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STRENGTHENING OF THE TIMBER MEMBERS USING FIBRE REINFORCED POLYMER COMPOSITES

BY
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The reinforcement of structural wood products has become in the last decades an efficient method of improving structural capabilities of load carrying members made of this material. Some important steps in earlier stages of research were focussed on using metallic reinforcement, including steel bars, prestressed stranded cables, and bonded steel and aluminium plates. A disadvantage of the metallic reinforcement was the poor compatibility between the wood and the reinforcing materials. In comparison with metallic reinforcement, fibre reinforced polymers (FRP) composites are compatible with structural wood products leading to efficient hybrid members. Some interesting strengthening alternatives using FRP applied to wood beams and to wood columns are presented in this paper.

1. Fibre Reinforced Polymers (FRP) as Reinforcing Material

The advantage of fibre reinforced polymers (FRP) is that the FRP material could be easily incorporated into the manufacturing process utilized to produce wood composite. Another advantage of FRP reinforced wood composite materials is the expanding potential to use the engineering wood composites in the constructions industry which include residential building, industrial buildings and non building construction application (wood ships, principal and secondary members of old planes or cars, wood toys, etc.). FRP are also proper to retrofit damaged wood members for an extended service life of timber structures [1],...,[5].

Compared with concrete and steel the FRP reinforced wood composites have a remarkable strength-to-weight ratio leading to weight saving structures. From this point of view FRP reinforced wood composites promise to revolutionize the structural wood and also wood composite industry. Earlier studies were initiated by Plevris and Triantafillou in 1992 [6]. They have studied the effect of reinforcing fir wood with carbon/epoxy FRP. The results of their studies show an increasing in strength properties of FRP reinforced lumber with the specification of the significant costs of strengthening.

New reinforced wood product was the main issue in September 1995 at the International Conference of Building Officials (ICBO) [7]. Engineers are using a variety of synthetic fibres including glass, carbon and kevlar and different types of resin to give greater strength, stiffness and ductility to timber members.

2. Repair and Strengthening Methods

Before starting a repair or strengthening using FRP or other materials it is useful to compare and analyse the mechanical properties of materials involved in the

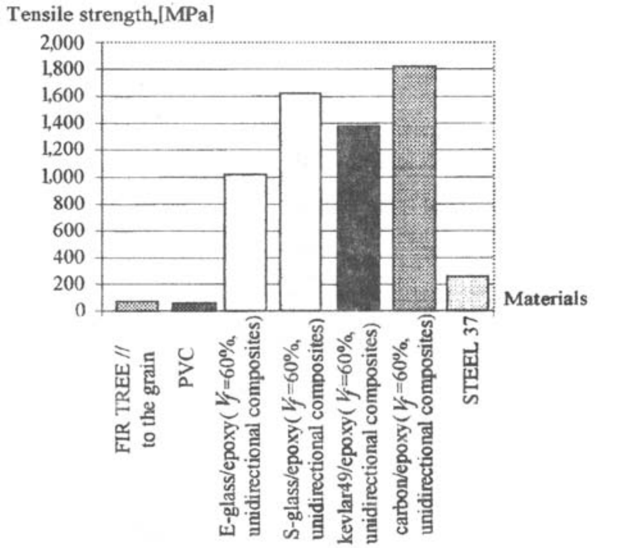

Fig. 1.– Tensile modulus for traditional and composite materials.

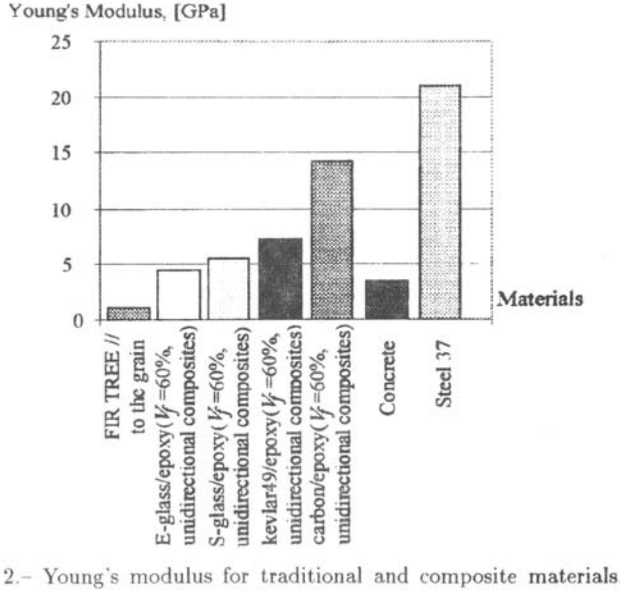

Fig. 2.– Young's modulus for traditional and composite materials.

procedure. In Figs. 1,...,3 the upper limits of tensile strength, Young's modulus and density for different types of materials are illustrated.

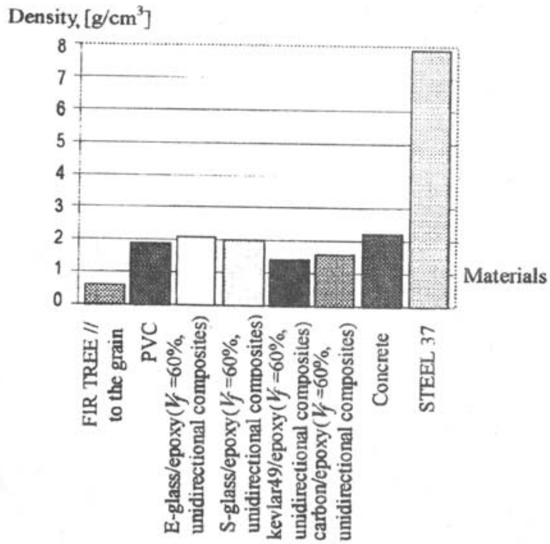

Fig. 3.- Density for traditional and composite materials.

S t e i g e r [8], from Swiss Federal Laboratories for Materials Testing and Research (EMPA), has developed a new perspective design in using of HSF (High Strength Fibres) for repairing and strengthening timber construction.

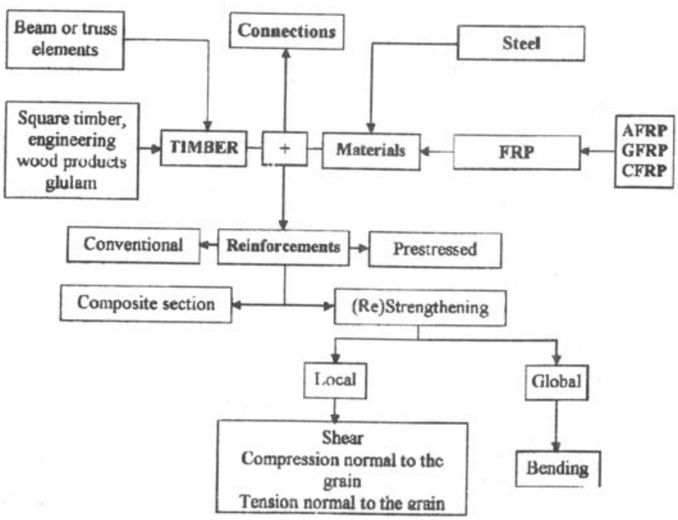

Fig. 4.- Possible routes in case of wood strengthening with FRP.

Timber strengthening with FRP includes: column, beams, rafters, joints, etc. Possible combinations of FRP with timber elements are illustrated in Fig. 4 [12]. The notations from the scheme are the following: AFRP – aramid fibre reinforced polymers, CFRP – carbon fibre reinforced polymers, GFRP – glass fibre reinforced polymers, etc.

3. Wood Beam Strengthening

A timber beam heavily loaded may fail in some characteristic modes. These failure modes may be classified according to the way in which they develop as tension, compression, horizontal shear, etc.

According to the appearance of the broken surface, failure mode could be as brash and fibrous. A number of forms may develop if the beam is completely teared. Since the tensile strength of wood is on the average about three times as great as the compressive strength, a beam should, therefore, be expected to fail by the formation in the first place of a fold on the compression side due to the crushing action, followed by failure on the tension side.

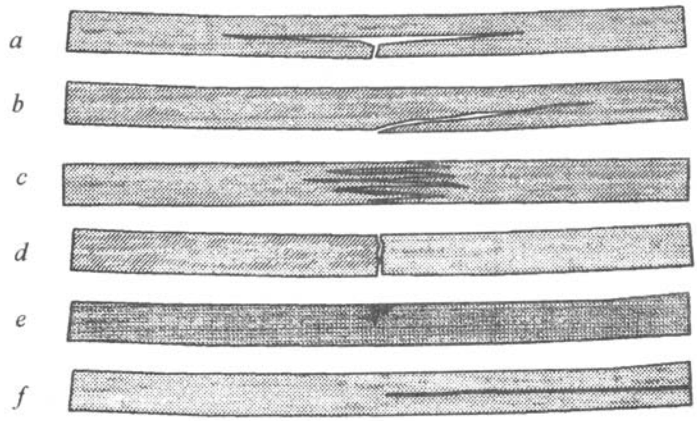

Fig. 5.– Types of failure in static bending.

The following failure modes [9] can be usually met:

a) *Simple tension*, characterized by a direct pulling in two of the wood on the under side of the beam due to a tensile stress parallel to the grain. Fig. 5 *a* illustrates the situation in case of straight-grained beams, particularly when the wood is seasoned.

b) *Cross grained tension*: the fracture is caused by a tensile force acting oblique to the grain (Fig. 5 *b*). This kind of failure occurs where the beam has diagonal, spiral or other form of cross grain on its lower side.

c) *Splintering tension* (Fig. 5 *c*), where the failure consists of a considerable number of slight tension failures, producing a ragged or splintery break on the under surface of the beam.

d) *Brittle tension*, where the beam fails by a clean break extending entirely through it (Fig. 5 *d*). It is characteristic of a brittle wood which gives way suddenly without warning, like a piece of chalk. In this case the surface of fracture is described as brush.

e) *Compression failure* (Fig. 5 *e*) has few variations except that it occurs at various distances from the neutral plane of the beam.

f) *Horizontal shear failure* (Fig. 5 *f*), where the upper and the lower portions of the beam slide along each others for a portion of their length either at one or both ends; it is fairly common in air dry material and in green material when the ratio of the depth of the beam to the span is relatively large.

When using FRP to strengthening wood members (column, beams, panels, connections, etc.) the following advantages are identified [5]:

a) Increasing in strength and/or stiffness.

b) The variability in mechanical properties is reduced.

c) Allow using lower-grade and/or fast-growing species in construction products.

d) Reducing the size and weight of the wood structural members.

e) Increasing the product ductility, serviceability, and fatigue performance.

f) Enhancement of the product durability and dimensional stability.

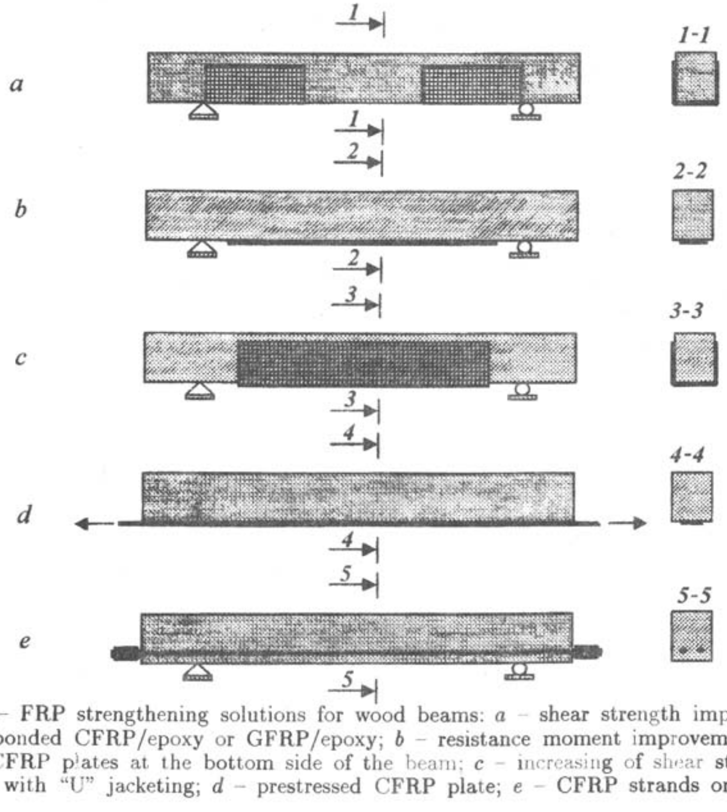

Fig. 6.- FRP strengthening solutions for wood beams: *a* – shear strength improvement using bonded CFRP/epoxy or GFRP/epoxy; *b* – resistance moment improvement using bonded CFRP plates at the bottom side of the beam; *c* – increasing of shear strength and moment with "U" jacketing; *d* – prestressed CFRP plate; *e* – CFRP strands or rods [13].

Strengthening of timber beams for flexure is similar to strengthening concrete beams in flexure. The strengthening procedure utilized impregnated fabrics (made of carbon or glass fibres) with epoxy resins, sheet or plate adhesively bonded to the bottom of the wood beams. Because the FRP are strong in tension and the tension zone of the wood beam is on the bottom side, the combination FRP and wood beams make an efficient composite material in itself. By placing FRP plates or fabrics on the bottom of the wood beams some defects (like knots, cracks, and decay zones) can be outrun, making the wood beam stronger.

T r i a n t a f i l l o u and D e s k o v i c [6] presented the effectiveness of the strengthening method using prestressed CFRP plates bonded at the bottom side of the wood beams. Their experimental results have proved a significant increasing in strength and ductility of the specimens.

Unlike concrete beams, wood beams fail in a different way in shear. Timber shear failure consists of sliding along grain perpendicular to the applied load (Fig. 5), while concrete shear failure consists of diagonal cracking in the shear critical zones. Because the diagonal cracks did not develop in wood beams, researchers, in their experimental tests, placed the fibres in parallel to the grain, across the grain or both [6], [10].

4. Wood Column Strengthening

Important applications of timber are in the utility and railroads where much of the infrastructure uses timber. Other timber application examples are timber bridges specially used in villages and remote areas. A large number of these structures is in critical condition and need repair and strengthening. Many of these bridges are between 50 and 100 years old, and are still necessary for daily operation. Replacement of the structures with concrete or steel is not cost effective solution and repair is becoming increasingly difficult because of limited availability of the large timber sections required for these kinds of engineering structures.

Before tackle the strengthening of wood column with FRP, the designer must understand the failure modes of these. Starting with the fact that the compression is the main load in case of the wood columns we analyse the possible failure modes.

Different types of failure (Fig. 7), from compression tests performed parallel to the grain on wood specimens ($51 \times 51 \times 200$ mm) have been identified. The shear failure (Fig. 7 *c*) can be accepted but the brooming failure (Fig. 7 *f*) is unacceptable.

These types of failure must be controlled when a strengthening solution with FRP is adopted. Telephone poles for example are a familiar application of large timber sections and represent a significant installed investment.

The steps strengthening of poles with FRP, especially for poles affected under the ground line, are shown in Fig. 8. These ones are:

a) excavation, bearing of the pole, cracks identifications, brushing, artificial drying of the surfaces;

b) resin injection in the cracks of the pole;

c) surface priming with the epoxy resin or the adhesive;
d) confinement of the pole with fabrics.

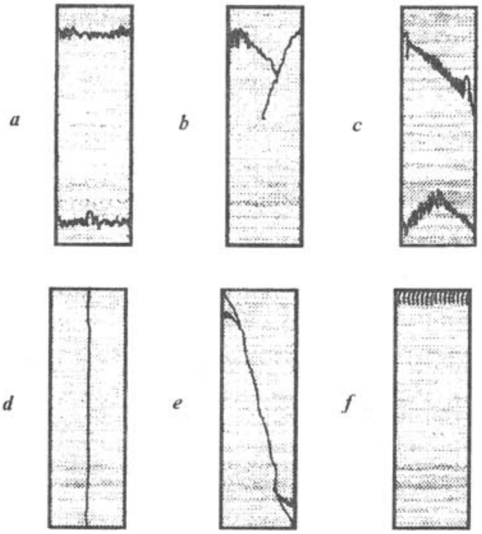

Fig. 7.- Types of failure in compression: *a* – crushing, when the plane of rupture is approximately horizontal; *b* – wedge split, could be radial or tangential; *c* – shearing, the plane of rupture makes an angle of more than 45° degrees with the top of the tested specimen; *d* – splitting, this kind of failure occurs usually in wood specimens having internal defects; *e* – compression and shearing parallel to grain, failure occurs in cross-grained pieces; *f* – brooming or end-rolling, failure caused by excess moisture content at the ends of the wood specimens.

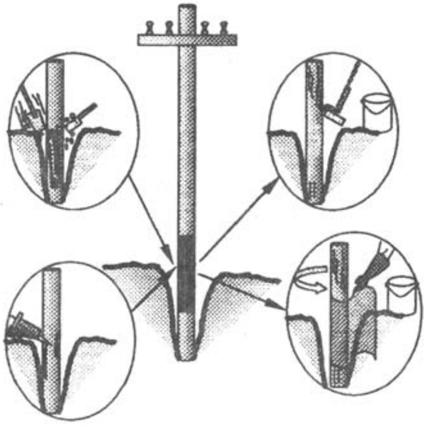

Fig. 8.- Methods of strengthening applied at the ground line of the pole.

One of the wood advantages is the fact that wood have compression and tension strength better then reinforced concrete and brick masonry. In case of normal condition of exploitation we can talk about the durability of wood; there are many cases where wood constructions have been in use for more than 200 years.

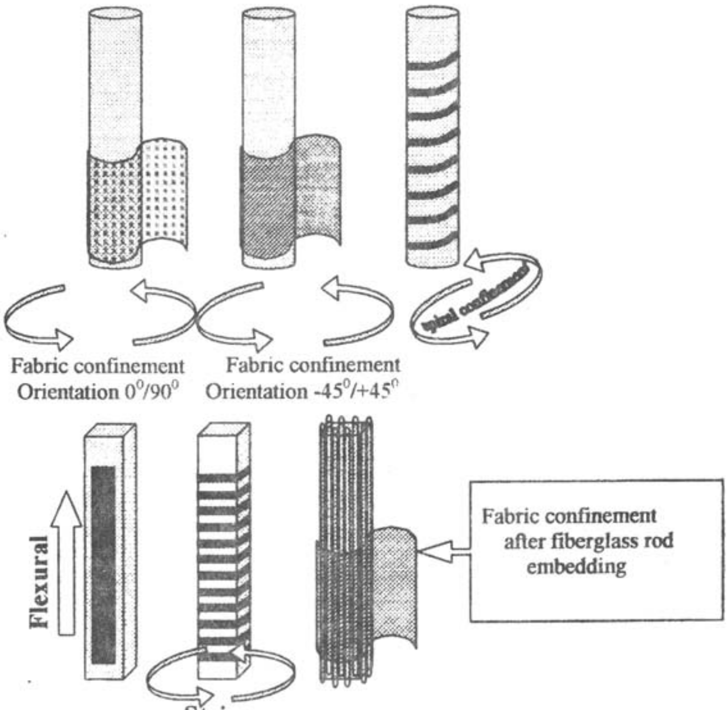

Fig. 9.– FRP strengthening technique applied to wood columns.

FRP strengthening provide an extension of exploitation duration of the wood and assure the ability to assemble, move, rebuild or strengthen (partially or totally) the timber structures. The compatibility of the wood and FRP characteristics is certain and a convenient combination of these materials can be designed. Some repair and strengthening schemes for timber columns are suggested in Fig. 9. These types of strengthening using FRP materials could be applied on portions of wood column or on the entire length of the element, when the size of the damaged area requires such an intervention.

5. Conclusions

Wood is an important construction material and many structural members made of this material may require repair or strengthening operations. FRP composite are materials compatible with wood and are a favourite choice for strengthening solutions.

The benefits of FRP composite used in wood members strengthening are the followings:

a) FRP composite (shell, epoxy-fabrics) act like a shield against exterior damage factors (insects, moisture, fungal decay, ultraviolet light, etc.).

b) The FRP jackets are light weight in comparison with traditional materials used in strengthening (steel, concrete, etc.). [11].....[14].

c) FRP composites could be used to strengthen wood beams and piles, which are designed to withstand a wide range of loadings.

d) FRP composites may protect and extend the life of the wood load carrying elements stressed under various loading schemes and exploited in various working conditions.

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CONSOLIDAREA ELEMENTELOR DIN LEMN CU AJUTORUL COMPOZITELOR POLIMERICE ARMATE CU FIBRE

(Rezumat)

În ultimele decenii armarea produselor din lemn a devenit una dintre metodele eficiente pentru îmbunătăţirea calităţilor portante ale acestui material. Unele etape inportante ale acestor preocupări s-au concentrat pe folosirea armăturilor metalice sub formă de bare şi platbande realizate din oţel sau aluminiu. Totuşi, slaba compatibilitate a lemnului cu aceste materiale metalice reprezintă un dezavantaj pe care îl elimină folosirea compozitelor polimerice armate cu fibre. Se prezintă unele alternative de reabilitare structurală a elementelor uzuale din lemn folosind compozite polimerice armate cu fibre.