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Charring Rate for Fire Exposed X-Lam

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Abstract. Design of timber structures has been outlined in Eurocode 5. Notional charring rate for softwood and hardwood timber is given. For the performance of X-LAM panels in fire, only little information on charring is available and whether the fire behaviour of X-LAM is similar to homogenous timber panels has not yet been systematically analysed. This paper presents an overview of fire performance of X-LAM and evaluation of its resistance to elevated temperature as an element of structure in comparison to homogeneous timber panels. Numerical study has been carried out based on available experimental results. Charring rates for X-LAM panels obtained from experimental results are compared with those obtained from Eurocode 5 and proposed simplified model.

1. Introduction

Timber frame is one of the fastest growing modern method of construction in the United Kingdom, as wood is effectively carbon neutral, with timber frame benefiting from being the only organic, non-toxic and naturally renewable building material, whilst minimising energy consumption. In recent years many developments have been made in relation to timber technology and construction products. For heavy timber construction, cross-laminated timber (X-Lam) panel load bearing wall and floor assemblies system is becoming increasingly common.

X-Lam panels, with thickness varies from 50mm to 300mm in 3 to 8 layers, are cut to size in the factory according to the structural drawings taking into account openings such as doors, windows and stairwells, using layers of softwood planks glued together with each layer arranged at right angles to one another (figure 1), and are delivered to site ready for immediate erection of walls, floors and roofs. The benefits of this huge building system are the good structural performance, thermal and acoustic insulation characteristics, the great prefabrication, and the rapidity of erection [1]. The use of large solid timber panels is also favorable case of fire, as the risk of fire spread through void cavities is reduced in comparison to light timber frame constructions. Although, large solid timber panels increase the fire load in the room.

Advanced and simplified calculation methods have been recommended for analysing how timber behaves when exposed to elevated temperatures [2]. Experimental investigations on small and large scale tests of unloaded and loaded X-Lam specimens manufactured by various producers with different characteristics have been carried out [3-5]. The outcome of the tests revealed that the fire behavior of X-Lam elements were mostly linked to the thickness of the layers and the type of adhesive used to produce the timber panels [1]. Analytical and numerical methods are effective ways to study the mechanical and thermal performance of cross-laminated timber elements exposed to fire without performing experimental tests which are hazardous and expensive [1].

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This paper presents an overview of fire performance of X-Lam and evaluation of its resistance to elevated temperature as an element of structure in comparison to homogeneous timber panels. Charring rates for X-Lam panels obtained from experimental results are compared with those obtained from Eurocode 5 [2] simplified calculation methods and proposed simplified model.

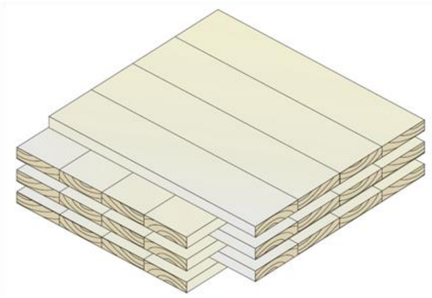

Figure 1. Individual timber panels used to make a typical X-Lam [6].

2. Performance of timber in fire

All buildings must be constructed to meet national building regulations, which requirements for fire resistance. Fire-resistance-rated construction requires structural components and assemblies to meet defined fire performance standards. The fire resistance rating of a building assembly has traditionally been assessed by subjecting a replicate of the assembly to ISO 834 standard fire-resistance test [7]. In term of fire resistance, a structural element should not collapse or deflect beyond the permitted levels when subjected to the applied load throughout the fire test. Combustible building materials like timber burn on their surface, release energy and thus contribute to fire propagation and the development of smoke in case of fire. It is often perceived that timber will perform unsatisfactorily during a fire situation; this is not necessarily the case as timber burns slowly and resists heat penetration by the formation of a self-insulating char.

When exposed to heat of a fire, timber undergoes a thermal breakdown (pyrolysis) into combustible gases. Pyrolysis takes place in the timber when they are exposed to elevated temperatures between 150 ℃ to 200 ℃. A layer of charcoal forms on the burning surface, the char layer grows in thickness as the fire grows, reducing the cross-sectional dimensions of the wood element. The char layer is a poor thermal conductor and protects the un-charred remaining residual cross-section from fire. When large timber members are subjected to fire, the uncharred inner portion maintains its strength, giving the structure a higher survival factor and more importantly, it retains its structural integrity being one of the reasons why large timber sections can often be used in unprotected situations where non-combustible materials such as steel would require special fire protection.

The rate at which timber chars varies between species and is predominately dependent on density and moisture content. When timber burns, it occurs at a predictable speed known as the charring rate. For unprotected wood surfaces throughout the duration of fire exposure, the charring rate for softwood is 0.65 mm/min as given in Eurocode 5 [2].

For protected timber surfaces, a simplified model has been suggested [2] taken into consideration the fact that different charring rates should be applied during different phases of the fire exposure, where an increased charring is expected after failure of the protection materials. It was recommended double the rate of initially unprotected surfaces, until the charring depth has reached 25mm [2].

3. Performance of X-Lam in fire

The interest for X-Lam as a buildings system is increasing whilst for X-Lam panels in fire only little information on charring is available. A few experimental investigations are available [3-5] on the fire behavior of X-Lam panels. It has been revealed that, the fire behavior of X-Lam panels is characterised by the behavior of the single layers. In the case of fire, if the charred layers of X-Lam panel remain in place, the charcoal protects the remaining uncharred layers of the X-Lam solid panels

against heat, behaves similarly to homogenous timber panels in fire [3]. An increased charring is expected if the charred layers fell off after the panel system. This appearance is similar to the increased charring observed for protected timber surfaces after failure of the protection materials.
The thickness of the X-Lam layers as well as the behavior of the bonding adhesive at elevated temperature can influence the falling of the charred layers [3]. X-Lam with thicker panel layers behave better in fire than that of thinner, due to the fact that X-Lam panels with thicker panel layers expected behave similar to homogenous timber panels and therefore the one-dimensional charring rate of 0.65 mm/min can be assumed [2], while X-Lam with thinner panel layers should behaves more like plywood, where charring rate of 1.0 mm/min is assumed for plywood [2].
Observation from the fire tests on X-Lam panels under ISO-fire exposure [4,5], has suggested that at elevated temperatures falling off of the charred layers leading to increase charring rates in comparison to homogeneous timber panels. Similar effect to a protected timber member after the fire protection has fallen off. For X-Lam panels where no falling off of the charred layers was occurred, the fire behavior of the X-Lam panels is similar to that of homogeneous timber panels.
The individual layers forming the X-Lam members are bonded and pressed together using with durable, moisture-resistant structural adhesives. For X-Lam panels bonding system, Melamine-urea-formaldehyde (MUF) and one-component polyurethane adhesives (1K-PUR) are frequently used. At high temperature the performance of the assembled timber member depends highly on the resistance of laminating adhesives to elevated temperatures. It was demonstrated that in fire, the behavior of adhesive that used in the bond-line between the lamellas has little influence on the resistance of the glued laminated timber beam and anticipated that the fire resistance will be governed by the bending resistance rather than shear resistance [8]. A series of tests were conducted to study the shear behavior of different adhesives at high temperatures, has demonstrated that the fire behavior of cross-laminated timber panels is strongly influenced by the behavior of the adhesive that used for the X-Lam panels bonding system [5,9]. X-Lam panels manufactured with a less temperature-sensitive adhesive the charred layers almost remained in place throughout the fire tests and the panels behave just similar to homogenous timber panels exposed to ISO 834 [7] on one side. Test result has demonstrated that the measured charring rate of these timber panels has lower rate than the one-dimensional charring rate of 0.65 mm/min that assumed for solid timber according to Eurocode 5 [2]. Moreover, the thermal behavior of one component polyurethane systems can be greatly varied by modifying their chemical structure, test results that were based on 1K-PUR are therefore not valid for other polyurethane adhesives [5].

4. Simplified Calculation for X-Lam charring rate

To date, there has been limited experimental investigation into X-Lam in fire, and no published literature has been found regarding the charring rate of X-Lam panel. Based on the available fire tests on X-Lam panels [5, 10], a simplified charring model to determine the residual cross-section for X-Lam has been proposed [11]. Figure 2 illustrates the char depth vs. time plots, compared with the experimental results [5, 10], alongside the plot calculated based on the charring model according to Eurocode 5 [2]
The charring rate for the X-Lam panels studied in this investigation was calculated taken into account the subsequent fire-exposed layers, it is necessary to mathematically estimate an increased charring rate until the formation of a new 25mm thick char layer, the charring rate is suggested as below;

- 0.65 mm/min if only one layer is affected by exposure to fire;
- 1.30 mm/min for any additional layers affected by exposure to fire until charring or the formation of a 25mm thick char layer;
- a charring rate of 0.65 mm/min may be applied up to the next bonded joint.

From figure 2a it can be seen that, the best agreement between calculated and measured charring depth is observed from the fire test performed with X-Lam panel formed by two layers of 30mm panel. The effect of the increase of the charring rate can be seen from the test, the differences between calculated and measured charring depth are relatively small.

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The specimen with three layers of 20mm panel (figure 2b) showed reasonable good agreement with the calculated values for the first and second layer. It should be note that the charring rate of the first layer measured from the fire test is higher than the value of 0.65 mm/min which has been used in the calculation as according to Eurocode 5 [2]. Test result has shown that after second charred layer has fall off, there was no significant change in term of the charring rate, although the calculated values for the simplified model has conservatively assumed a charring rate of 1.30 mm/min to be used for any additional layers affected by exposure to fire until charring or the formation of a 25mm thick char layer. The calculated values for Eurocode 5 assumed a 0.65 mm/min to the third layer give non-conservative estimation.

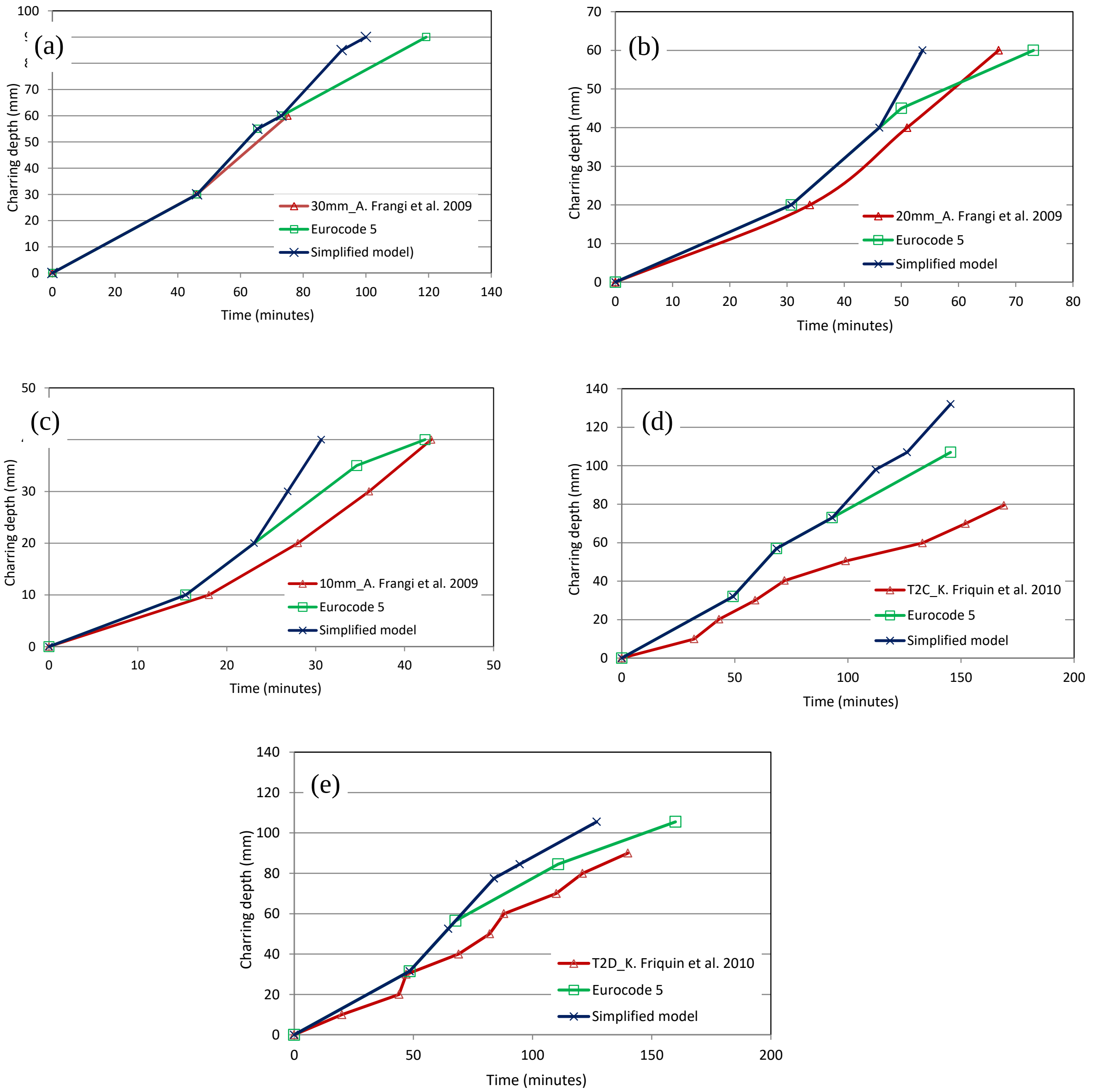

Figure 2. Charring depth for X-Lam panels [5, 10] compared with Eurocode 5 [2] and simplified model.

The effect of the increase of the charring rate can be seen from the test specimen with four layers of 10mm panel. The comparison between fire test and calculated values (figure 2c) showed that the simplified models lead to safe results. The specimen with three layers of 20mm panel showed reasonable good agreement with the calculated values for the first and second layer. Tests T2C and T2D (figure 2d and 2e) [10] were tested on X-Lam panel with different panel thicknesses. The average charring rate obtained from the test specimen T2C was 0.47 mm/min [10] which is lower than the value of 0.65 mm/min a charring rate for softwood [2] thus comparison of the test result against the simplified model does not agree. Whereas for fire test on specimen T2D, the test result shows that both the Eurocode 5 charring rate and the simplified charring models lead to safe results.

5. Conclusions

From the overview of available experimental results [3-5, 10] and comparisons made between test results and simplified models the following conclusions can be drawn:

- The thickness of a single layer of the X-Lam panel plays a significant role on the charring rate;
- The calculations of the charring depth of X-Lam panel should take into account the influence of the falling of charred layers;
- Eurocode 5 provides simplified model for homogenous timber but not overly conservative design methods for X-Lam.
- Fire behavior of X-Lam panel is being studied by using finite-element numerical approach, in order to extend and confirm the results of the experimental and simplified models performed. The studies however at the preliminary stage are still under investigation, the work will be presenting in the next stage.

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