAMINATED BEAMS AND CONTROL QUALITY OF BEAMS

Glued laminated timber (glulam) is manufactured from bonded lamellae with parallel fibre orientation. The timber is kiln dried, planed and classified into strength classes by visual or machine grading. The adhesive used to bond the lamella has to fulfil the requirements of EN 301 or EN 15425 for load bearing timber components. The suitability of the wood species in glulam construction has to be demonstrated. Spruce, pine and larch are most commonly used. Straight as well as curved beams can be manufactured. One can distinguish between homogenous (all lamellae across a beam's cross-section belong to one strength class) and combined (outer and inner lamellae belong to different strength classes) glued laminated timber. For glued laminated timber components of higher strength ratings combined beam lay-ups are to be considered for economical reasons. In combined beam lay-ups lamellae with higher strength properties are positioned in areas of higher tensile loading while lamellae with lower strength properties are positioned around the centre of the cross-section of the beam. Glued laminated timber is particularly suited for components bearing high stresses or spanning large distances which have to satisfy stringent requirements with respect to dimensional stability and appearance.

Glued laminated beams applied in dry, humid and external conditions. Depending on the service classes are made in the following lengths: for 1 and 2 service classes up to 18 m (standard) and for 3 service class up to 50 m (design components).

Mechanical properties (according to EN 1194) of glued laminated beams, are shown in the following tables:

Table 1. Characteristic values for homogeneous glued laminated timber manufactured according to EN 386

Strenght classes	Homogeneous glued laminated timber – Softwood (glued horizontally			
	GL24h	GL28h	GL32h	GL36h
ρ_k [kg/m^3]	380.0	410.00	430.0	450.0
$f_{m,k}$ [N/mm^2]	24.0	28.00	32.0	36.0
$f_{t,0,k}$ [N/mm^2]	16,5	19.50	22.5	26.0
$f_{t,90,k}$ [N/mm^2]	0.4	0.45	0.5	0.6
$f_{c,0,k}$ [N/mm^2]	24.0	26.50	29.0	31.0
$f_{c,90,k}$ [N/mm^2]	2.7	3.00	3.3	3.6
$f_{v,k}$ [N/mm^2]	2.7	3.20	3.8	4.3
$E_{0,mean}$ [N/mm^2]	11600.0	12600.00	13700.0	14700.0
$E_{90,mean}$ [N/mm^2]	390.0	420.00	460.0	490.0
$E_{0,5}$ [N/mm^2]	9400.0	10200.00	11100.0	11900.0
G_{mean} [N/mm^2]	720.0	780.00	850.0	910.0

Table 2. Characteristic values of combined glued laminated timber manufactured according to EN 386

Strenght classes	Combined glued laminated timber – Softwood (glued horizontally)			
	GL24c	GL28c	GL32c	GL36c
ρ_k [kg/m^3]	350.00	380.0	410.00	430.00
$f_{m,k}$ [N/mm^2]	24.00	28.0	32.00	36.00
$f_{t,0,k}$ [N/mm^2]	14.00	16.5	19.50	22.50
$f_{t,90,k}$ [N/mm^2]	0.35	0.4	0.45	0.50
$f_{c,0,k}$ [N/mm^2]	21.00	24.0	26.50	29.00
$f_{c,90,k}$ [N/mm^2]	2.40	2.7	3.00	3.30
$f_{v,k}$ [N/mm^2]	2.20	2.7	3.20	3.80
$E_{0,mean}$ [N/mm^2]	11600.00	12600.0	13700.00	14700.00
$E_{90,mean}$ [N/mm^2]	320.00	390.0	420.00	460.00
$E_{0,5}$ [N/mm^2]	9400.00	10200.0	11100.00	11900.00
G_{mean} [N/mm^2]	590.00	720.0	780.00	850.00

The characteristic strength values are determined in bending and tension and relate to product height (or width) of 150 mm. The characteristic values for tensile shear strength in the direction perpendicular to the grain are based on specimens measuring 45 mm x 180 mm x 70 mm. Shear strength values are determined on an evenly stressed volume measuring 0,0005 m3. A system of strength classes is given in Tab. 1 and Tab. 2. In accordance with EN 1995-1-1 the values have to be modified according to the duration of load (kmod, kdef).

Depending on the design and constructive solution of the architectural structure, the expected conditions of use (the intensity and type of load, environmental conditions - class service, etc.), wooden laminated beams together to be manufactured as a balanced or unbalanced beams.

Structural glued laminated timbers are permitted to be laid up with lumber grades placed symmetrically or asymmetrically about the neutral axis of the member. Timbers with symmetric lay-ups are referred to as “balanced” and have the same design values for positive and negative bending. Timbers with asymmetric lay-ups are referred to as “unbalanced” and have higher design stresses for positive bending (tension on bottom) than negative bending. Unbalanced lay-ups are generally used for simple, single-span beams, while balanced lay-ups are used for continuous or cantilevered beams. However, for most residential applications where cantilever lengths are relatively short, a stock unbalanced glulam can be used. Cantilevered roof overhangs of up to 20% of the main span can be accommodated using an unbalanced beam without special lay-ups. For longer length cantilevers, balanced beams should be specified. The topside of unbalanced beams is required to be marked “TOP” by the manufacturer to ensure proper installation. Balanced beams use the same grades in the top half of the beam as in the bottom half. The upper and lower halves are mirror images of each other. Unbalanced beams use higher grades in the bottom half than in the top half.

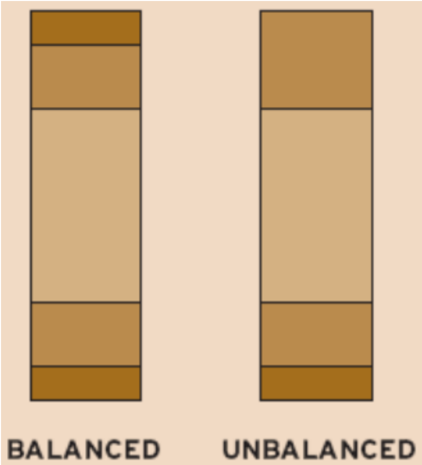

Figure 6 . Balanced and unbalanced beam

The properties of glued laminated beams and testing them should comply with the following standards: EN 14080, EN 386, EN 387 , EN 1194 , EN 1995-1-1/2 Eurocode.

Each manufactured carrier must be controlled during the process of making carrier, and at delivery carrier must have supporting documents with evidence of quality control. The supporting documents, including the following information: wood species and quality class, humidity lamella during the bonding phase, a kind of glue and adhesive manufacturer of certified documents, minimum and maximum thickness of lamella, temperature and humidity drives (polycondensation adhesives), generated pressure in the phase polycondensation glue, generated geometry in relation to the project, the results of shear adhesion strength, with exceptional structural test results of the tensile strength of adhesive joints and longitudinal lamella. Under exceptional structures include the console over 15 meters, the level of more than 30 carriers we arches over 60 meters in length. These studies shear strength adhesives are carried out on samples taken from each bracket (outside-designed dimensions).

Laminated beams are examined depending on the projected use of the application (loads, service class, fire resistance, etc.). Standard EN 14080 recommended to test the following properties of laminated beams: properties of glued laminated timber: bending strength, compressive strength, shear strength and modulus of elasticity; bonding strength – bending strength of large finger joints, natural durability, resistance glued laminated timber treated against biological attack, bonding strength: and joints in laminations and glue line integrity, reaction to fire, formaldehyde emission.

IV. Improved method for shear testing of glue lines and application of the new shearing tool

Among other tests, shear tests of the glue lines are required in the course of quality control measures to be carried out in glulam plants. The procedures to be followed are given in various standards like for example EN 392 (CEN 1995), ASTM D 905-03 (ASTM 2003) and ISO 12579 (ISO 2006). However, the method of applying shear stress to the glue line is only given by a principle scheme (Figure 7). Based on this scheme a variety of test equipment has been produced and is used by test laboratories and by producers of glulam and adhesives.

Depending on the actual construction of the test equipment as well as the procedure of testing, the resulting stress in the glue line is neither uniformly distributed nor pure shear but rather a combination of shear and normal stresses. In case of simultaneously acting shear stress and tensile stress perpendicular to the grain, the shear strength values drop dramatically, whereas compression stresses perpendicular to the grain lead to an overestimation of the shear strength of the bond line. The problem of the test method not being suitable to test the capacity of the glue line correctly has been addressed in several stages of the development of EN 392 but has not been solved yet. To overcome this problem, a prototype of a shear test device which ensures a clearly defined state of shear loading of the specimens should be developed.

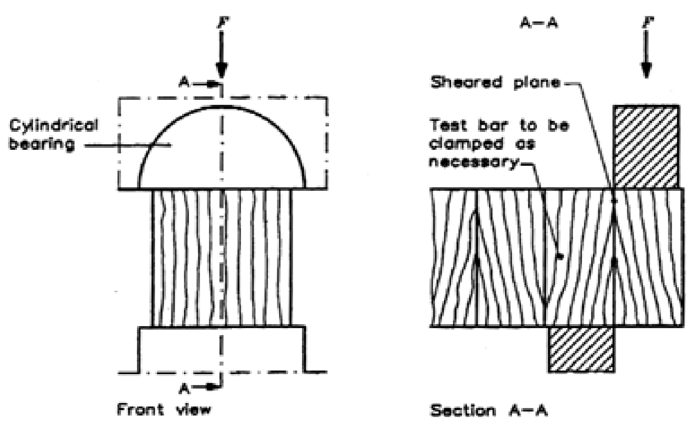

Figure 7: EN392 method of applying shear stress to a glue line

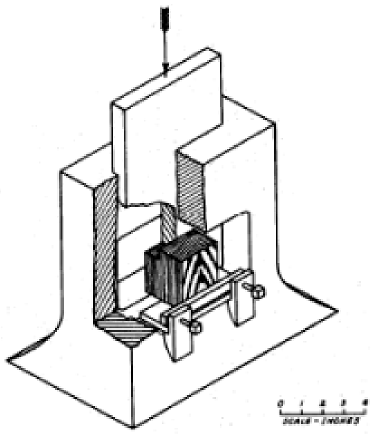

Figure 8: ASTM D 905-03 shearing test equuipment

In Europe the bonding strength of glue lines is assessed as a glue line integrity test according to one of the test procedures defined in EN 386 (CEN 2001), being either delamination tests according to EN 391 or block shear tests according to EN 392. The shear strength fv,a of each glue line shall be at least 6 N/mm2. For coniferous wood and poplar lower individual values of shear strength (down to 4 N/mm2) shall be regarded as acceptable if the wood failure reaches a certain percentage. The EN 392 block shear test is intended to be used in the course of continuous quality control of glue lines. A principle scheme for the shearing tool is given in the standard (Figure 7). The shearing force shall be applied self-aligning via a cylindrical bearing so that the specimen is loaded at the end grain with a stress field uniform in width direction and the distance between the glue line and the sheared plane nowhere exceeds 1 mm. The width and the thickness (in longitudinal direction) of the specimen shall be 40 to 50 mm each with loaded surfaces to be smooth and parallel to each other as well as perpendicular to the grain direction.

In the United States shear testing of glue lines is addressed by the standard ASTM D 905-03 (ASTM 2003). The standard makes aware of the fact that "this test method cannot be assumed to measure the true shear strength of the adhesive bond" because "many factors interfere or bias the measurement including the strength of the wood, the specimen, the shear tool design themselves and the rate of loading". It is also mentioned, that "stress concentrations at the notches of the specimen tend to lower the measured strength". The shearing tool to be used shall have a self-aligning seat ensuring uniform lateral distribution of the load. Figure 8. shows a respective tool.

The formulations in the ISO standards are similar to the European pendants. For block shear tests the standards ISO 12579 (ISO 2006) and ISO 6238 (ISO 2001) are ruling. ISO 12579 provides a combination of rules taken from EN 392 and ASTM D 905. Concerning the apparatus to be used for the shear tests, the ISO standard as well gives only a schematic sketch similar to EN 392. In ISO 6238 (ISO 2001) a shearing tool for compressive shear block tests being identical to the one shown in ASTM D 905-03 (Figure 8) is mentioned.

A test series was conducted aiming at comparing shear strengths and percentages of wood failure derived from tests with either the established EN 392 type device or the new one (Figure 9).

Figure 9: EN 392 type shearing tool (left), new test apparatus (center), close view of a specimen during testing with the new apparatus (right)

Comparability of test results was made possible by testing pairs of edge and centre bars taken from two slices cut from front ends of glulam beams directly after finishing the production in the glulam plant. Eight glulam producers of the Swiss Glulam Association SFH (www.glulam.ch) supplied the test bars cut from 3 to 4 different glulam beams each. The bars contained 8 to 10 bond lines of different types of adhesives (RF, UF, PUR, MUF, EPI) and had a cross-section of 50 x 50 mm2. Approximately 600 block shear tests were carried along the test series. In the far most cases the glulam strength classes were GL24h or GL24c.

Also, the glulam beams were made from Norway spruce (Picea abies Karst.). The block shear specimens were tested to shear failure using either the established shear test device or the new one (Figure 9). Force was applied by a100 kN universal testing machine Zwick with a loading rate of 3mm/min. Maximal error of the force measurement was <1%. Shear strength was calculated and the percentages of wood failure in the bond lines were determined using a new semi-automatic method (Künniger 2008). Before testing, the bars were stored in a climatic chamber at 20°C and 65% relative humidity. After the shear tests the moisture content of the specimens was derived according to ISO standard 3130. A mean value of 11.5% (variation between 9.8% and 12.5%) was found for the specimens tested with the established shear test device. The respective values for the specimens tested with the new device were 12.3% (mean value) and 11.3% to 13.3% (variation). The impact of the small moisture content difference (about 0.8%) on the shear strength, which may result in a maximum change of 2%, has been neglected.

Analyzing mean values, 10-percentiles and 90-percentiles of shear strengths and percentages of wood failure to can be concluded, that independent of the type of adhesive, shear strengths derived with the new test device as well as their variability are lower than those resulting from tests with the established device. The differences exhibit the same trend on the mean level and on levels of 10 and 90 percent, which at the first glance would mean that the differences are not affected by strength of material or of adhesive bond respectively. Wood failure percentages for PUR-type adhesives were generally very high and exhibited a small variation. On the other hand some very low percentages of wood failure, especially for MUF-type adhesives occurred.

Common shear tests suffer from a non uniform shear stress distribution with a stress concentration near the corner of the specimens. The test results are influenced by the actual materialisation of the shearing tool as well as by the person carrying out the test. Furthermore, the hindering of shear strains developed during testing shows side effects on the test results. To overcome these limitations, a prototype of a shear test device has been developed aiming to ensure a clearly defined state of shear loading of the specimens and to make test results independent from manipulations. The test principle is to perform axial compression tests with an oblique angle between the grain and the loading direction of 14° (slope 1:4). Test performed with the prototype device show that the new shearing tool has the potential of deriving reproducible shear strength values not being influenced by the operator. Shear strengths of bond lines exhibited lower variation when the tests were carried out with the new shearing tool, whereas with regard to percentages of wood failure no differences were found. The validity of target limits of shear strength and percentages of wood failure in glulam quality control standards has to be questioned. Actual limits seem to be related to certain types of shearing tools. Hence, construction details of these tools have to be prescribed more precisely in the respective standards. For the new test device respective limits for shear strength and percentage of wood failure have to be developed yet. In the course of quality control of glulam the main focus has to be given to shear strength, the latter directly influencing the mechanical properties of the glued-laminated timber.

Here percentages of wood failure are of lower interest. When investigating and further developing adhesives, percentages of wood failure gain of importance since they help improving adhesive products and application technique.

V. CONCLUSIONS

The modern design and construction which include glued laminated beams require high quality of products implemented in all construction. For that we decided to point certain matters in this field.

1. The application of glued laminated beams comes as very good matter for the special construction, where natural material is required,

2. Since it is a natural constructed material where gluing process is included, it is very important to quality control process in production and after,

3. No other composite natural building material offers the physical strength, toughness and durability of material as glued laminated well produced beams.

4. For quick laboratory test we introduced improved method for shear testing of glue lines which define the necessary level to be insured for the glued beams before building in construction,

5. It is recommended to perform both testing methods for standard samples for the glue line and the quality of finished laminated beam as it is in the standards we implement.

VI. LITERATURE

[1] **ASTM D 905-03**: *Standard test method for strength properties of adhesive bonds in shear by compression loading*", American Society for Testing and Materials ASTM , 2003

[2] **Coker, E. G. & Coleman, G. P.** *"Photo-elastic investigations of sheartests of timber"*, Institution of Civil Engineers, London, 1935

[3] **EN 392**: *Glued laminated timber - Shear test of glue lines"*, European Committee for Standardization CEN, 1995
[4] **EN 386**: *Glued laminated timber - Performance requirements and minimum production requirements",* European Committee for Standardization CEN, 2001
[5] **EN 391**: *Glued laminated timber – Delamination test of glue lines",* European Committee for Standardization CEN, 2001
[6] **EN 408**: *Timber structures - Structural Timber and glued laminated timber - Determination of some physical and mechanical properties"*, European Committee for Standardization CEN, 2003
[7] **Gehri, E. & Steurer, T**. *"Holzfestigkeit bei Beanspruchung schräg zur Faser"*. SAH Bulletin, Vol 7, Issue 2, pp 1-27. Schweizerische Arbeitsgemeinschaft für Holzforschung SAH., 1979
[8] **ISO 6238**: *Adhesives - Wood-to-wood adhesive bonds - Determination of shear strength by compressive loading"*, International Organization for Standardization., 2001
[9] **ISO 12579.2**: *Timber structures - Glued laminated timber - Method of test for shear strength of glue lines*", International Organization for Standardization., 2006
[10] **Keylwerth, R.** *"Die anisotrope Elastizität des Holzes und der Lagenhölzer"*. Düsseldorf, Germany, 1951
[11] **Kollmann, F.** *"Die Abhängigkeit der Festigkeit und der Dehnungszahl der Hölzer vom Faserverlauf"*. Der Bauingenieur, Vol 15, Issue 19/20, pp 198-200., 1934
[12] **Künniger, T.** *"A semi-automatic method to determine the wood failure percentage on shear test specimens"*. Holz als Roh- und Werkstoff, Vol 66, Issue 3, pp 229-232.,2008
[13] **Radcliffe, B. M. & Suddarth, S. K.** *"The notched beam shear test for wood"*. Forest Products Journal, Vol 5, Issue 2, pp 131-135.,1955
[14] **Stüssi, F.** *"Holzfestigkeit bei Beanspruchung schräg zur Faser"*. Schweizerische Bauzeitung, Vol 64, Issue 128/20, pp. 251-252., 1946
[15] **Stüssi, F.** *"Holzfestigkeit schräg zur Faser"*. Schweizerische Bauzeitung, Vol 67, Issue 6, p 90, 1946
[16] **Ylinen, A.** *"A comparative study of different types of shear test of wood"*, Helsinki, Finland, 1963