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Full Length Research Paper

GFRP bar element to strengthen timber connection systems

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Timber is an excellent construction material with a strength-to-weight ratio comparable with steel and concrete. It is necessary to strengthen the timber, particularly in the weak joint places, in order to obtain both durability and originality. The aims of strengthening in the connecting places are to decrease the stress concentration, keep on the fibre continuity, and reduce disadvantages of connection element including nail and bolts. Nowadays, Glass Fibre Reinforced Plastics, (GFRP) produced via pultrusion process, are used to strengthen the structural elements because of its high strength, light weight, corrosion resistance and easy application of the structures. The aim of this study is to obtain the fibre continuity of connecting places of timber using GFRP bar elements. Mechanical performances of the connecting places of longitudinal notched lap joints have been investigated. Specimens have been prepared from black pine timber. Seven different groups of specimens, one group massive timber, one group only adhesively bonded and remaining strengthened with pultruded GFRP bar samples, have been prepared to determine the performances of the connections. The specimens have been tested subjected to bending strength and the obtained results have been compared to with each others. The outcomes demonstrate the fact that the bending strength of the connection strengthened with GFRP bar has about 300% higher than adhesively bonded connection. Timber is an excellent construction material with a strength-to-weight ratio compare to with steel and concrete. However, its use to date in the construction industry has been hampered by the weakness of the jointing systems used. In order to decrease the stress concentration and reduce disadvantages of connection element it is necessary to strengthen timbers particularly in the weak joint places.

Key words: Timber structures, bending strength, longitudinal notched lap joint, glass Fibre reinforced plastic.

INTRODUCTION

In the continuing quest for improved performance of structural materials, scientists and engineers strive to improve the traditional natures or produce completely new one. Composite materials are examples of the latter category. Within the past five decades there has been a rapid increase in the development of advanced composites incorporating fine fibres, termed fibre reinforced composites. These materials, depending on the matrix used, may be classified as a polymer, metal or ceramic matrix composites. Due to the high cost of metal and ceramic matrix composite materials, the majority of composites used in the construction industry are based on polymeric matrix materials. Additional factors in choosing polymeric composite materials for structural engineering applications are: The materials are lightweight, non-corrosive, chemically resistant, possess good fatigue strength, non-magnetic, and subject to the materials selected, can provide electrical and flame resistance. Material surfaces are also durable and require little maintenance (Extren, 1998). The construction industry appears to be gradually recognising the additional benefits offered by these materials. Nowadays, Glass Fibre Reinforced Plastics, (GFRP) produced via pultrusion process that is one of fibre reinforced polymer types, are used for strengthening the structural elements. Recently, the GFRP increased the strength of timber structural elements through its high strength, light weight,

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Figure 1. Restrengthening of bottom chords of the timber bridge (Steiger, 1999).

corrosion resistance and easy application of the structures.

Timber has been extensively used in construction for many decades and applied in many structural applications in engineering. In addition to it's being renewable, recyclable, relatively inexpensive resource. It also has a high strength to weight ratio and is architecturally attractive. However, it has a number of disadvantages such as biological deterioration over time, dimension instability in alternating environmental conditions and in flexural members, it exhibits brittle tensile failures.

A number of research studies have examined the option of reinforcing wooden flexural members with pultruded fibre reinforced plastic laminate, sheet and bar forms. Significant strength and stiffness' increase in comparison with unreinforced members have been reported by a number of researchers (Fiorelli and Dias, 2003; Micelli et al., 2005; Akgul et al., 2009). This technique can be easily and efficiently carried out and adds negligible depth and mass to the member being reinforced. Upgrading structures for higher working loads or restoring original design strength has been an engineering task for structures of any material. Before high strength fibre (HSF) was available, steel was mostly used for such purposes. The bonding of steel plates onto concrete was developed in the seventies. In the early eighties the steel plates were substituted by Carbon Fibre Reinforced Plastic (CFRP) that is, a well-established technique. It has been used successfully on approximately 400 structures world-wide as shown in Figure 1 (Steiger 2003).

The main advantages of using CFRP-laminates rather than the early steel plates are their light weight and the corrosion resistance, as well as their flexibility allowing their convenient and easy transport on rolls to the place of application. It was very tempting to use this material on timber structures as well. A considerable number of timber structures have already been reinforced successfully with CFRP.

This paper aims to obtain the fibre continuity of connecting places of timber structural elements of construction systems under the bending conditions. Mechanical performances of the connecting places of GFRP longitudinal notched lap joints have been investigated. Experimental specimens have been prepared from black pine timber which is very abundant in nature. To determine performances of the specimens, massive and five different types of adhesively bonded and strengthen with GFRP bar samples have been prepared. The specimens tested was subjected to bending strength and the obtained results were compared with traditional connection systems. It is intended that this work should contribute to the material available to design engineers when selecting joint types for use with large timber sections in structures.

MATERIALS AND METHODS

Timber

Black Pine timber specimens were used in the test program. The timber was all plain sawn and harvested from the same stand. Consequently, variability in the wood resulting from contrasting environmental conditions during growth was significantly reduced. An important concern was the high juvenile wood percentage in the material and increased dimensional instability present in the longitudinal direction. It is clear that the epoxy resin were very sensitive to moisture contents (ahşap adhesive). Therefore; the timber was oven dried in the sawmill to approximately 12 ± 0.5% moisture content upon delivery to the laboratory.

Adhesive

The epoxy resin adopted for this investigation was the Teknobond 300 adhesive, capable of curing at room temperature and providing strong adherends, used for bonding wood to wood as well as wood to FRP materials. This adhesive posse's very high adherence strength, penetrating very thin details due to low viscosity. As it does not contain cavities, it is used in places where electrical insulation is desired. Teknobond 300 adhesive consists of two parts, a liquid resin A and a powerful hardener B. The sets of A and B components were mixed until it takes homogenous grey colour. The technical advice contained in the adhesive data sheets and that given by the manufacturers was followed closely during preparation of the test specimens.

Pultruded glass fiber reinforced plastic

The pultrusion process is a proven manufacturing method for obtaining high quality fibre reinforced plastic components having consistently repeatable cross-sections. Much improved mechanical properties can be obtained with this procedure due to higher fibre volume fractions than those achieved in labour intensive manual lay-up procedures. In this method, a continuous E-glass fibre reinforcement in the form of alternate layers of randomly oriented mat and layers of unidirectional roving bundles are pulled through a resin impregnator and then on through a heated die to form continuous prismatic members similar in geometry to those produced by the steel industry as seen Figure 2 (Extren, 1998; Mallick, 1997). The pultrusion process allowed GFRP to become a competitive alternative to traditional structural materials (steel, concrete and wood). At the same time, GFRP provided a lower specific weight with respect to strength and good environmental

Figure 2. Examples of pultruded GFRP profiles.

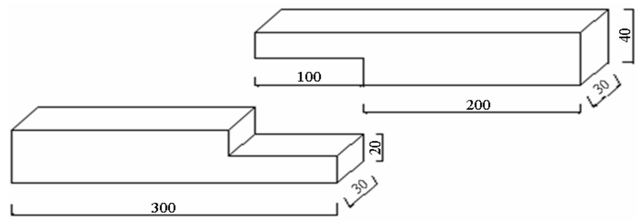

Figure 3. Longitudinal notched lap joint configurations.

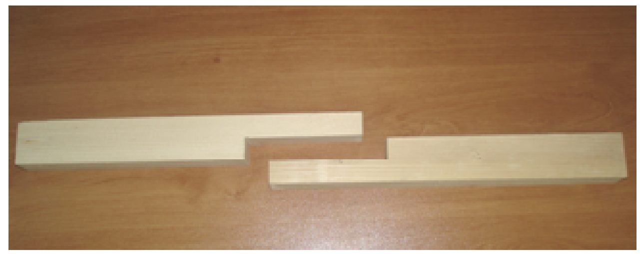

Figure 4. Longitudinal notched lap joint application of timber.

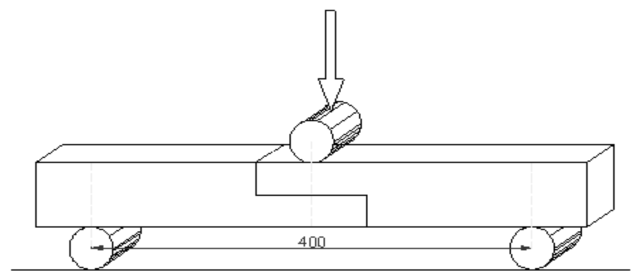

Figure 5. Three point bending test configurations.

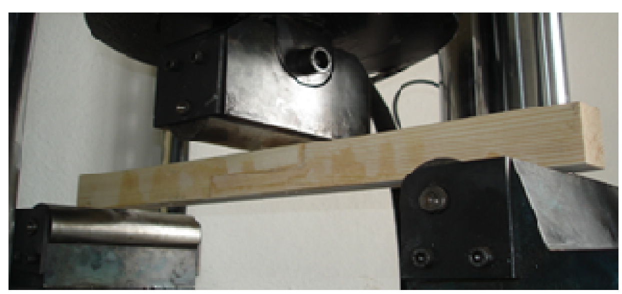

Figure 6. Three point bending test application.

resistance.

Having resolved fundamental manufacturing constraints through the development of the pultrusion process, the mass adaptation of GFRP sections as secondary and primary load bearing elements have been used in a number of civil engineering applications. Pultruded GFRP bars having a circle diameter of 0.45 cm is obtained from ESA Chemistry and Metal Industry, used in strengthening of the timber connection places.

TESTING PROGRAMME

Specimen preparation

Black Pine timber was all plain sawn and harvested from the same stand. Suitable test samples were selected from this stock based on a further visual inspection for large defects such as splits, knots and resin pockets. The wood was stored four weeks before joint fabrication and assembly. No attempt was made to condition the samples down to the same moisture content. After the conditioning period, the specimens were sawn and planed. The standard length of the wood samples was 500 mm and cross-section was 30 × 40 mm (Figures 3 and 4). These dimensions were used throughout the programme for all joint types. Seven different groups of specimens, one group massive timber, one group only adhesively bonded and remaining strengthened with pultruded GFRP bar samples, was prepared. At the beginning, the plain samples (without connection) were prepared to evaluate timber bending strength. In the second level, samples with the same sizes of plain timber are prepared by cutting into two pieces, and combining with half-lap size in the middle (Figure 3). One or two grooves (dimensions of 5 × 5 × 30 mm) were cut in each beam in the tension/compression or in both zones. Subsequently, sawdust was completely removed. Finally, two pieces of woods were bonded to each other and GFRP bars introduced in their place by using Teknobont 300 Epoxy resins.

The specimens were kept for a week at a temperature of about 20°C. The resin was cured under a press for 7 days at room temperature before testing. Smoothing the surface of the beam completed the application process.

Testing

Three point bending tests were performed on a bending loading (Figures 5 and 6) positioned on a universal tensile test machine. The samples were positioned and the load was applied. Deformations of the connections were recorded with LVDTs used to determine the relative bending of the connector. The load cell and LVDTs were connected to a PC via a signal conditioning unit. Measurements were taken at five intervals giving approximately 150 sets of measurements per test. The specimens have been prepared and tested according to the Turkish Standards (Turkish Standards (TS 647, 1979; TS 4499, 1985).

The specimens tested were subjected to bending strength and the obtained results were compared to each others. The adhesively bonded and strengthen GFRP bar connection sample types are named as:

1. Massive timber (ST1).
2. Adhesively connected timbers without reinforcement (ST2).
3. Adhesively connected timbers with a GFRP bar under the samples (ST3).

4. Adhesively connected timbers with two GFRP bars under the samples (ST4).
5. Adhesively connected timbers with a GFRP bars under and top of the samples (ST5)
6. Adhesively connected timbers with two GFRP bars under and a GFRP bars on top of the samples (ST6).
7. Adhesively connected timbers with two GFRP bars under and top of the samples (ST7).

TEST RESULTS

Both the fibre continuity of connecting places of timber structural elements of construction systems and resulting mechanical performances of the connecting places of fibre reinforced longitudinal notched lap joints were investigated using three point bending tests. The performances of the connection specimens with five different types of both adhesively bonded and strengthened with GFRP bar samples (ST3-ST7) were tested. The obtained outcomes were compared with massive timber (ST1) and connection without reinforce specimens (ST2). The test results of the timber connection bending strengths are shown in Figure 7 and average outcomes are given in Table 1.

The bending strength of the five massive timber tests` average failure load outcomes were computed as 83 N/mm^2. The initial load–deflection behaviour was linear until wood yield occurred in compression and crushing. After yielding, the beam evidenced non-linear behaviour, with reduced stiffness up to failure. The observed mode of failure was due to cracking of the timber.

The load–deflection behaviours of massive and connection with un-strengthened timber beams are shown in Figure 8.

The average failure load of five connection samples without any strengthening is found as 16 N/mm^2. The result demonstrated that the cut and reconnection of the timber fibre reduced the bending strength about 80% as shown in Figure 9. Therefore, the connection place needs an extra strengthening material to improve the bending strength capacity of timber joints.

Five different groups of adhesively bonded, strengthen with GFRP bar samples (Figure 10) were prepare to increase the performances of the connection. The outcomes were compared with massive timber and adhesively bonded connection without reinforcement. The average failures of bending strength of timbers strengthened with both single GFRP bar under the specimen (ST3) and single GFRP bars under and on top of the samples (ST5) were found as 41 N/mm^2 (Figure 11). The load–deflection behaviours of the selected ST3 and ST5 samples are compared with the samples of massive timber and adhesively connected one, as shown in Figure 12. The result showed that the strength of the connected timber increased about 155% when compared with the adhesively bonded connection (Figure 12). However, the results are 50% less than massive timber. The results showed that the GFRP bar on top of the specimens have no effect on the bending strength of the connection. The initial load–deflection behaviour was linear until GFRP bar re-bonded. After the slipping of the GFRP bar, the beam evidenced non-linear behaviour, with reduced stiffness up to failure. The observed mode of failure was due to de-bonding of the GFRP bar from the timber.

In order to increase the performances of the connection strength, two GFRP bars under the specimen (ST4) and connection with two GFRP bars under and top of the specimens (ST7) were prepared (Figure 13) and tested. The results demonstrate that the average bending strength of the connected timber increased about 287% when compared with the bonded connection without reinforcement as shown in Figure 14. The results showed that the GFRP bar on top of the specimens had very little effect on the bending strength of the connection. Similarly, the initial load–deflection behaviour was linear until GFRP bar re-bonded (Figure 15).

The beam evidenced non-linear behaviour following the slipping of the GFRP bar. The stiffness was reduced up to failure. The observed mode of failure was due to de-bonding of the GFRP bar from the timber. Figure 16 shows a synthesis of failure load values obtained from experimental results.

Conclusions and Recommendations

Mechanical performances of the black pine timber connecting places of fiber reinforced longitudinal notched lap joints were investigated. The specimens tested were subjected to bending strength and the obtained results were compared with massive timber specimens.

The use of GFRP can be applied as a strengthening technique in the connection of the wood structural element. The technique used proved to be easy and fast to execute, even when on *in situ* parts. In particular, it demonstrated to be very promising in many cases of reinforcement of old, historical structural wood connection parts.

The use of GFRP bars as a reinforcing method increased the connection capacity. The rupture of the GFRP reinforced wood beams was always reached due to the crisis of the wood in the tensile zone. The adhesion between wood and composite materials failed only after wood rupture.

Results are relevant with regard to the increase in stiffness. The bending strength of the connection points strengthened with GFRP bar was higher than un-strengthened adhesively bonded connection about 300%. It was subsequently demonstrated that it is possible to obtain a further increase in stiffness. Since the number of specimens tested was limited, results must be confirmed by a larger experimental programme that also takes into account differing wood types and properties.

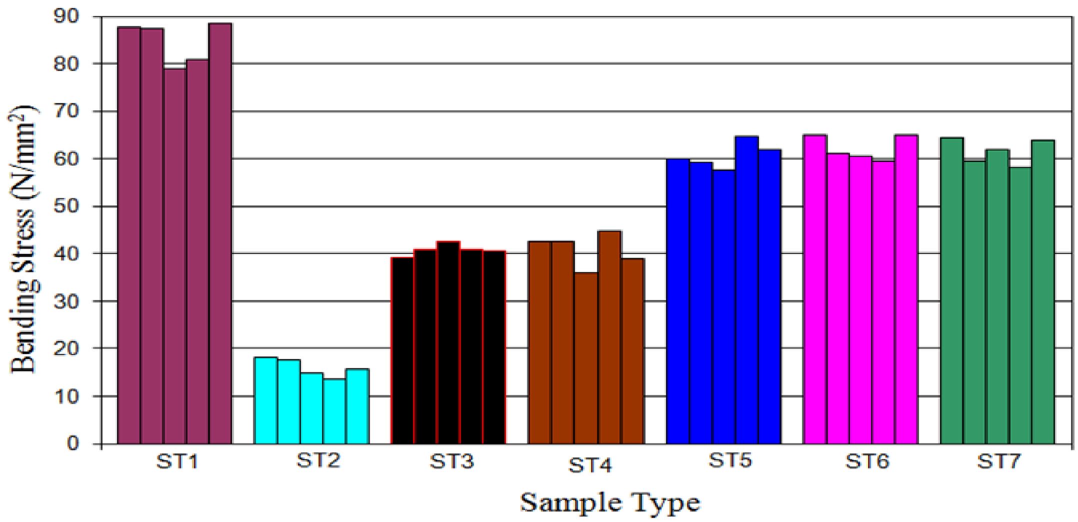

Figure 7. Bending analysis of timber and connection.

Table 1. Mean value of bending strength of timber connection.

Samples name	Symbol	Bending strength (N/mm^2)
Massive timber	ST1	83
Adhesively connected timbers without reinforcement	ST2	16
Adhesively connected timbers with a GFRP bar under the samples	ST3	41
Adhesively connected timbers with two GFRP bars under the samples	ST4	60
Adhesively connected timbers with a GFRP bars under and top of the samples	ST5	41
Adhesively connected timbers with two GFRP bars under and a GFRP bars on top of the samples	ST6	62
Adhesively connected timbers with two GFRP bars under and top of the samples	ST7	62

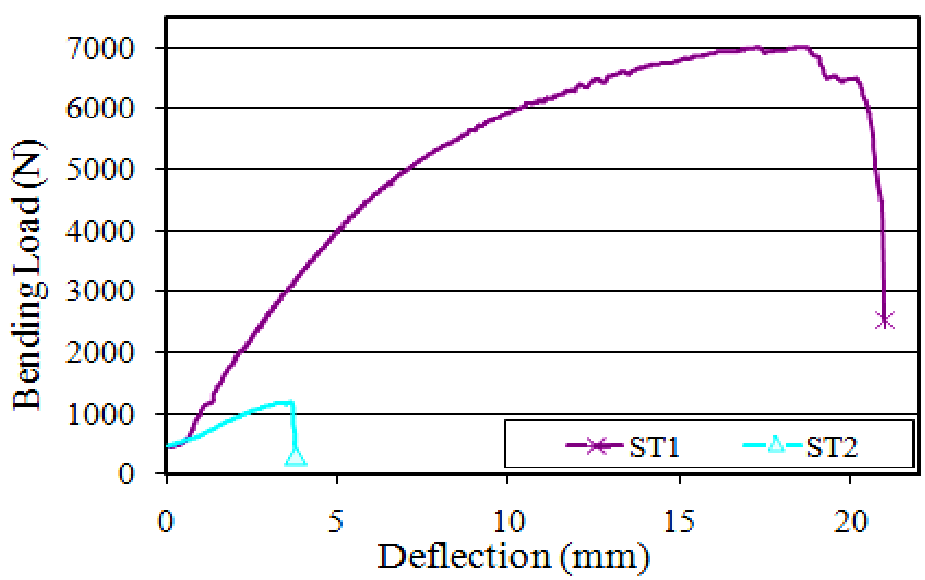

Figure 8. Load–deflection behaviours of massive and connection with un-strengthened timber beams.

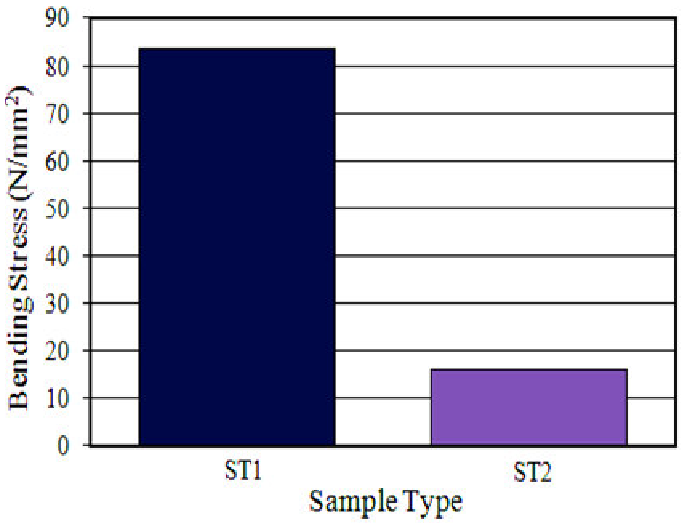

Figure 9. Bending strength massive and connection with un-strengthened timber beams.

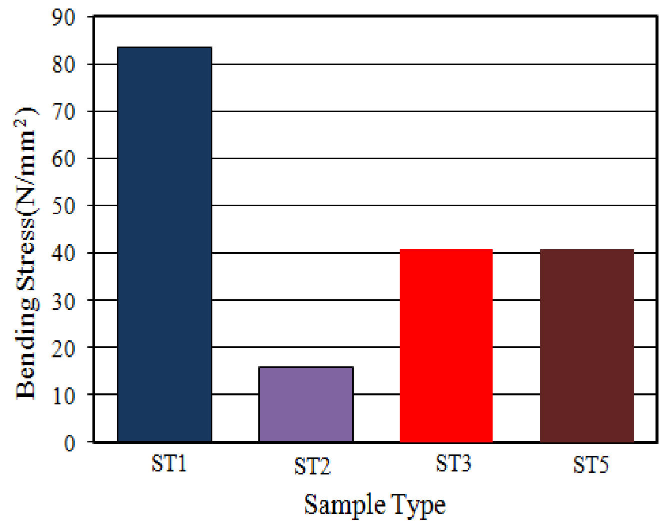

Figure 12. Bending strength of massive, connection without reinforcement and connection with a GFRP bar under and top of the timber.

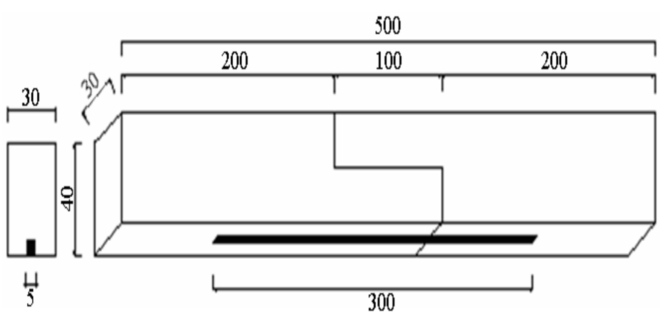

Figure 10. Configuration of timber connection strengthen with a GFRP bar.

Figure 13. Timber connection samples with two GFRP bars.

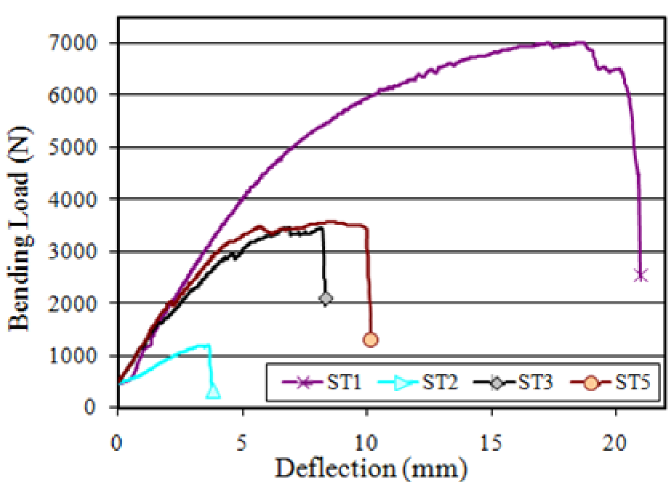

Figure 11. Load–deflection behaviours of massive, connection without reinforcement and connection with a GFRP bar under and top of the timber.

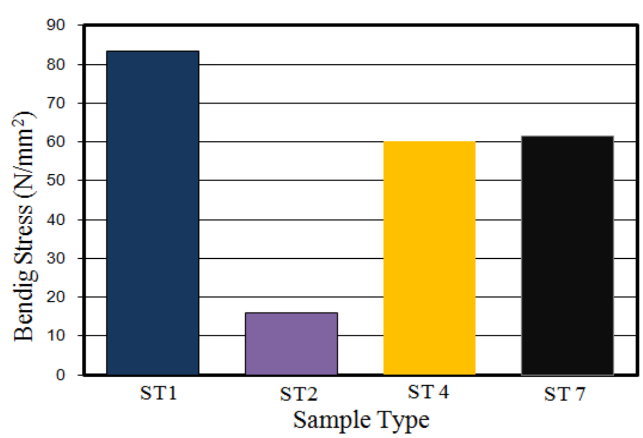

Figure 14. Bending strength of massive, connection without reinforcement and connection with double GFRP bars under and single GFRP bars on the top of the timber.

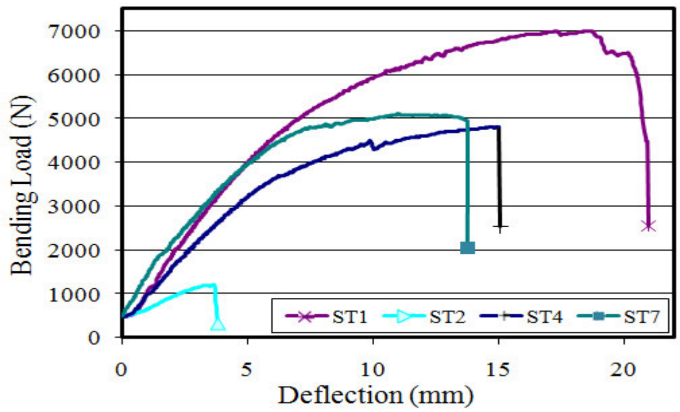

Figure 15. Load–deflection behaviours of massive, connection without reinforcement and connection with double GFRP bars under and single GFRP bars on the top of the samples.

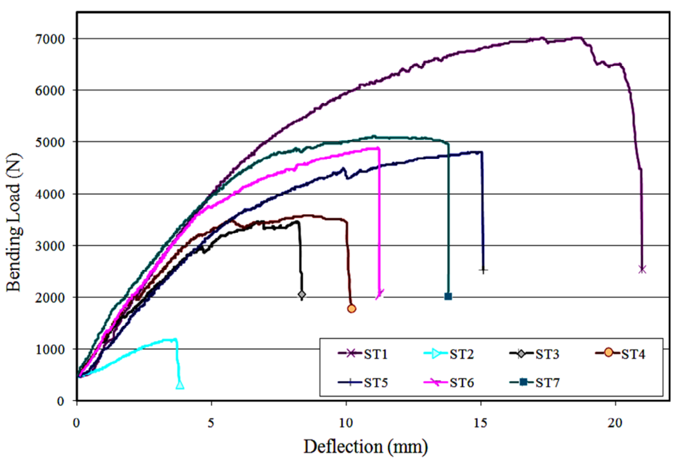

Figure 16. Synthesis of failure load values obtained from experimental results.

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