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Title:

STRUCTURAL ADHESIVES FOR THE RESTORATION AND ASSEMBLING OF TIMBER STRUCTURES.

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Introduction

Recent trends in building technology have introduced the need for structural wood adhesives that can be applied on-site (or in factory conditions, but without pressure) for:

- restoration and improvement of old timber structures;
- prefabrication of more efficient joints;
- on-site assembling, to lower the construction time and cost.

Joints in timber structures have traditionally been made with steel connectors, and the building codes give little consideration to adhesives, especially for on-site use.

Requirements and developments

A pressureless, thick-joint, gap-filling application is very demanding for a structural adhesive, especially if environmental conditions may vary during cure. No specific standard exists at present, although the subject is covered by the Construction Products Directive of the European Union.

Restoration is the field for which on-site bonding of timber structures has been originally developed, over 30 years ago (Avent, 1992; Phillips and Selwin, 1978). The on-site intervention with adhesives requires an integrated approach, combining exhaustive diagnostics, careful design, highly skilled and trained personnel and a specifically tailored glue formulation. The requirements tend to be towards a versatile and robust product, as different wood species, moisture content, ambient temperature and surface quality may be found (Mettem and Milner, 2000).

In the field of new construction, the use of gap-filling adhesives is quite recent and in quick evolution. The products tend to be tailor-made for a specific application, in terms of wood species, moisture content, method of application, cure conditions and glueline thickness. This is mostly true for prefabrication in mill conditions, because on-site assembling of new timber structures tends to be more similar to restoration, although a better surface preparation is normally achieved with CNC machinery before transportation to the building yard.

In both cases the emphasis is on good *physical and chemical compatibility* between the adhesive and the timber, because of the strong differences in the rheology of the two materials. Extensive research has been conducted in Europe, North America and Japan, focused on the improvement of compatibility, the understanding of long-term behaviour of glued joint and the development of design equations. An extensive R&D program was run at IRL/CNR (Wood Research Institute/National Research Council) in Firenze, with both scientific and financial collaboration from Mapei spa, in order to address these problems and to develop better adhesive systems. As a first step, a test method was developed specifically for **shear tests** of adhesives used in thick joints, as no standard test was available. The test method developed at IRL/CNR is based on compressive shear loading of glued joints (GJ) and solid wood (SW) specimens, before and after a suitable accelerated ageing cycle. The results are evaluated as the ratios of wet strength to dry strength, with the comparison of GJ specimens to SW specimens which are prepared from the same batch of wood, in order to minimise the influence of the variability in wood characteristics. On a group of 10 epoxy-based adhesives, specifically marketed for the consolidation of old timber structures, the method has proven to be effective to differentiate the performances of each product (Lavisci et al., 2001a). A further development of this test method allowed to measure the shear strength of both the glueline and the solid wood adherends within the same test specimen, with the advantage that the comparison is really direct, the influence of wood variability is minimised and the test is quick and simple (Pizzo et al, 2002a), although it has proven to be useful also for “fine tuning” of the formulations (e.g. understanding the effect of different fillers or different filler levels). It has also enabled the calculation of a **compatibility**

coefficient (Pizzo, 2002c), which is considered a very useful parameter by the Conservation Authorities. The evaluation of wood adhesives based on the “direct” comparison of their performance with that of solid wood is indeed a new and useful criterion, which might be interesting also for other applications (structural adhesives as in EN 301; non-structural adhesives as in EN 204).

A new, specific 3-ply test set-up was developed also for **delamination** (Lavisci et al., 2001b) which applies higher stresses than the 6-ply ASTM D 2559 and EN 302-2 specimens, and proves to be very selective because of its efficiency in developing delaminations.

Research has been dedicated also to the **fracture behaviour** of thick joints (Lavisci et al., 2002a) and the comparison of **thermal expansion coefficients** of wood and epoxy adhesives (Pizzo et al, 2002b).

As far as the application is concerned, a large research program on **glued-in rods** has recently been completed (Bengtsson and Johansson, 2001), with the following results:

- suitable calculation models have been developed, based on properties that can be easily determined by laboratory tests;
- fatigue is a significant factor in the performance of glued-in rods, and needs always to be considered in applications like for instance bridges;
- the effects of rod spacing and edge distances have been demonstrated and proposals for design have been made;
- the effect of duration of load for epoxy adhesives was found to be similar to that of wood (the “Madison curve”), therefore the same modification factors may be used in design;
- suitable production control tests (for mill conditions) have been developed.

A complementary work (Feligioni et al, 2002), showed that the glue rheology modifications may improve the performance of joints with bonded-in rods, and good correlation was found between pull-out strength and glue volume. The glueline thickness is therefore a very important parameter in the design, because it allows to optimise the stress transfer from the wood to the rod, limiting stress concentrations and yielding plastic deformation (a critical factor in seismic design). Based on these results, some modifications of the Eurocode 5 design equation have been proposed (Gustafsson et al., 2001; Feligioni et al, 2002), integrating the basic joint properties, that allow to use the performances offered by the new adhesive types specifically formulated for timber.

Standardisation

The Eurocode 5 (ENV 1995) limits the use of bonded-in rods to service classes 1 and 2 (although some examples of application in service class 3 are known) because at the time of its drafting the design factors for durability and creep behaviour of glued joints were not well established (Trada Technology, 2000). This problem has been addressed by recent research. Although it is unlikely that the current revision of the Eurocode 5 will be able to incorporate the latest results, the CEN (Comité Européen de Normalisation) is already working on these subjects with two working groups activated within its TC193/SC1: WG6, dedicated to bonded-in rods and WG11, dedicated to adhesives used for on-site application.

Conclusions

It is nowadays acknowledged that specifically formulated adhesives can match or exceed the performances of timber. When correctly applied on site, by trained personnel, adhesives do improve working quality and productivity. Research has been extensive and will continue, because the building professionals like the advantages that bonded joints have shown in terms of flexibility and quickness of construction. Standardisation will enable the designers to acknowledge the performances of adhesives specific for timber structures.

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Figure 1 – Typical applications in restoration. Glued-in rods for the substitution of rotten heads of Oak beams at "Poggio Cusiano" (Miasino - NO). Design: Arch. Daniele Scalcon. Works: LegnoPIÙ snc. Scientific advice: IRL/CNR.

Figure 2 - Typical applications in new construction. Glued-in rods for glulam structures at “L’Aquilone di Chicco” (Grandate - CO). Design: Geom. Giovanni Cenci. Works: Holzbau spa. Scientific advice: Prof. Piazza, Università di Trento.