Inductive and resistive heating of Glued-in-Rods

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Résumé:

Les tiges collées représentent une typologie d'assemblage dans la construction du bois qui fait l'objet d'une attention accrue de la part des praticiens et des chercheurs. En tant que liaison collée, sa mise en œuvre pratique est souvent limitée par des exigences spécifiques imposées par la réticulation de l'adhésif. D'une part, des temps de durcissement relativement longs, comptés en heures ou en jours ; d'autre part, une plage de température relativement étroite avec des températures minimales et maximales très strictes. Ces deux limitations représentent des inconvénients par rapport aux liaisons mécaniques, qui ne connaissent pas de telles limitations.

Abstract:

Glued-in-rods represent a joint typology that receives increased attention from both practitioners and researchers. As a bonded connection, its practical implementation is often limited by specific requirements imposed by the curing of the adhesive. Firstly, relatively long curing times, counting in hours, or days; secondly, a relatively narrow temperature range with minimum and maximum temperature. Both limitations represent drawbacks in comparison with mechanical connections, which do not know such limitations.

Mots clefs: Glued-in-Rods, accelerated, curing, adhesives

1 Introduction

Glued-in-rods (GiR) represent a particular class of adhesively bonded joints for engineering applications, in which load is transmitted from one timber element to another by means of stiffer and more resistant linear elements (rods) through a layer of adhesive [1]. Owing to the practicalities, it has become practice standard to employ textured or threaded metallic rods in order to maximize mechanical interlock. Glued-in-rods are most commonly connected to the timber using cold-curing 2K adhesives, typically either epoxies (EPX) or polyurethanes (PUR). The use of the aforementioned adhesives requires some minimum and maximum temperatures for curing. Because of these limitations a specific technique is needed, such as resistive heating and inductive heating. The authors of this paper have recently published [1–3] experimental results on both techniques.

2 Material and Methods

Resistive and inductive curing was performed using 2K-EPX and 2K-PUR. These two classes of adhesives have the advantage to cure even under normal temperature condition (23°C) even though longer curing time is needed. This particular feature ensures that potentially uncured areas pass a post-curing and therefore don't imperil the strength of the joint in service life. This effect can also be used to limit the accelerated curing to a partial curing of the adhesive, e.g. to achieve some minimum handling strength. However, 2K adhesives are generally not formulated to be cured at high temperatures; they are particularly sensitive to sudden increases of temperature. Four adhesives were considered for this study: the two component polyurethanes (2K-PUR) CR421, and the two component epoxies (2K-EPX) EP32, Jo692.30 and FIS EM.

For all experimental investigations presented herein, beech LVL from the company Pollmeier/Germany was used. The material consisted was manufactured by gluing thin rotary-peeled Fagus sylvatica L. veneer layers of 3 mm in thickness from beech trunks.

Threaded bars are the most widely used connector for GiR, since the textured surface is expected to achieve significant mechanical interlocking with the adhesive. They usually come from bar stock (or all-thread) material and are thus often fully threaded stud bolts available in any length. Threaded rods M16–8.8 bars were used herein. In a first step, all adhesives were subjected to test to determine the maximum allowable heating rates and maximum curing temperatures. The procedure, largely empirical, consisted in inductively heating lap-shear specimen following different heating regimes. The heating regimes were defined by two parameters: a constant heating rate (in K/s) up to a defined temperature (curing temperature, in °C). The results, which were subsequently agreed with the adhesive manufacturers, are shown in Table 1.

Table 1: Maximum heating rates and curing temperatures

Adhesive	Curing time at RT	Max. Curing temp	Max. Heating rate
CR412	10d	100°C	2 K/s
FIS EM	18h	100°C	2 K/s
EP32	10d	90°C	2 K/s
Jo692.30	2d	80°C	2 K/s

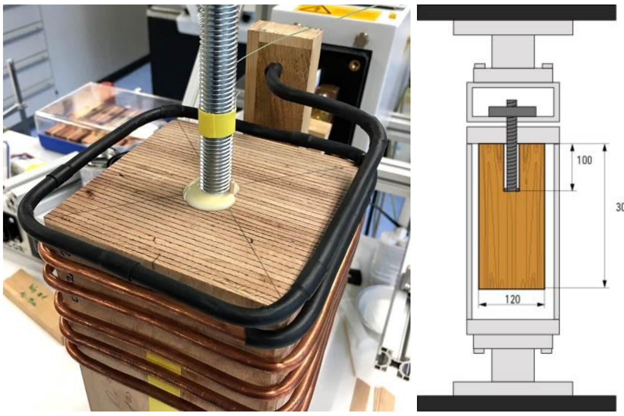

Figure 1: Inductive heating of a large scale GiR and pull-compression test device

Threaded bars Ø16 mm were centred and bonded in holes Ø20 mm up to a depth of l = 100 mm in beech LVL blocks 120 x 120 mm². For both inductive and resistive heating setup, adhesives were injected via a small tunnel drilled starting at the side of the LVL block to the bottom of the hole until it squeezed out at the top thereof. Centring of the rods was achieved via small wooden tooth sticks. All series of large scaled GiR were tested in tension at a load rate of 2 mm/min in a pull-compression test frame specifically designed for that.

Inductive heating was ensured via a hollow copper coil winded in a square shape. The coil was cooled via a water circuit, and connected to an induction device, which delivered a frequency of 51 kHz alternating electric current with a voltage of 3.4 V, and variable intensity. Electric intensity was controlled via thermocouples connected to the rods, such to precisely follow the thermal regime defined by **Erreur ! Source du renvoi introuvable.** (first a thermal ramp, then a constant curing temperature); the total induction time lasted for exactly 5 min, after which the GiR-system cooled down. The setup is depicted in Figure 1.

Prior to insertion, wires consisting of constantan were wrapped around the rods up to a length corresponding to the embedment length.(Figure 2(b)) Each probe was instrumented with thermocouples for temperature measurement, and then electrically connected and subjected to an electrical current (constant voltage: 3V, variable intensity: controlled by the reading of the thermocouples). Figure 2 (a) gives an overview of the experimental resistive setup. The heating regime was adapted to last for 60 min in total, with heating rates corresponding to the tenth of the values listed in Table 1, but identical curing temperatures. Total duration of the resistive curing was kept to 60 minutes.

(a) (b)

Figure 2: (a) Experimental setup of resistance heating; (b) wire guide

3 Results

Since induction power was controlled by a thermocouple fixed at the threaded rod, the exact thermal profile defined by Table 1 was imposed to all GiR. In particular temperatures were raised following the defined temperature ramp, and the targeted curing temperature was maintained. In all cases total induction durations of 5 min were maintained.

Mechanical testings were performed for all adhesives after curing the adhesives according to the TDS (referred to as cold-cured), and 24 h after inductive heating. Additionally, selected adhesives were inductively cured and tested after 30 min and 2 hours. The reference values obtained through cold curing, which lasted from several hours up to days, as well as those obtained via inductive heating after 24 h, are both listed in Table 1.

Failure patterns mostly resulted in a wooden plug that remained sticked to the threaded rods, as illustrated by Figure 4 and resembled those observed for the cold-cured specimen. Corresponding joint capacities, however, were not identical. In most cases inductive heating resulted in lower capacities. In particular, the 2K-PUR resulted in values lower by approx. a fifth; only for EP32 (2K-EPX) did induction curing lead to higher strength by 10%. A first series, involving FIS EM (2K-EPX) was tested 30 min after the inductive heating process of 5 min. The results are presented in Figure 3. The specimen had not yet fully cooled down, and exhibited temperatures ranging between 30 °C and 38 °C at the moment of testing. Corresponding joint capacities ranged between 9 kN and 78 kN. Specimes with EP32 (2K-EPX) were tested after 8 hours demonstrated that if sufficiently time is given to cool down, joint capacities are almost indistinguishable from cold-cured specimen, or from specimen which have been left to cool down for 24 hours.

Table 2: Experimentally determined load capacities (in kN) of the large scale GiR

Adhesive	Cold cured		Inductive, after 24h		Inductive vs. cold cured
	Average	Std.-Dev.	Average	Std.-Dev.	
CR421	69,4	11,2	54,7	18,9	-21%
EP32	88,8	6,1	97,6	1,5	+10%
Jo692.30	75,5	8,2	57,9	30,2	-23%
FIS EM	88,0	1,8	83,8	12,2	-5%

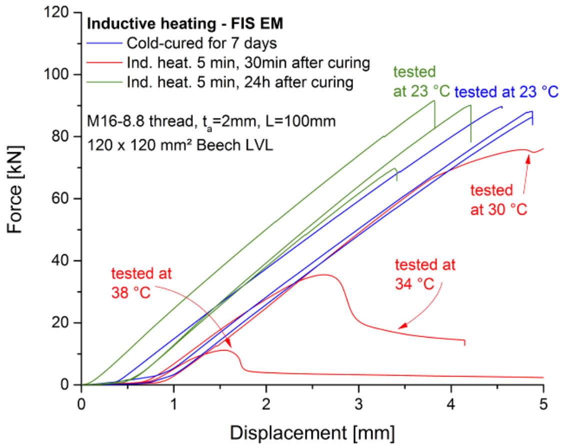

Figure 3: Load-displacement behaviour of inductively cured specimen tested after cooling for 30 min and 24 h, compared to cold-cured specimen

Figure 4: Failure pattern of an inductively heated probe with FIS EM, tested 24 h after curin**g**

As for the inductive heating, temperature regime for the resistively heated specimen was controlled by thermocouples. Measurements showed that the temperature control was very effective, with deviations of ±5 °C from the imposed values. This proved true for the 15 min. long temperature ramp, and the subsequent constant 45 min. curing phase.
Mechanical testing of the resistively heated specimen revealed similar results as for the inductive ones. Failure pattern, depicted exemplarily in Figure 6 (EP32, 2K-EPX), proved similar to those observed for the cold-cured specimen. Joint capacities obtained through resistive heating, however, proved lower by a fifth, if compared to cold-cured ones.
And, similarly to what has been observed for the inductively cured specimen, not giving sufficient time for cooling down, and testing e.g. after just two hours, lead to lower joint capacities.

All adhesives considered in this study were 2K-epoxies or 2K-polyurethanes. According to their TDS, they require between 18 h to up to 10 days to cure at room temperature (23 °C). The experiments showed that 2K adhesives can be cured much faster. It appeared, however, that 2K-epoxies are much more adapted than 2K-polyurethanes; this is not fully surprising, since polyurethanes rely on a supply of moisture to cure. The capacity of the adhesives to cure significantly faster was subsequently verified on GiR. Two methods were investigated: inductive and resistive heating. Both methods proved the validity of the concept of accelerate curing, as only slightly lower joint capacities were obtained for specimen tested 24 h after their respective accelerated curing, if compared to cold-cured ones. Also, the fracture pattern of fast-cured and cold-cured GiR were the same. If testing specimen before they completely cool down, load capacity was in part lower. However, as shown in the tests, this was mostly due to the fact that the threaded bar still exhibited significant temperatures. And yet,, the results, showed that significant handling strength was offered by the accelerated curing, which has the potential to ease the problematics of slow curing 2K adhesives in industrial processes.

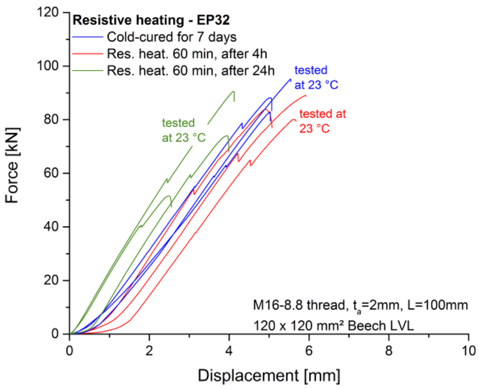

Figure 5: Load-displacement behaviour of inductively cured specimen tested after cooling for 4 h, 24 h, compared to cold-cured specimen

Figure 6: Failure pattern of a resistively heated probe with EP32, tested 24 h after curing

5 Conclusion

Accelerated curing of commercially available and widely used 2K-epoxies and polyurethanes was investigated in the context of Glued-in rods.

Preliminary tests on the adhesives showed that all adhesives could be fully cured in significantly shorter times, to be counted in minutes rather than in hours or days.

Subsequent validation thereof on large scale GiR proved the validity of the concept, as inductive heating allowed to cure 120 x 120 mm² sections of beech LVL within 5 minutes, and resistive heating within one hour. Resulting joint capacities proved comparable in strength, if tested after complete cooled down. If tested within 30 minutes, with threaded bars still exhibiting temperature beyond 30 °C, significant handling strength was observed.

6 Acknowledgment

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