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Influence of elevated temperature on glued-in steel rods for timber elements

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HIGHLIGHTS

- The decay in bond properties of GiR avoiding post-curing is experimentally determined.
- The temperature-induced decrease in bond strength is product dependent.
- A different trend is noticeable on failure temperatures depending on the timber type.
- No significant difference is found for different shapes of the drilled holes.

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ABSTRACT

Load bearing capacity of Glued-in Rods (GiR) is significantly influenced by the temperature of the adhesive. This paper presents an experimental program for GiR inserted into both laminated and solid timber elements, when subjected to elevated temperatures. Twenty-four specimens with a single 8 mm rod glued parallel to the grain were tested to evaluate the effect of elevated temperatures on GiR performance. To avoid post-curing effects in the adhesive, a constant load was applied to the bar in a pull-compression configuration prior to temperature increase. Two types of adhesives were tested, as well as two different shapes for the internal hole surface (cylindrical and threaded), in order to evaluate whether different geometrical properties of the hole could affect the performances of the connection subjected to elevated temperatures.

Experimental results show that an increase in the temperature of the bonding layer causes a significant decrease in the bond shear strength of the adhesive with respect to the cold state (approximately halves when approaching the Heat Deflection). Furthermore the strength of the adhesive at elevated temperature demonstrates a clear dependence on the adhesive type and a negligible dependence on the geometry of the hole.

1. Introduction

Glued-in rod technology is becoming increasingly popular in the construction of new timber structures and repairing of some pre-existing timber structures. Glued-in rod timber joints provide many improvements over traditional timber joints, including lower weight, greater strength and stiffness, improved aesthetic appearance and good protection of the steel rods against corrosion and fire. The simplest method for manufacturing glued-in rod timber joint is to inject the resin into the pre-drilled hole and then insert and rotate the rod into the resin-filled hole until the rod reaches the base of the hole thus ensures a reliable bond between the rod and the timber.

Over the past four decades, a large number of experimental and theoretical studies on glued-in rod timber joints have been carried out. Most of them were pull-out tests, aimed to investigate the effects of geometrical and material properties on the pullout strength and bond behaviour of glued-in rod joints [1].

Other research investigations analysed the effect that high temperatures have on the connection. While a few experiments were carried out to discover how a variation in the air temperature in hot climate environments could affect the mechanical performance of the adhesive connection in service, most of the research studies examined the performance of the connection under fire conditions.

Some authors in their studies [3,4] revealed that the adhesive lines inside timber structural members followed the outer temper-

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ature regime both in heating and cooling phases. This phenomenon was confirmed by a Finite Element Analysis, performed by Fave and Le Magoriu [5], which shows a 4/5 h delay for the adhesive in reaching ambient temperature (Fig. 1). Temperature inside roofs could reach peaks of 75 °C. The European standard EN 301 [6] accepts 50 °C to be the limit between normal conditions and hot service conditions, to which different requirements are imposed concerning the adhesives performances. Currently, the European structural timber code (Eurocode 5 [7]) does not cover the design of structures subjected to prolonged exposure to temperatures over 60 °C. Besides, other studies [8,9] have shown that the load bearing capacity of glued-in rods significantly decreased when the epoxy resins reached an intrinsic critical temperature also called the glass transition temperature (T_g). At this temperature, it is known that irreversible modifications of the inner structure of the polymer occurred. Starting from this temperature, it is known that mechanical properties of the adhesive, and consequently the capacity of the GiR connection, significantly decrease. Design rule proposals, predicting the pull-out strength of glued-in rods, are available [10,1,11], but the effect of temperature is not taken into account. The lack of information regarding the performance of these connections under temperature changes is still an obstacle for their use.

In past studies two different methods were frequently used to test glued-in rods (GiR) in timber at elevated temperatures. The first method is generally referred to as “residual capacity test” and it involves the use of an oven to heat the connection up to a selected temperature. The connection is usually left in an oven overnight to allow the sample reach a homogeneous temperature in all its parts. Subsequently, the sample is removed from the oven (and eventually cooled down to room temperature) and a tensile test is performed to assess its pull-out capacity.

Another method used to study GiR at elevated temperatures involves the use of a gas oven (furnace) where the sample is heated up, usually following the standard time–temperature curve of ISO 834 [12], while subjected to a constant tensile load. In Harris’s [14], for example, the constant load corresponded to 30% of the design load in cold state (room temperature). These testing methods provide knowledge of the fire performance of the joint but their comparison reveals several inconsistencies. The electrical oven tests resulted in being less severe than the experiments carried out in furnace, showing failure temperatures much higher than the temperatures obtained by the furnace heating process. This inconsistency between the two aforementioned methods is mainly due to the fact that in the electrical oven the joint and therefore the adhesive are heated without being subjected to tension loads, so there is a post-curing effect; on the contrary, in the gas oven the whole adhesive connection is tested in tension under load.

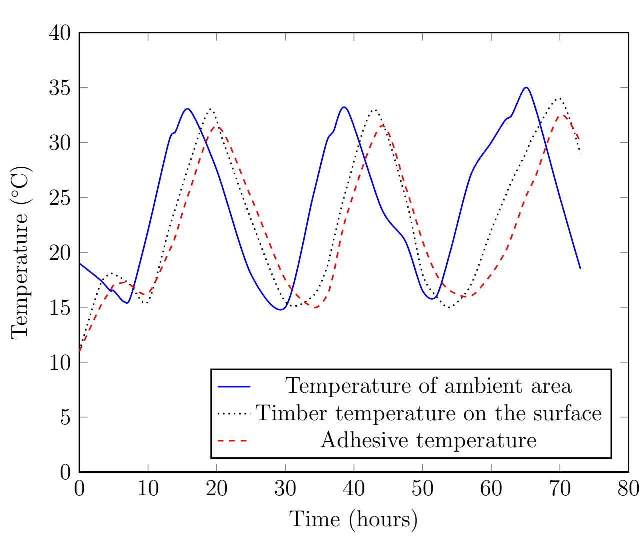

Fig. 1. Relation ambient/adhesive temperature through a finite element analysis [5].

However, the scope of this paper is not of assessing the structural performance of a specific GiR connection, but rather to investigate the decay in the bond properties as a function of the local temperature at a given point of the connection.

Such an approach is similar to the one used by Muciaccia et al. [15] for post-installed rebar connections in concrete. In future, it shall be coupled with a proper design method for a GiR under temperature, which may account for a non-uniform distribution of temperature along the bar that may occur in a real design case (e.g. in a GiR used as timber reinforcement).

In such cases the layer closer to the exposed surface would suffer an higher temperature with respect to inner layer. Consequently, a gradient in temperature and a gradient in the bond properties as well will be expected.

In the present investigation, the samples were heated as uniformly as possible after applying a constant load. It can be assumed that, in absence of significant thermal gradients along the bar length, the decay in the bond properties is uniform. Additionally, applying the load prior to temperature increases prevents the effects of post-curing, which is typical in residual capacity tests.

Heating the samples after applying the load is considered a more severe method to determine the critical temperature, as many researches proved in past studies.

Preliminary tests were carried out in standard conditions ($T = 20\,^{\circ}$C and $HR = 65\%$), in order to evaluate the bond strength of the connection at cold state. Two-component epoxy resins were used to glue 8mm steel rods into pre-drilled holes (characterised by cylindrical or threaded internal surfaces), in timber samples in order to assess the bond shear strength (hereinafter referred to simply as “bond strength”) at critical temperatures. The samples were loaded applying a constant load and heated up in an electric furnace until failure.

2. Materials and methods

2.1. Materials

2.1.1. Timber

Two types of timber were used in the tests: solid timber (Douglas fir C16 class, according to EN 338 [16]) and glulam (Spruce GL24 class, according to EN 1194 [17]), whose properties are reported in Table 1.

The glulam elements were obtained by cutting bigger timber blocks to the desired height. Samples of both timber species were conditioned using a climate chamber according to EN 408-2010 ([13]) for 1 week. Subsequently, before testing the specimens were weighted and their moisture content was assessed by using a pin-moisture meter in order to verify equilibrium amongst all specimens.

2.1.2. Steel

Threaded steel bars of grade 12.9 and diameter $d = 8$ mm were used in this study.

Table 1
Material properties of timber specimens.

Type	Solid (Douglas fir)	Glulam (Spruce)
Density (kg/m^3)	560	430
MC (%)	10.1	9.2