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Abstract

Colour of wood changes both during natural aging and during heat treatment. Colour measuring, which is non-destructive and requires only a small area, might be an useful tool as an aging or deterioration index. Exact modelling of colour changes is important not only to predict deterioration but also to understand the aging and deterioration mechanism of wood. This study deals with the modelling of colour changes that occur both during natural aging and during heat treatment by using kinetic analysis. For better understanding of the process of colour change, we employed multi-process kinetic analysis.
Hinoki (*Chamaecyparis obtusa* Endl.), which is a typical species used for historical buildings and Buddhist sculptures in Japan, was used. Naturally aged wood specimens were prepared from the members of historical buildings built in from 7th century to 15th century. Namely, the aging time ranged from approximately 550 years to 1600 years [1][3]. The specimens for heat treatment were prepared from the wood harvested in 1988. Completely-dried specimens were treated at 90°C, 120°C, 150°C, and 180 °C. The treatment duration ranged from 0.5 hours to approximately 2 years [2]. The colour of the specimens was measured with a spectrophotometer (KONICA MINOLTA CM-2600d) and was expressed by CIELAB colour parameters (L^*, a^*, and b^*). Figure 1 shows the examples of the colour change during natural aging and heat treatment.

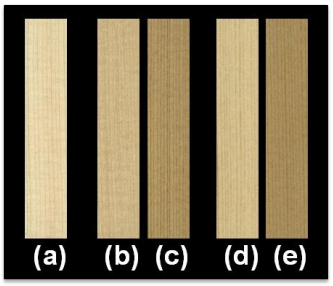

Figure 1: Colour change of hinoki wood during natural aging and during heat treatment. (a) wood harvested in 1998 as a control, (b) aged in the ambient condition for 750 years; (c) for 1600 years, (d) treated at 180°C for 2 hours; (e) for 12 hours.

When modelling colour changes induced by natural aging and heat treatment, we assumed that the change of a colour parameter x can be decomposed as

$$x = x_0 + x_1 + \ldots + x_N \quad (1)$$

where x_0 represents the initial colour value before natural aging or heat treatment, x_k (k>0) are variation of x related to independent chemical or physical processes. Each x_k starts from 0 in the initial state and approaches a limiting value X_k following a first-order kinetic;

$$x_k(t) = X_k[1 - \exp(-t/a_T)] \quad (k = 1 .. N) \qquad (2)$$

where t is aging or treatment time and a_T is a time-temperature dependent shift factor at the aging or treatment temperature T. We chose N = 3 on a trial basis because the trend of colour changes indicated that at least 3 processes of the reactions occurred; i.e. the change of a colour parameter x can be expressed as follows:

$$x(t) = X_1[1 - \exp(-t/a_T)] + X_2[1 - \exp(-t/a_T)] + X_3[1 - \exp(-t/a_T)] \,. \qquad (3)$$

The apparent activation energies for each process were calculated.

The models calculated well fitted with the measured colour changes in all colour parameters, L^*, a^*, and b^*. The modelled and measured value of L^* is shown in Fig. 3 as an example. The calculated activation energies for the first, second, and third process were 130, 109, and 135 kJ/mol, respectively. The successful modelling and the calculated kinetic parameters will bring important information about the behaviour of colour during aging and heat treatment.

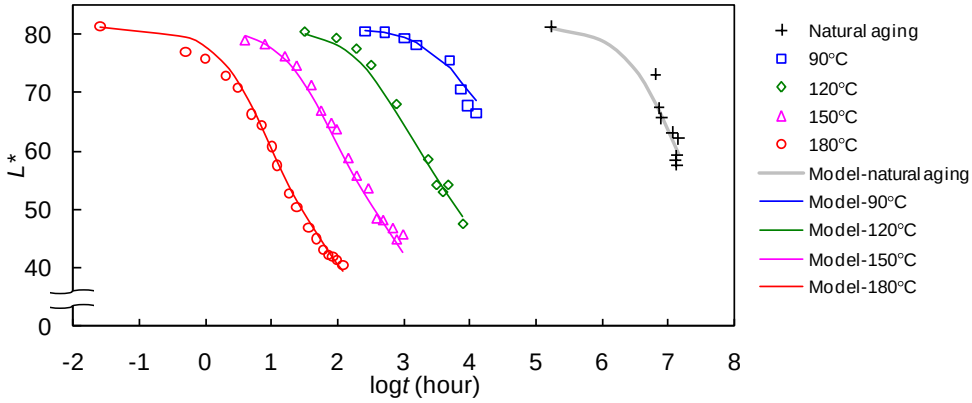

Figure 2:Measured colour value L^* of natural aging wood and heat treated wood and the models produced by kinetic analysis considering 3 first-order processes.

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