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INVESTIGATION OF CHARRING RATE FOR SOLID MALAYSIAN TIMBER IN 2-D STANDARD FIRE EXPOSURE USING FINITE ELEMENT MODELLING APPROACH

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ABSTRACT

The study aims to examine the fire behaviour and char formation of Malaysian timber under two-dimensional (2-D) standard fire conditions through finite element simulations. Utilising Abaqus software and transient thermal analysis, a finite element model (FEM) was constructed and validated against furnace fire tests conducted on Resak timber beams. The results indicate that the charring rate of Resak timber below 0.55 mm/min, demonstrating better fire resistance compared to charring rate stated in Eurocode 5 standards. Notably, there is a close alignment between numerical and experimental findings, with only a 3% variance observed. Using finite element analysis to investigate the charring rate could be a cost-effective technique in studying Malaysian tropical timbers under varied fire loading conditions.

Keyword: charring rate, FEM, Malaysian tropical timber, heat transfer.

1. INTRODUCTION

Timber is an important building material due to its structural adaptability, aesthetic appeal, and sustainability. When exposed to fire, timber goes through a combustion process that results in the formation of a char layer. This char layer acts as a protective barrier for the timber against further damage. Therefore, charring rate values are an important parameter to be considered when designing the timber structures for building construction. Currently, there is little data on the charring rate available for Malaysian tropical timber in MS 544 Part 9, which only offers the design charring rate value for solid timber based on the different strength groups (SG) from SG 1 to SG 5, rather than exactly according to timber density [1]. Finite element method (FEM) analysis developed by computer software provides a reliable method for determining charring rates in solid timber under standard fire exposure conditions. FEM provides the thermal degradation process by simulating the fire behaviour as well as the charring depth predictions. Špilák et al. (2022) highlighted the significance of medium-scale fire tests and FEM in investigating the charred layer of structural elements, achieving an average simulation accuracy of 93.0% in defining the total charred area [2]. In fact, Werther et al. (2012) conducted a comprehensive investigation into heat transfer modelling in wood using multiple finite element software packages, adding depth to the body of research on timber behaviour under fire conditions[3]. Research on the finite element model built with Abaqus software for determining the charring rate of Malaysian tropical timber has not yet been adequately discovered. Therefore, the numerical model finite element was developed in order to obtain the temperature distribution and followed by the charring rate analyses of the solid timber subjected to standard fire exposures.

2. METHODOLOGY

The fire tests were conducted at the Forest Research Institute Malaysia (FRIM) laboratory, adhering to BS476 standards [4]. Resak timber beams of specified dimensions were exposed to a three-sided fire for 60 minutes in a furnace equipped with thermocouples to monitor temperature changes. The charring rate was determined based on the onset of charring, using the accepted 300ºC isotherm defined in EN 13381-7:2002[5]. Simultaneously, the study employed the development of a finite element model (FEM) with thermal properties and geometry following the furnace fire test. The FEM analysis began with the establishment of the heat transfer step. The thermal conductivity and specific heat properties were assigned to the timber materials according to EC5 standards [6]. Transient thermal analysis was utilised for finite element model development, with the simulation time period set at 3600 seconds equal to the fire test duration. Since the thermal properties of most materials such as thermal conductivity and specific heat or density vary with temperature, the analysis is, typically, nonlinear. The boundary conditions for convection and surface radiation were specified with coefficients of 25 W/m^2K and surface emissivity of 0.8 respectively. With the input data on the material properties, the model utilised the eight-node linear solid elements type DC3D8 which were available in the Abaqus library. The model parameters were adjusted based on the furnace temperature to simulate the heat transfer dynamics within the timber beam subjected to fire exposure. The output from the simulation included the images of beam sections, which were used to determine the area of the charred layer.

3. FINDINGS

The findings of the study, as in Figure 1, illustrate a significant correlation between numerical simulations and experimental observations for the 60-minute fire exposure. It can be seen that as the temperature increases, the graph of the temperature versus time changes, especially for the graph at 6mm, 12mm and 18mm char depth. Initially, temperature rises slowly and evenly. Subsequently, it rises faster. The FEM model can accurately predict the temperature field distribution of the timber section in the experiments, with a 3% difference as shown in Table 1. The results indicate a charring rate of Resak timber below 0.55 mm/min, demonstrating better fire resistance compared to charring rate stated in EC 5 standards. Figure 2 displays the development of char in two-dimensional fire exposure. It is observable that charring starts at the corner due to the heating from the three sides. Charred wood is represented by the colour grey, the charred front at the 300 °C isotherm by the colour red, pyrolysis wood at temperatures below the 300 °C isotherm by the colour yellow and green, and wood at ambient temperature is represented by the colour blue. It reveals that the formation of charred layers in the cross section increases as the fire exposure time increases. Using finite element analysis to investigate the charring rate could be a cost-efficient technique in studying Malaysian tropical timbers under varied fire loading conditions.

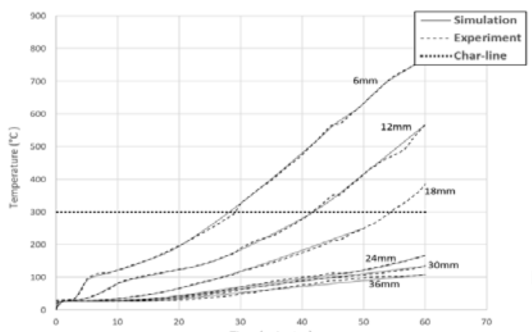
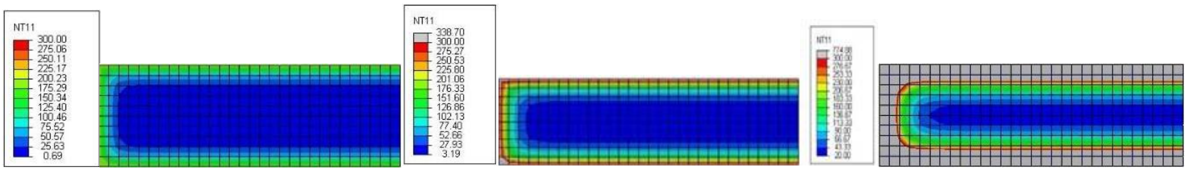


Figure 1 Comparison of the numerical simulation and experimental temperatures profiles of the Resak timber



a) Time=0 minit b) Time =30 minutes C) Time =60 minutes

Figure 2 Formation of charring layer at different fire exposure time for Resak timber

Table 1 Two-Dimensional Charring Rate

	Density (kg/m^3)	Charring Rate (mm/min)
Resak (Model)	932	0.38
Resak (Fire Test)	932	0.39
Eurocode 5	>450	0.55
BS5268	>640	0.55

4. CONCLUSION

In conclusion, this study utilised finite element analysis to assess the charred layer of a solid wood Resak beam subjected to two-dimensional fires, employing transient thermal analysis for simulations. The modelling results closely illustrated the results of fire testing, demonstrating a mere 3% variance between the finite element method (FEM) and experimental results. This validates the developed FEM model, indicating its suitability for subsequent investigations. Further works on the model development can be conducted with different timber density of Malaysian tropical timber and different types of wood-based materials.

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