# FIRE PERFORMANCE OF TIMBER DOOR FRAMES

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**GAN KS, KHAIRUL AZMI J, ZAIRUL AMIN R, PANG SK, TAN YE, LAU LH, MOHD ADAWI TO & ZAIHAN J. 2013. Fire performance of timber door frames.** Currently, only solid timber door frames of balau, keranji and chengal are used in fire-rated doorsets. This study evaluated if finger-jointed and laminated timber, as well as other heavy timbers could be used. The fire performance of door frames made of balau, keranji, red balau, kekatong and kempas were investigated. Four profiles of door frames were made: solid wood; finger-jointed; finger-jointed + face-wise laminated and finger-jointed + edge-wise laminated. The fire performance tests were conducted using a 3 m × 3 m gas furnace in accordance to MS 1073. Only door frames were evaluated and a standard panel was installed in place of the door leaf. For balau, red balau, kekatong and kempas, there was no significant difference in the fire performance of the different door frames. However, for keranji, the fire performance for solid door frame was significantly lower than finger-jointed + edge-wise laminated and finger-jointed frames. The results indicated that finger-jointed + laminated and finger-jointed door frames performed equally well or better than the solid frames.

Keywords: Finger-joint, laminate, door jambs, fire-rated doorset

**GAN KS, KHAIRUL AZMI J, ZAIRUL AMIN R, PANG SK, TAN YE, LAU LH, MOHD ADAWI TO & ZAIHAN J. 2013. Prestasi rintangan api kerangka pintu kayu.** Kini, hanya kerangka pintu yang dibuat daripada kayu padu balau, keranji dan chengal digunakan dalam sistem pintu rintangan api. Kajian ini menilai sama ada kayu sambungan jejari dan laminasi serta kayu keras berat yang lain boleh digunakan. Prestasi rintangan api bagi kerangka pintu daripada kayu balau, keranji, balau merah, kekatong dan kempas dikaji. Empat profil kerangka pintu dihasilkan: kayu padu, kayu sambungan jejari, kayu sambungan jejari + laminasi pada muka lebar dan kayu sambungan jejari + laminasi pada muka sisi. Ujian rintangan api dijalankan menggunakan relau gas bersaiz 3 m × 3 m berdasarkan MS 1073. Hanya kerangka pintu dinilai dan satu panel piawai dipasang menggantikan pintu. Bagi kayu balau, balau merah, kekatong dan kempas, tiada perbezaan ketara diperhatikan dalam prestasi rintangan api pelbagai kerangka pintu. Bagaimanapun, untuk keranji, rintangan api kerangka kayu padu adalah lebih rendah daripada kerangka kayu sambungan jejari + laminasi pada muka sisi serta sambungan jejari. Keputusan menunjukkan bahawa kerangka sambungan jejari + laminasi dan sambungan jejari menunjukkan prestasi yang sama atau lebih baik daripada kerangka kayu padu.

## INTRODUCTION

Fire-rated doors are normally supplied as a whole door system, i.e. door frame and leaf together with all door accessories. In Malaysia, the approving authority requires the complete door system to pass the fire performance test conducted according to MS 1073 (MS 1996) before it is allowed to be used in buildings. It is common practice that only a few selected timber groups/species are used for door frames, i.e. chengal, balau and keranji. Incidentally, there are 22 timber groups with average densities above 750 kg $m^{-3}$ that are recommended for fire-rated door manufacturing, both for door leaf and frame (Abdul Rashid 1987). The actual densities for some of these timbers range from about 600 to above 1200 kg $m^{-3}$. Due to natural density variations, heavier timbers with densities above 750 kg $m^{-3}$ are used.

Even though timber is classified as combustible, a properly designed timber building component can be considered as performing very well in fire. The heavy timber construction member has good inherent fire resistance because a char layer is formed which retards heat penetration.

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Thus, besides timber groups/species and density, charring rate of timber may be used as a guide for timber selection and design of construction members suitable for fire-rated use. Some Malaysian timbers have been reported as having charring rates between 0.525 and 0.600 mm min$^{-1}$ (Abdul Rashid 1987). There is generally an inverse relationship between charring rate and wood density (Hall 1982). For the denser heavy hardwood, a charring rate of 0.50 mm min$^{-1}$ may be used as opposed to 0.64 mm min$^{-1}$ for softwood.

Due to factors such as species or timber group, density, charring rate, design, size or dimension, installation and workmanship, and accessories influencing the fire performance of fire door system, it is common practice to use only solid wood of chengal, balau and keranji for the door frame. This helps the manufacturer to conduct further improvements on the design, material uses and fabrication of the door leaf should the fire performance test of a doorset fail. Finger-jointed and laminated door frames are hardly used. The lack of interest among manufacturers to use finger-jointed/laminated door frames is due to concerns over the development and testing costs involved in trying out various types of door frames.

Timber resources from natural forest are declining and the cost of solid timber of big dimension is increasing (Anonymous 2012). The supply of quality material for door frame manufacture is affected. Finger-jointing and lamination technologies may be used to recover shorter lengths and smaller dimensions timber. Finger-jointed and laminated timbers have been used in building constructions and have demonstrated the ability to withstand fire. The charring property of thick structural members proved to be an advantage over metal during fire. This study was designed to demonstrate the performance of finger-jointed and laminated door frame of various profiles compared with solid timber door frames. The objective of this study was to provide quantitative support for the use of finger-jointing and lamination technologies in fire-rated door frames.

## MATERIALS AND METHODS

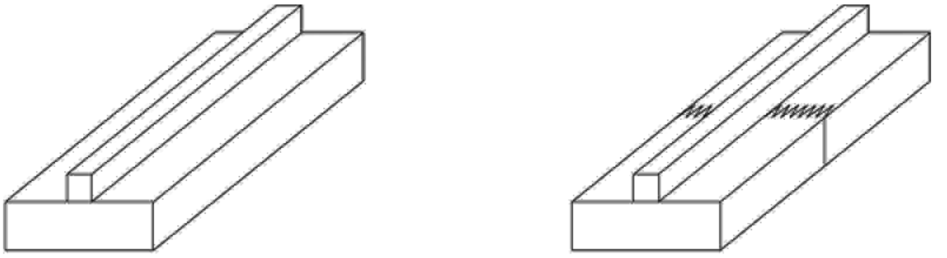
Sawn timber of balau, red balau (seraya ketam), keranji, kekatong and kempas were purchased from local sawmills. Balau, red balau and keranji were kiln dried according to the drying schedule of Gan (2011) to target moisture content of 12 ± 2% as required for gluing. Kekatong and kempas were dried using the radio-frequency vacuum dryer to the target moisture content. Four types of door jamb profiles were prepared: solid, finger-jointed, finger-jointed + face-wise lamination and finger-jointed + edge-wise lamination (Figure 1). For all types of door jambs, solid timber strips or stopper were glued onto the grooved door jambs (Figure 2).

The glue used for finger-jointing was phenol resorcinol formaldehyde while for lamination, resorcinol formaldehyde. The glues were purchased and used in accordance to the manufacturer's recommendation for hardwood. The mixing ratio for hardener and resin used in the finger-jointing process was 100:15 by weight while the specific pressure and pressing time were 150 kg cm$^{-2}$ and 20 s respectively. For the lamination process, the mixing ratio was 100:25 by weight while the specific pressure and pressing time were 15 kg cm$^{-2}$ and 4 hours respectively. Glue spread for the lamination was 315 g m$^{-2}$.

The final profile of door jamb was the double rebate type which is commonly used in the industry. The dimensions are as shown in Figure 2. Intumescent strips of 4 mm × 20 mm were used.

In place of the door leaf, two pieces of 19 mm magnesium oxide boards were glued together to form a standard blank for all fire performance tests. No door accessory was used. The magnesium oxide boards were held in place using wooden wedge for the door leaf opening-out and metal jigs for the door leaf opening-in. A piece of 3 mm plywood was used to enhance rigidity of the magnesium oxide board on the unexposed face of the installation (Figure 3). A gap of 3 mm between the magnesium oxide boards and door frame was maintained as in the actual doorset.

Basic densities of the timbers were measured in accordance to ISO 3131 (ISO 1975). For fire performance test, a set of three trials were conducted on each door jamb type per timber group. Fire performance tests were conducted in accordance to MS 1073 (MS 1996) at the Forest Research Institute Malaysia. For each test, two sets of door frames were mounted on the test jig with masonry wall. One doorset was opening-in and another opening-out of the furnace measuring 3 m × 3 m. (Figure 3). The temperature sensors

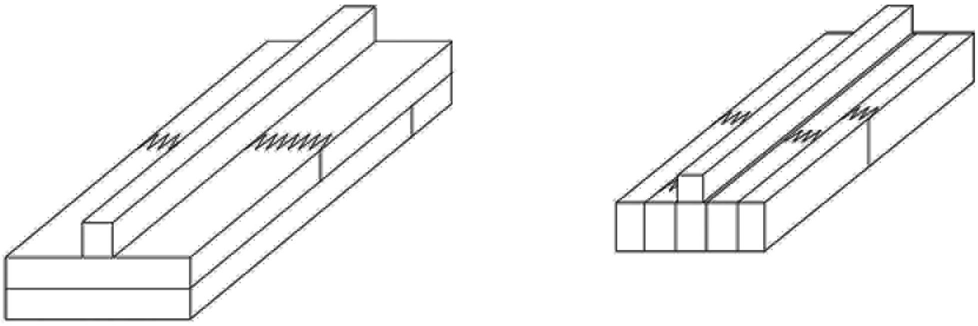


Type 1 - Solid

Solid door jamb and glue-on stopper

Type 2 - Finger joint

Finger joint for the jamb and stopper as in solid



Type 3 - Finger joint + Laminate face-wise

Two planks laminated for the jamb and stopper as in solid

Type 4 - Finger joint + Laminate edge-wise

Five strips laminated for the jamb and stopper as in solid

**Figure 1** Types (1, 2, 3 and 4) of door jamb profiles

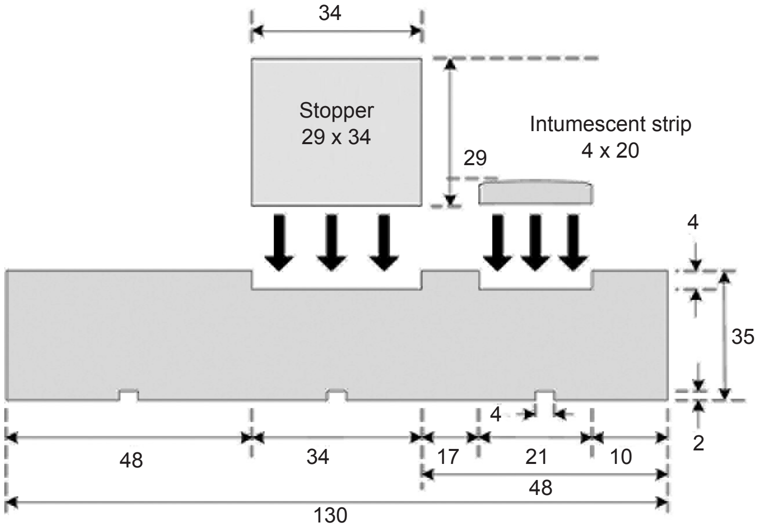


**Figure 2** Dimensions (mm) of the door frame profile

for insulation performances were mounted as per standard requirement. Ambient temperature in the general vicinity of the test site was 25 to 35 °C just before heating. The door frames mounted on the test jig were exposed to fire following the temperature–time relationship as specified in the standard. Six thermocouple probes measured and controlled the gas burner to conform to the following temperature–time relationship:

$$T = 345 \log(8t + 1) + T_0$$

where

$T$ = furnace temperature at time $t$ (°C)
$t$ = time of test (min)
$T_0$ = ambient temperature (°C)

Throughout the test, the pressure in the furnace was maintained at 8 to 12 Pa, higher than the pressure within the laboratory. The

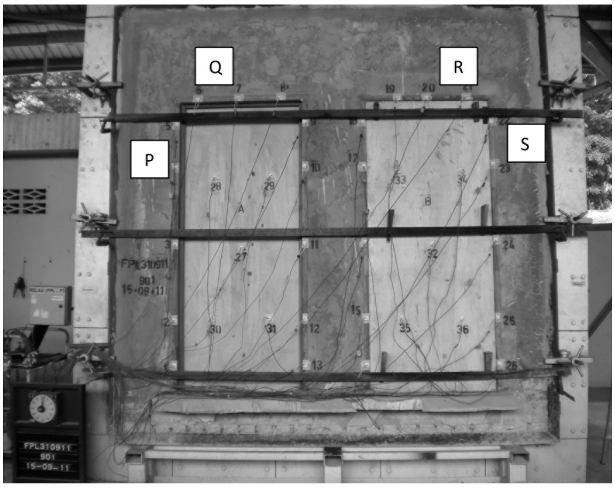


**Figure 3** Set up of test samples at the furnace with all temperature sensors in place

temperature sensors (thermocouple type K) mounted on the door frames and panel (door leaf) continuously measured the temperatures on the unexposed face. During test, observations were made on the general behaviour of the test door frames and panel on the exposed and unexposed faces. The door frames were tested on their ability to comply with the integrity and insulation criteria. The time to first failure of either criterion was noted for each test.

### Performance criteria

Insulation is the ability to prevent excessive increase in temperature. Failure occurs when the mean temperature of the unexposed face increases by more than 140 °C above the initial value or if the temperature recorded at any position on the unexposed face is in excess of 180 °C above the initial mean unexposed face temperature.

Integrity is the ability to resist development of holes, cracks, fissures or penetration of flame. Failure occurs when the test object collapses or sustains flaming for more than 10 s on the unexposed face.

### Data analysis

The mean time to failure for each timber group and fabrication type was calculated. Two-way analysis of variance and Tukey's test were conducted to determine the effects of timber group and fabrication type.

## RESULTS AND DISCUSSION

### Wood density

The basic density of timber used in this study and adjusted density to moisture content 16% are shown in Table 1. The adjusted densities of all the timber groups were within the ranges for the respective timber groups reported by Gan and Lim (2004). All timber samples had densities above 750 kg $m^{-3}$ as recommended by Abdul Rashid (1987) for fire-rated doorset applications. If wood density is to be a guide for fire performance property, then the order of decreasing performance will be kekatong, kempas, balau, keranji and red balau.

### Fire performance

The time to first failure due either to integrity or insulation was taken as the result of each fire test. All samples failed due to integrity failure. Individually, all samples failed after 60 min for the 1-hour fire rating (Table 2) except for two tests on Type 1 profile of kekatong (result not shown).

There was no significant difference between profile types for each timber group except for keranji (Table 2). The mean for Type 1 (solid timber) door frame was significantly lower than Types 2 and 4. Failure was due to deformation or twisting of the solid door jamb that affected the overall door frame. The stability of the door frame seemed to have been enhanced with finger-jointing and lamination. There was significant difference between timber groups for Types 1 and 2 door frames. However, effects of timber group were not significant for Types 3 and 4 door frames.

The furnace temperature with time and the corresponding typical surface temperatures on the door frame at two corners: one each for the opening-in (P and Q in Figure 3) and opening-out (R and S) doors are given in Figure 4. The surface temperatures at the corner of the door frame of opening-in door were generally lower than those at the corner for the opening-out door frame. However, all four temperatures were lower than 100 °C at the time of failure and the furnace temperature at that time was more than 1000 °C. None of the tests failed due to insulation.

**Table 1** Densities of timber used for making door frames

| Timber group | Basic density[a] (kg m$^{-3}$) | Mean density adjusted to air-dry (moisture content 16%) condition (kg m$^{-3}$) | Air-dry density range[b] (kg m$^{-3}$) |
|---|---|---|---|
| Balau | 766 ± 22 | 889 | 880–1040 |
| Red balau | 704 ± 13 | 817 | 800–880 |
| Keranji | 761 ± 16 | 883 | 755–1250 |
| Kekatong | 826 ± 28 | 958 | 880–1155 |
| Kempas | 818 ± 38 | 949 | 770–1120 |

[a] Basic density at 95% confidence level; [b] Gan & Lim (2004)

**Table 2** Mean results (± standard deviations) of time to first failure (min) for fire performance tests of various types of door jamb profiles

| Timber group | Door jamb profile | | | |
|---|---|---|---|---|
| | Type 1 | Type 2 | Type 3 | Type 4 |
| Balau | 88 ± 13 aA | 98 ± 5 aA | 85 ± 10 aA | 88 ± 7 aA |
| Red balau | 88 ± 11 aA | 93 ± 8 aA | 87 ± 6 aA | 83 ± 4 aA |
| Keranji | 69 ± 6 aAB | 93 ± 10 bA | 77 ± 11 abA | 92 ± 5 bA |
| Kekatong | 60 ± 7 aB | 65 ± 2 aB | 70 ± 9 aA | 70 ± 15 aA |
| Kempas | 68 ± 8 aAB | 70 ± 5 aB | 68 ± 10 aA | 74 ± 7 aA |

Values with the same lower-case alphabet within the same row denote no significant difference at 95% confidence level, values with the same upper-case alphabet within the same column denote no significant difference at 95% confidence level; Type 1 = solid, Type 2 = finger-jointed, Type 3 = finger-jointed + laminated face-wise, Type 4 = finger-jointed + laminated edge-wise; values are means of three tests

Figure 5 shows the normal distribution curves of the fire performance results of the timber groups tested for the different door jamb profiles. For randomly selected sample of balau and red balau, there was less than 1% risk of fire performance failure that could be attributed to the door frame for the 1-hour rating. However, for the Type 1 (solid wood) door jamb of kekatong, there was 50% risk of failure for the 1-hour rating. Door jambs that were finger-jointed with or without lamination did not reduce the fire performance compared with solid door jamb, but seemed to enhance the overall performance. The bell curves of finger-jointed and laminated door jambs moving to the right of the graphs indicated that their fire performances were better.

Although it is not the main objective of this paper, it is interesting to examine the influence of density which is considered by many researchers as the main factor affecting fire resistance and charring rate. The correlation between fire performance of solid wood door frame (T1) and wood density was not very strong, $r^2 = 0.64$ (Figure 6) and on a reducing trend. Kempas and kekatong had almost similar adjusted density above 900 kg m$^{-3}$ but their fire performances were lower than those of balau, red balau and keranji. This may indicate that besides density, other characteristics may influence fire resistance. Charring rates are reported to reduce with increasing density (Njankouo et al. 2004, Cachim & Franssen 2010, Hugi & Weber 2010). However, when charring rates of only timbers with densities above 750 kg m$^{-3}$ are observed, the inverse relationship of charring rate with density may not be true. This was demonstrated in the present paper and that of Cachim and Franssen (2010). The denser heavy density timbers may not necessarily perform better in fire. This concurred with the finding of Lipinskas and Maciulaitis (2005) who found that the influence of wood density on charring rate, and thus fire resistant, was inconsistent and contradictory. The use of density alone to assess

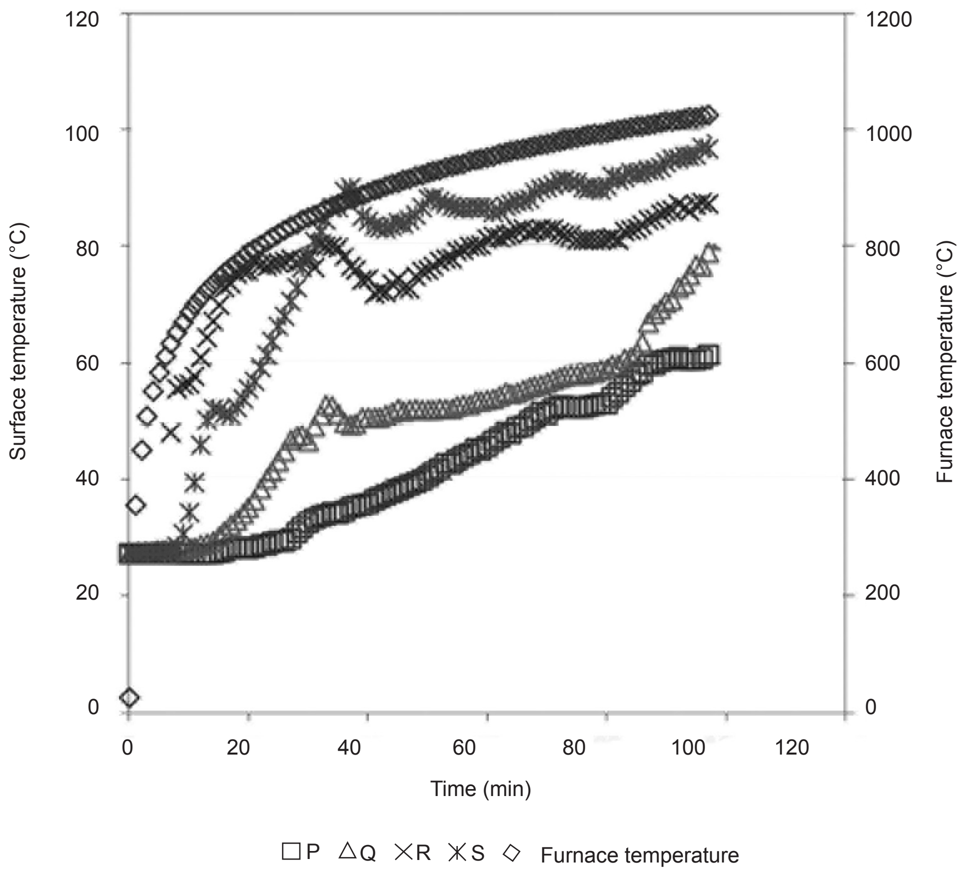


**Figure 4** Furnace and surface temperatures on the door frame at positions P, Q, R and S at the unexposed face as indicated in Figure 3 against time for test on Type 2 for balau

alternative timber for fire resistant door system is not reliable (Hugi & Weber 2010).

## CONCLUSIONS

Besides the commonly used chengal, balau and keranji timber, red balau, kekatong and kempas could be used for making fire-rated door frames without affecting the fire performance of a door system. Finger-jointing with or without lamination according to the profiles tested in this study did not affect the fire performance of the door frame. In some instances, it enhanced the fire performance compared with that of solid timber door frame.

## ACKNOWLEDGEMENTS

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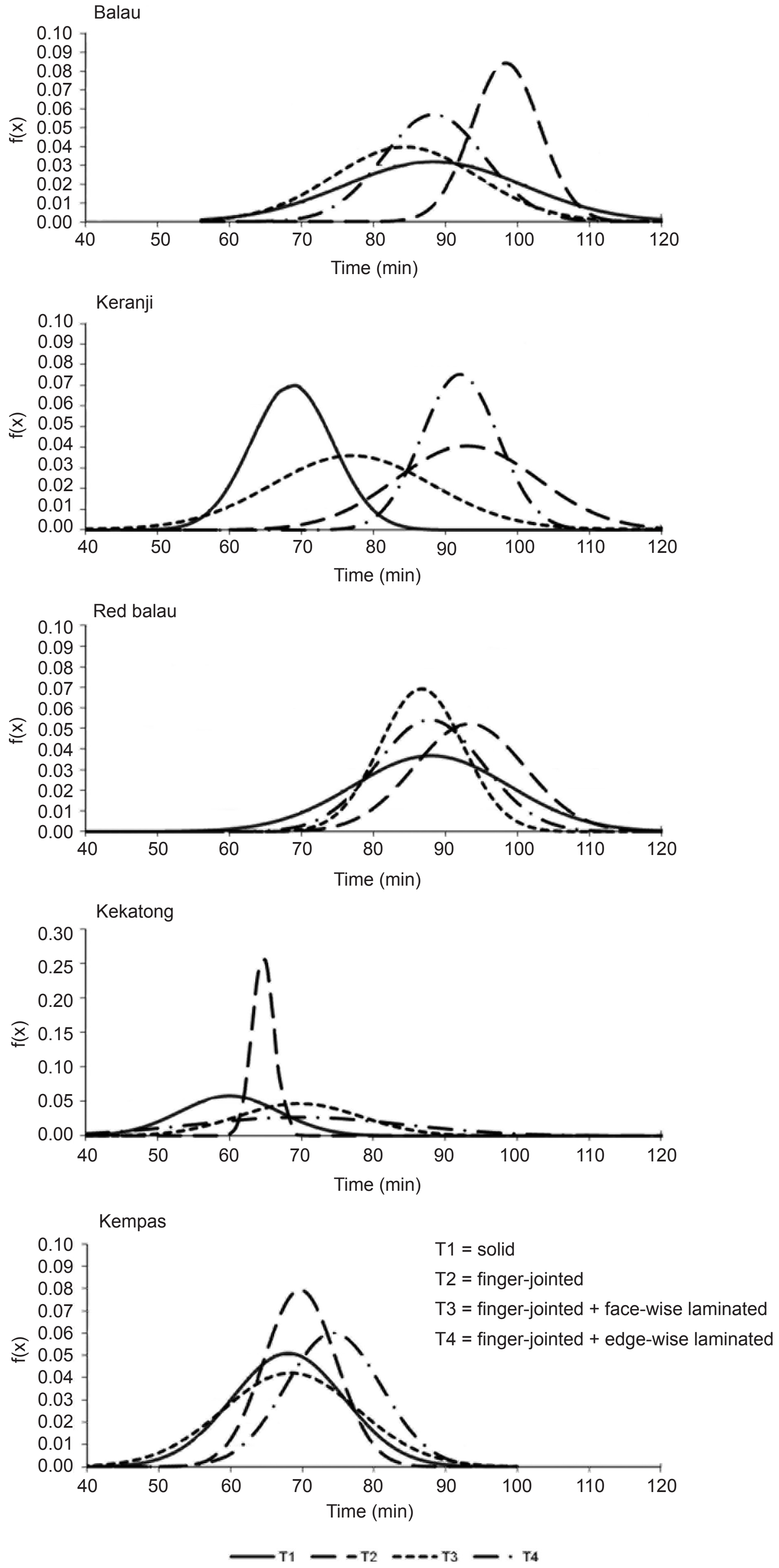

**Figure 5** Normal distributions of the fire performance of different door jamb profiles by timber groups; f(x) = probability

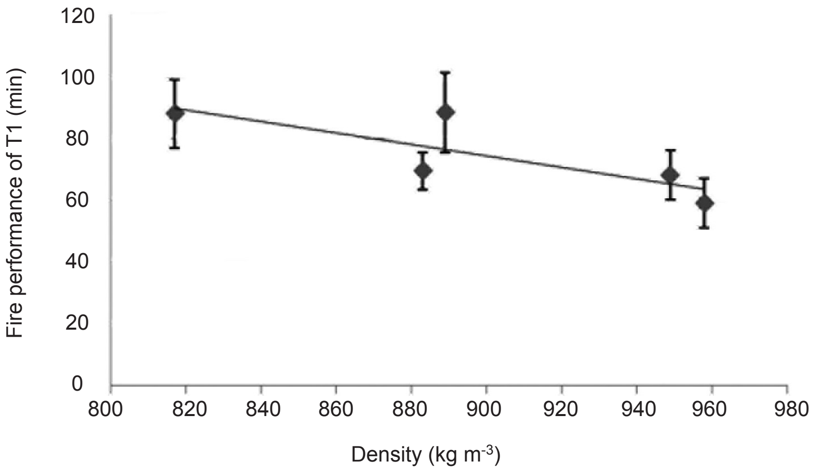

**Figure 6** Relationship between wood air-dry density and fire performance results of solid door jambs (T1)

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