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EXPERIMENTAL STUDIES ON GLUED LAMINATED TIMBER BEAMS REINFORCED WITH POLYMER FIBERS

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Abstract: The use of wood as building material is considered a viable alternative to other materials in the increased seek of means to fight against the severe negative impact of construction sector on the environment.

The study program aims to performing a series of adherence tests on 6 different specimen types composed by glued laminated timber elements (glulam) joined together with different polymeric materials (FRP - fiber reinforced polymer) by means of a series of different adhesives.

The goal of the study is to find the composition of elements (wood, adhesive and FRP) for optimum specimens from both structural and economic point of view.

Furthermore, a detailed analysis has been made on how to implement these new materials in the nowadays construction sector.

Keywords: composite material, glulam, fiber reinforced polymers, wood, construction

1. Introduction

Timber has been used as a traditional material for structures because it is a natural material, available worldwide with good mechanical properties. Nowadays, this material has started to increase in its use because it is a sustainable material, friendly with nature [1].

The enhanced response of glulam structural elements led to new research subjects, focused on producing composite materials with improved strength characteristics like the ones which are the subject of this study: glulam elements reinforced with fiber reinforced polymer (FRP) systems.

Fiber-reinforced polymer (FRP) is composed of reinforcing fibers, polymer resin and other additives in order to create a strong and durable material with better properties. These materials can be used as reinforcement in order to provide a higher load-bearing capacity and stiffness.

The idea of using fiber-reinforced polymer (FRP) as reinforcement for glulam structural elements is a relatively new solution still under research for proving its qualities. Nevertheless, the studies recently performed on this new type of material have shown an increase of the massive wood element's strength with 40% to 100% [2].

The overall behavior of the composite material is decisively influenced by the adherence between glulam lamellas as well as between the wood strips, adhesive and polymer fibers.

The study presents a series of adherence tests performed on different specimens subjected to shear forces. The specimens are composed of 3 glulam elements with different combinations of polymer fibers (FRP) and adhesives in order to point out the best solution in terms of enhanced strength.

2. Materials

2.1. Wood species

For this research, spruce which is a common wood essence was used for all the tests specimens, this being the material generally used for glued laminated timber elements produced following the standard SR EN 386.

2.2. Fiber reinforced polymer (FRP)

For joining together, the three glulam elements, two types of FRP (fiber reinforced polymers) were used: Sika CarboDur S1012 strips and Sika Wrap®-230 C (Fig. 1).

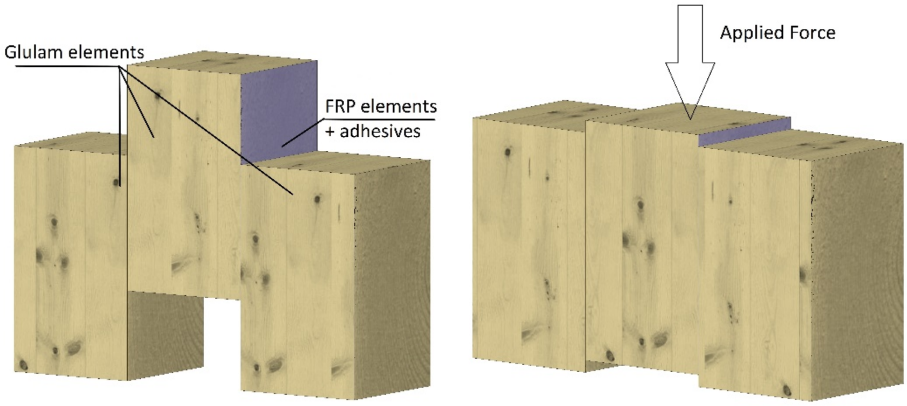

Fig. 1 - Model of wooden specimen before and after the application of the force

The Sika CarboDur S1012 strips has a thickness of 1,2 mm and a width of 100 mm (manufacturer information).

The modulus of elasticity is 165.000 N/mm2, with a density of 1,60 g/cm3 and a percentage > 68% of volumetric fibres. The material structure consists of unidirectional fiber orientation with the chain made of black carbon fiber (99% by weight total area) thermally fixed with white thermoplastic fibre (1% by weight total surface).

Sika Wrap®-230 C has 0,129 mm thickness with a surface weight of 235g/m2 + 10g/m2 (carbon fibre only) a mass on the surface of 235g/m2 + 10g/m2 (carbon fibre only) and a fibre density: 1,82 g/cm3. Sika Wrap-230® is a unidirectional medium-strength carbon fibre (textile) fabric designed for installation through the wet or dry application process (manufacturer information).

2.3. Adhesives

For joining together the glulam elements and the polymer fibre system, an epoxy resin based adhesive is necessary:

The three types of epoxy resin are:

- Melamine-urea-formaldehyde adhesives MUF, the adhesive used for processing the glued laminated timber elements. MUF (melamine-urea-formaldehyde) is made of melamine or polyurethane and is one of the most common used adhesives in the wood industry.
- SikaDur 330, SikaDur 30 adhesives that are currently used in civil engineering:

  - Sikadur 330 is a bicomponent impregnating, solvent-free, thixotropic epoxy resin

  - Sikadur30 is a thixotropic, structural 2-component adhesive, based on a combination of epoxy resins and special fillers, designed for use at normal temperatures between +8 °C and +35 °C.

2.4. Preparation of the specimens for adherence tests

The specimens that were used for the tests in this study tests are composed of 3 glued laminated timber elements (pieces) joined together with different types of adhesives and different types of polymeric materials (Fig. 1):

- 3 types of adhesive: Melamine-urea-formaldehyde adhesives (MUF), SikaDur 330, SikaDur 30
- 2 types of polymeric materials: Sika CarboDur strips, Sika Wrap-230C.

Tests were performed on specimens using the materials specified in Table 1.

For each specimen in the adherence test, the force F_{fin} was measured. This force represents the value displayed by the testing machine when failure is produced in the specimen.

The arrangement between all the components are given in the table below (Table 1), where Type 1 is the specimen containing the glulam elements and the MUF adhesive without the fiber reinforced polymers and will be considered as reference for further analysis. Three samples of each specimen were subjected to the adherence test.

Table 1

Specimens used for the tests

Specimen	Section b x h - L	Adhesive	Polymeric materials
Type 1 (T1, T2, T18)	120 x 200 - 300	MUF	Without Polymeric materials
Type 2 (T3, T4, T5)		MUF	Sika CarboDur
Type 3 (T6, T7, T8)		MUF	Sika Wrap 230C
Type 4 (T9, T10, T11)		SikaDur 30	Sika CarboDur
Type 5 (T12, T13, T14)		SikaDur 330	Sika CarboDur
Type 6 (T15, T16, T17)		SikaDur 330	Sika Wrap 230C

Function of the elements composing the specimens, the failure occurred due to the adhesive failing in the joint or due to the wood elements' loss of capacity.

Fig. 2 - Experimental images for shear test

3. Results and discussion

3.1. Tests

For performing all the 18 tests a press HECKERT 262/6 was used. The specimens were subjected to a shear force applied in loading stages of 10 kN until failure. The test conditions of the laboratory environment were relative humidity 47% and temperature 23°C. The specimens were divided following the type of polymer fibres used (seen in Table 1).

The failure patterns of the elements are shown in Fig. 3 together with images in the laboratory during the test performance (Fig. 4).

Rupture in the wood section | Rupture on the adhesive line (glue) | Rupture in the wood section and on the adhesive line

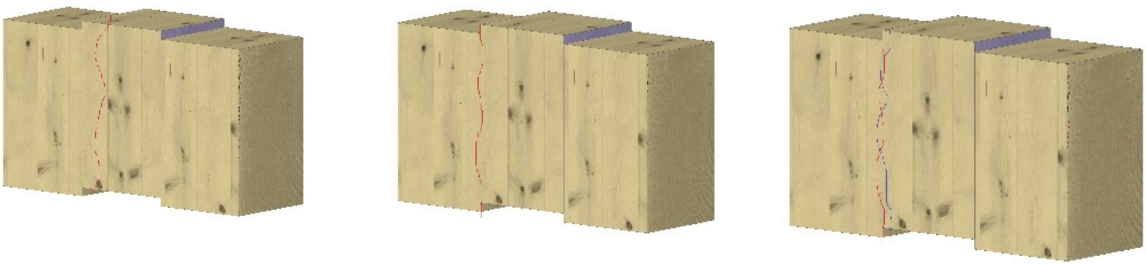

Fig. 3 - Failure pattern of the tested specimens

Fig. 4 - Images of the of wooden elements after experiments

Table 2 presents the maximum failure force, failure pattern and the time interval until the failure for each tested specimen.

The maximum value of the failure force was found for **Type 3** specimens (glulam, FRP SikaWrap 230C and MUF adhesive), the failure pattern showing that both the adhesive and the wood are losing their capacity.

In case of **Type 2** specimens, the arrangement of the 3 components (wood elements, adhesive and FRP element) proved to be the most disadvantageous as the value of the failure force is negligible small.

The graph in Fig. 5 compares the test results in terms failure force and type of specimen.

Table 2

Experimental results for shear test

Specimens (3 Samples)	No. of samples	Failure force F_{fin} (kN)	Time of failure (min)	Failure place
Type 1 (T1, T2, T18)	3 x 3	176	4 min	Rupture of the central element of the section
Type 2 (T3, T4, T5)	3 x 3	26	2,4 min	Rupture on the adhesive line (glue)
Type 3 (T6, T7, T8)	3 x 3	267	2,7 min	Rupture in the wood section and on the adhesive line
Type 4 (T9, T10, T11)	3 x 3	175	1,6 min	Rupture in the wood section
Type 5 (T12, T13, T14)	3 x 3	227	1,8 min	Rupture on the adhesive line (glue)
Type 6 (T15, T16, T17)	3 x 3	235	2,9 min	Rupture in the wood section

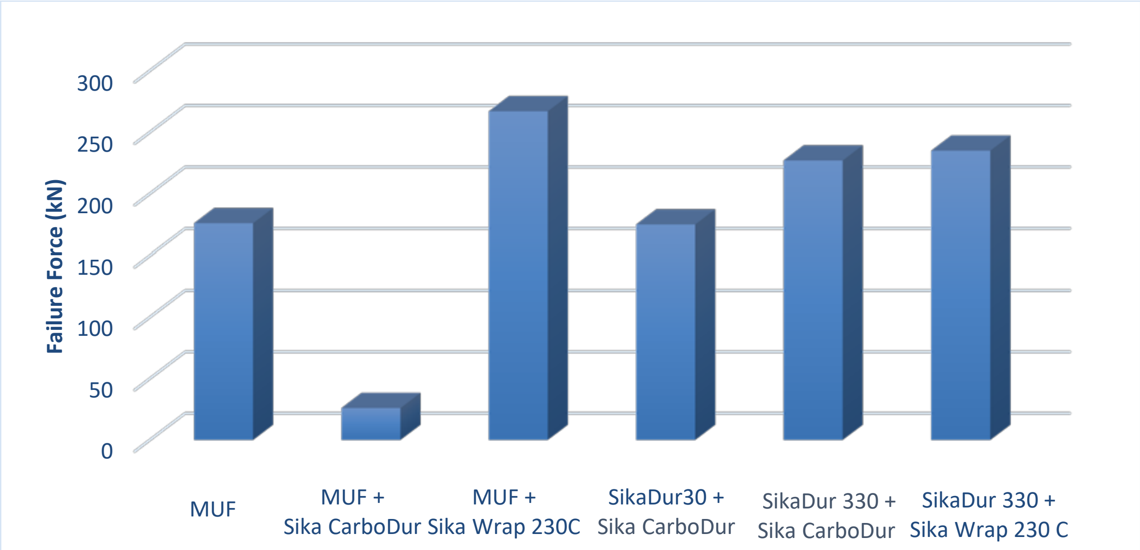

Fig. 5 - Test results in terms failure force and type of specimen

3.2. Failure behavior in shear

Type 1 specimen represents the reference of all the other composite elements, because it is represented by the glulam elements jointed together with the MUF adhesive and without the FRP elements; therefore, all the other specimens will be compared with this one. The measured failure force is F_{fin} = 176 kN.

Type 2 specimen: 3 samples were tested (T3, T4, T5); the section is combined with Sika CarboDur strips and MUF adhesive and a failure force F_{fin} = 26 kN was measured. Due to this poor behavior, the Type 2 specimen was declared inconsistent with the testing purpose and was eliminated from further analysis. The lack of adherence between CarboDur strip and MUF adhesive led to the failure of the surfaces in contact.

Type 3 specimen: 3 samples were tested (T6, T7, T8); the section is combined with Sika Wrap 230C and MUF adhesive and a failure force F_{fin} = 267 kN was measured representing an increase of 52% with respect to **Type 1** specimen.

Type 4 specimen: 3 samples were tested (T9, T10, T11); the section is combined with Sika CarboDur strips and SikaDur 30 adhesive and a failure force F_{fin} = 175 kN was measured, closed to the reference value. It was eliminated from further analysis.

Type 5 specimen: 3 samples were tested (T12, T13, T14); the section is combined with Sika CarboDur strips and SikaDur 330 adhesive and a failure force F_{fin} = 227 kN was measured, representing an increase of 29% with respect to **Type 1** specimen.

Type 6 specimen: 3 samples were tested (T15, T16, T17); the section is combined with Sika Wrap 230C and SikaDur 330 adhesive and a failure force F_{fin} = 235 kN was measured, representing an increase of 33% with respect to **Type 1** specimen.

3.3. Price analysis

When relating to an optimal structural solution, the price of the component materials represents a decisive argument in taking any decision.

Table 3 shows the total price for each of the tested specimens taking into account the price of wood elements, adhesives and FRP elements.

Table 3

Total price for each specimen

Sample	Price wood ($)	Adhesive	Reinforcement	Price adhesive ($)	Price reinforcement ($)	Total price per specimen ($)
Type 1	26,20	MUF	Without Polymeric materials	2,62	---	28,82
Type 3	26,20	MUF	Sika Wrap 230C	2,62	9,27	38,09
Type 5	26,20	SikaDur 330	Sika CarboDur	1,44	22,89	50,53
Type 6	26,20	SikaDur 330	Sika Wrap 230C	1,44	9,27	36,90

*The prices were provided by the producers

As for the price for specimens reinforced with Polymeric materials, the total price differs depending on the type of adhesive used (MUF, SikaDur 30 and SikaDur 330) and the type of reinforcement (Sika Wrap 230 C and Sika CarboDur).

3.4. Price-to-failure force ratio

Coordinating the performed adherence test results with the price evaluation for each of the 4 remaining specimens the values in Table 4 below were issued. It was observed that the **Type 3** specimen presents the best price to failure force ratio.

Table 4

Price-to-failure force ratio

Specimen	Failure force (kN)	Total price per specimen ($)	Ratio = Price / Failure force (%)	Optimization rate (%)
Type 1	176	28,82	16,37	reference
Type 3	267	38,09	14,26	+12,88
Type 5	227	50,53	22,26	-35,98
Type 6	235	36,90	15,70	+4,09

(“+” favorable, “-“ unfavorable)

The values in Table 4 also present an optimization ratio for the tested specimens where **Type 1** is reference value. **Type 3** presents the largest optimization ratio value (+12,88%).

4. Conclusions

The experimental tests detailed in this paper showed that the different solutions used for the composite materials glulam elements, adhesives (MUF, SikaDur330, SikaDur30) and the FRP elements (fiber reinforced polymers) have displayed a good behavior in the adherence test results some more than other.

The results of the adherence tests performed on the specimens described above led to overall positive conclusions regarding the opportunity of using composite solutions as an enhanced alternative to classic glulam sections (using MUF adhesive without any FRP material).

Type 2 specimen, due to its poor behavior, was declared inconsistent with the testing purpose. The lack of adherence between CarboDur strip and MUF adhesive led to the failure of the surfaces in contact, which proves that the 2 elements are not compatible and do not work together correctly.

Even if in terms of economy, the **Type 1** reference specimen (MUF adhesive without any FRP material) is the best, following the optimization analysis carried out, we consider the **Type 3** optimized solution (MUF adhesive with Sika Wrap 230C material) to be more efficient and effective than the first.

The conclusions of this study are necessary for the future research on glulam structural elements having these types of composite sections (reinforced with FRP elements) in terms of obtaining the optimum material consumption for larger spans and greater cross sections.

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