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► **To cite this version:**

Lucas Terrei, Giacomo Erez, Boris Aguilar, Zoubir Acem, Suzanne Mathieu, et al.. Char depth of several wood species under single or double heat exposures. ESFSS, Oct 2024, Barcelona, France. Journal of Physics Conference Series (JPCS). hal-04767996

**HAL Id: hal-04767996**

**<https://hal.science/hal-04767996v1>**

Submitted on 5 Nov 2024

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# Char depth of several wood species under single or double heat exposures

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## Context and Objectives

Fire investigation is a complex field due to the destructive nature of a fire, which erases most of the evidences and leaves investigators with only traces on the remaining materials, which can vary greatly **depending on a number of parameters**. Investigations are mainly based on observations or direct measurements of degraded or decomposed materials, such as the char depth of wood. The latter is highly dependent on the wood species and the fire conditions. The most commonly used data for investigation is the char layer thickness, but two other measurements can provide additional data, namely the remaining wood and the char that has burned and thus **disappeared due to the char oxidation**.

**There are few studies focusing on char depth with variable heat fluxes**. In this context, a study using cone calorimeters was performed to investigate char formation and combustion for a large number of wood species under different conditions, **including two successive controlled heat fluxes**.

## Wood samples

Eight wood species were studied. These cover a very wide range of densities, from 327 to 1100 kg.m<sup>-3</sup>. Ipe, oak, beech and poplar are hardwoods whereas larch and spruce are softwoods. All sample sizes were 10 × 10 × 5 cm<sup>3</sup> and had a moisture content close to 10 %. A total of **582 samples** from LEMTA and **201** from LCPP were initially used in this study. Table 1 shows the number of samples and the density of each species.

Table 1. Number and density of the eight wood species.

	Poplar	Spruce	Fir	Larch	Particleboard	Oak	Beech	Ipe
Number of samples	170	26	51	135	44	169	130	58
Means densities (±std kg.m <sup>-3</sup> )	355±15	471±52	500	652±63	660	707±81	710±81	950±35

## Experimental setup

At LEMTA, wood samples were tested using a double cone heater in vertical orientation, without pilot and were exposed to incident heat fluxes from 15 to 85 kW.m<sup>-2</sup>. The test set-up allowed the wood to be exposed to one or two incident heat fluxes for prescribed times. Fig. 1. shows the experimental setup of the double cone calorimeter on its sliding system.

At LCPP, wood samples were exposed to a conventional cone calorimeter (single heating element) in horizontal orientation, with a pilot and for incident fluxes between 20 and 80 kW.m<sup>-2</sup>, for 3 to 45 min.

With these experimental devices, the samples could be subjected to different conditions:

- **A single heat flux** for a prescribed time, in a vertical configuration without a pilot or in a horizontal configuration with a pilot. In this condition the second heating cone of the LEMTA was not used.
- **Two heat fluxes** using the LEMTA device, the first heat flux causing auto-ignition (55, 75 or 85 kW.m<sup>-2</sup>) for a given time (6, 9, 15 or 18 min) and a second lower heat flux for 5 min.

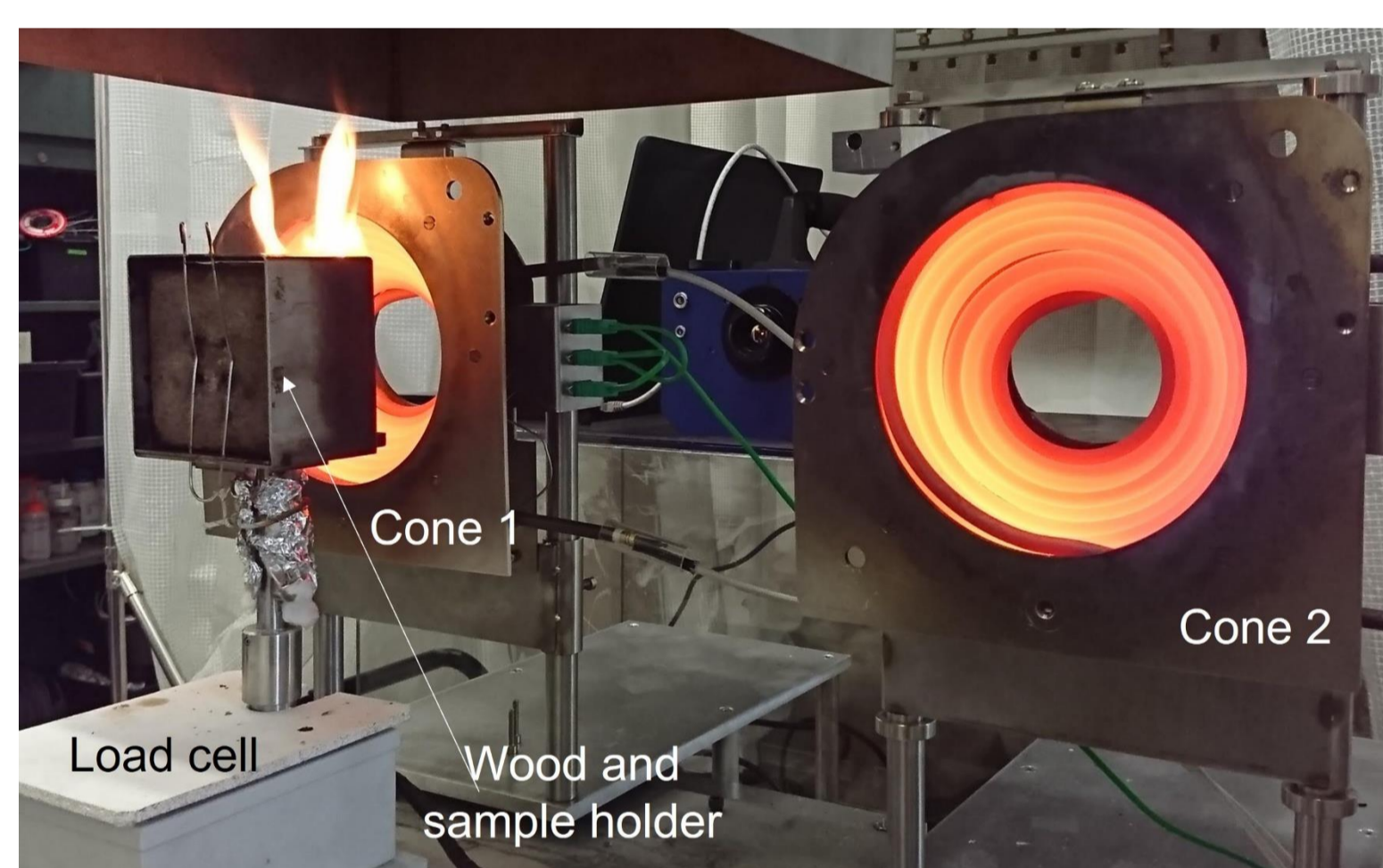


Fig. 1. Double sliding cone heater.

The concept of **cumulative exposure (CE ; MJ.m<sup>-2</sup>)** is introduced in order to characterise the wood degradation based on the energy received:

$$CE = \int_0^{\tau} \dot{q}(t)'' dt$$

$\dot{q}(t)''$  (kW.m<sup>-2</sup>) is the incident heat flux and  $\tau$  the exposure time (s)

## Char measurement

The sample was cut in half and measurements were taken **in the centre of the sample** (Fig. 2.). The char and remaining wood thicknesses can depend on the location, but due to the very large number of samples measurements were only performed in the middle, using a caliper gauge. These measurements were then used in conjunction with the original sample thickness to deduce the char regression.

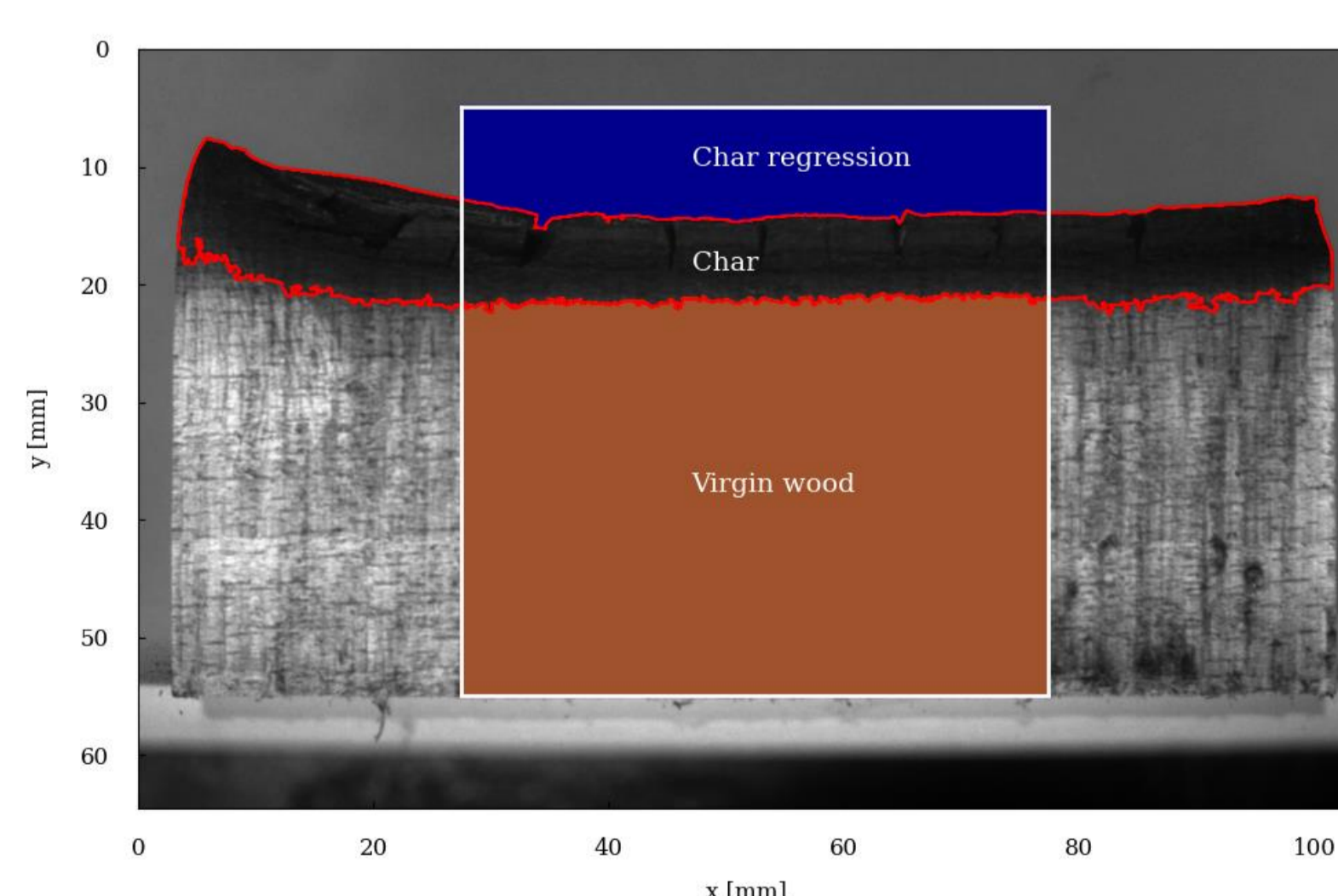


Fig. 2. Cross-section of a wood sample.

In accordance with most of the literature, the combination of char regression and char layer (i.e. missing and remaining char) is referred to as char depth. Outliers were removed from the analysis by detecting, over the entire dataset, char layer, virgin wood or char depth measurements that were more than 1.57 times the interquartile range of the entire dataset. These points may be due to problems during the experiments, or simply some extreme experimental conditions that were less replicated than others.

## Results

Fig. 3. gives an example of the thicknesses of the remaining char layer, virgin wood and missing char for several wood species as a function of the heat fluxes for 40 min. Each point represents one test.

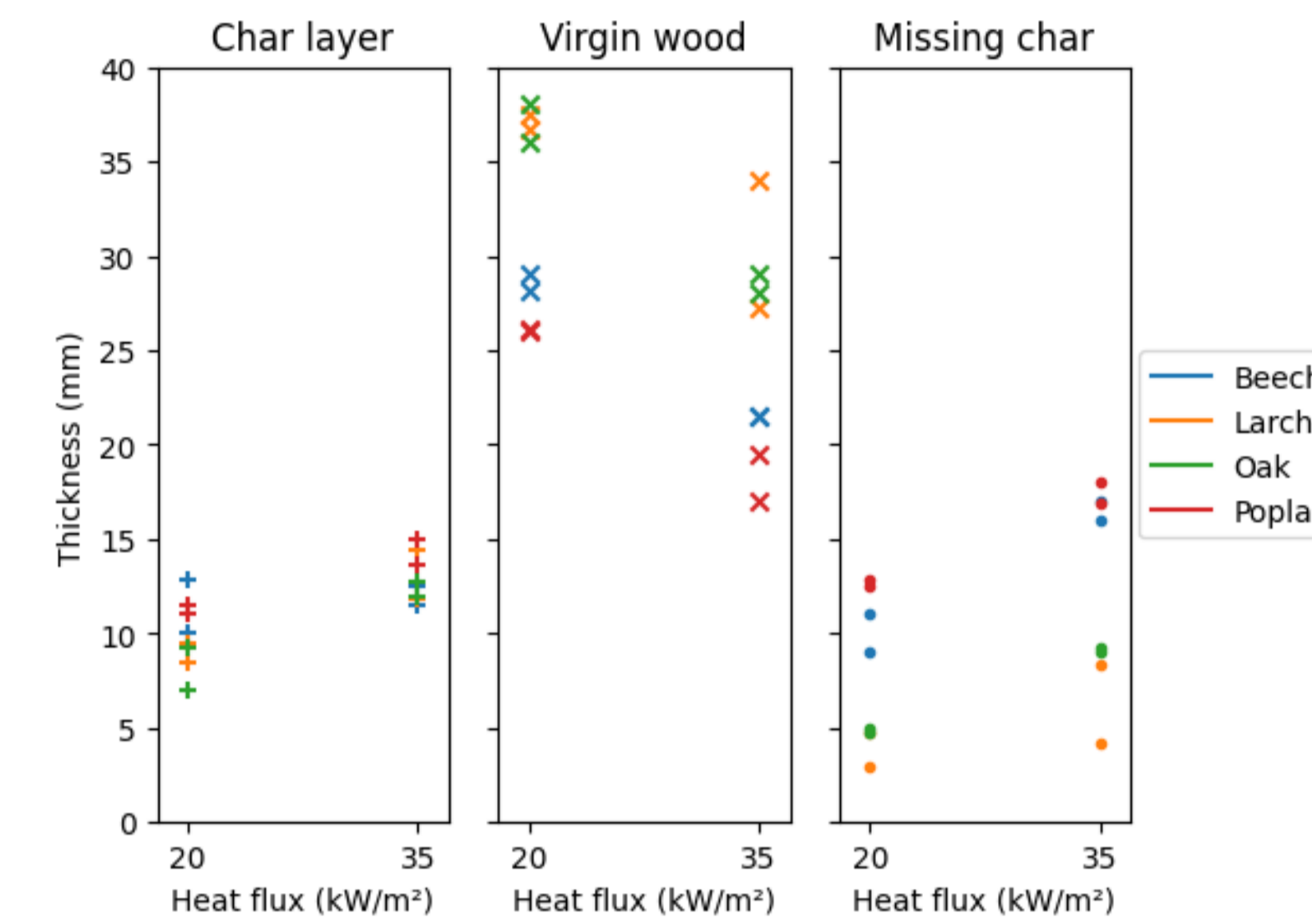


Fig. 3. represents only one exposure time for two imposed heat fluxes. **It becomes difficult to show clear correlations** when time is added as a variable, and even more difficult when heat fluxes and times are varied during a test.

The char depth measured after a single (red and green marks) or a double exposure (blue marks) are well represented by the CE. Moreover, the trends are well described by a fit based on a previous work, i.e. **char depth = a√(CE - CE<sub>crit</sub>)**, inspired by the relationship between the propagation time of a thermal disturbance and the characteristic depth of propagation in the transient regime. CE<sub>crit</sub> is the value below which there is no charring. In particular, the Fourier number relates this time to the square of the characteristic diffusion length. Since the time is the integration variable used to obtain the CE, it seems quite natural that the char thickness associated with the depth of the 300 °C isotherm should be related to the square root of CE.

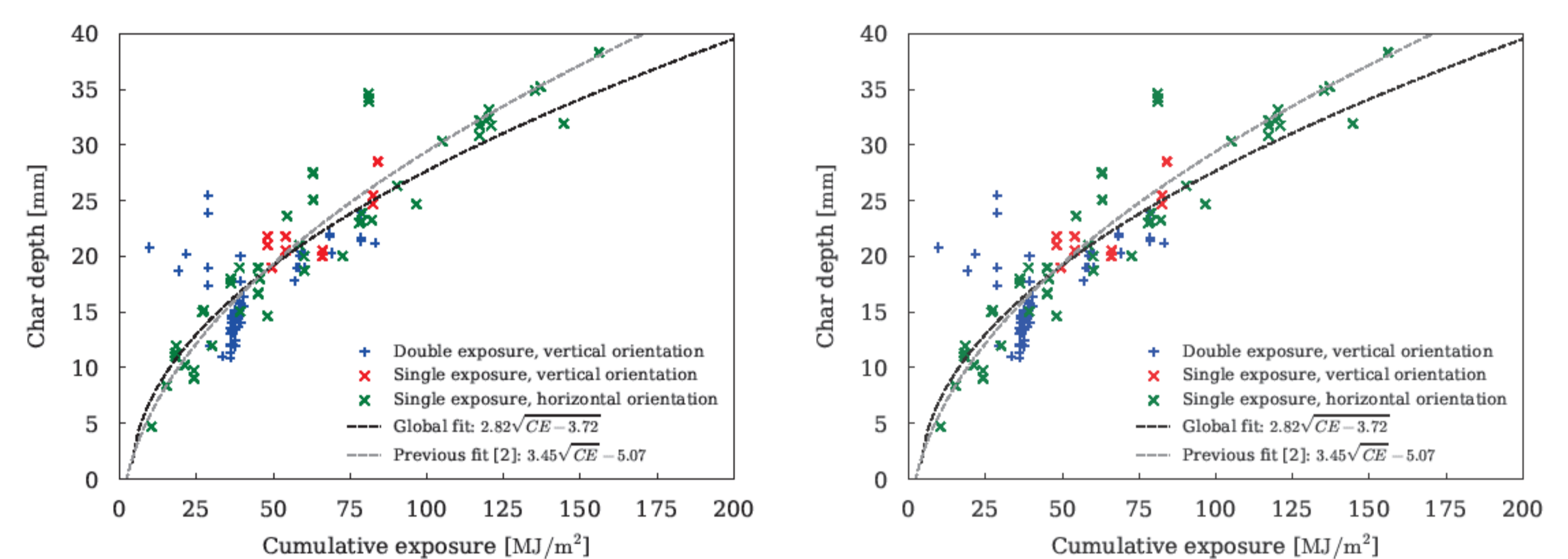


Fig. 4. Examples of char depth as a function of the CE. Left: beech (124 tests), right: oak (162 tests).

All the data were fitted by this equation, and previous fits, made only on experiments from LCPP, are also provided when available. Both are very similar, although the new datasets from LEMTA were obtained in quite different conditions: single or double exposure, but also orientation, ignitor, etc.

**This trend is also true for the other wood species presented here**, as illustrated in Fig. 5 which gives an overview of all the data used in this study and the fits that were obtained.

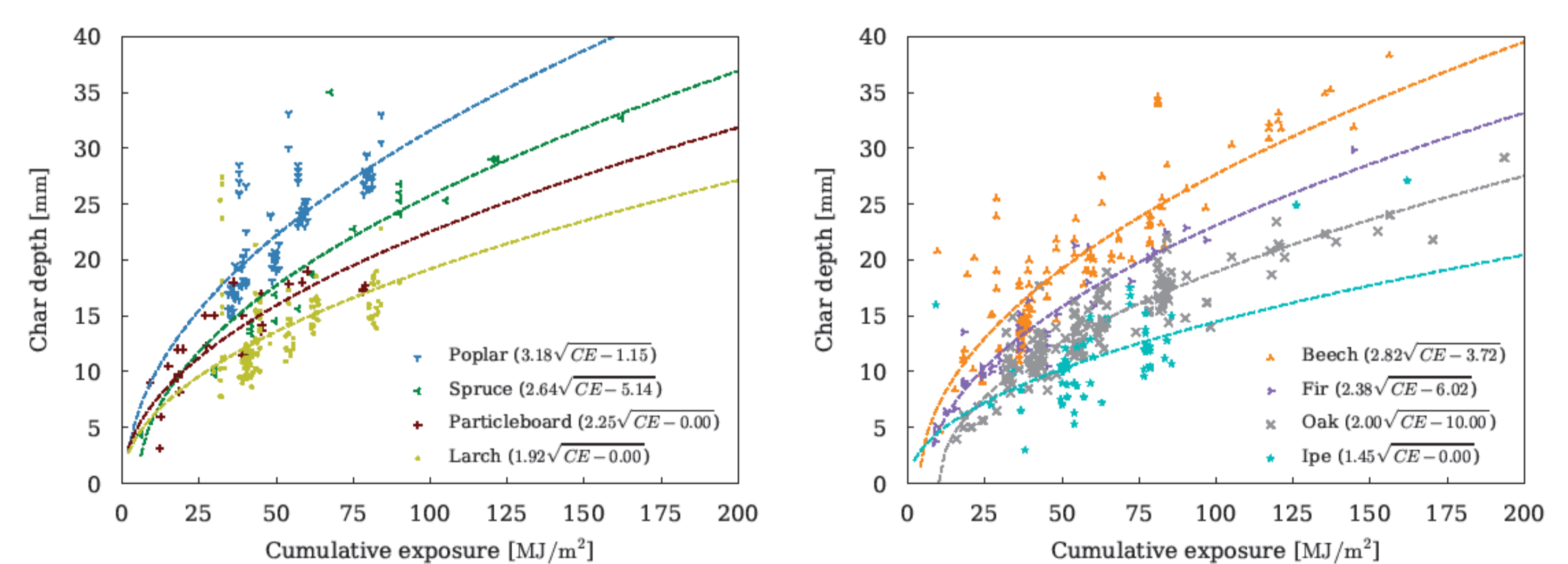


Fig. 5. Char depth as a function of the total cumulative exposure (split out for better readability).

The char depth evolution appears to be, at least in part, related to the wood density, with faster charring for poplar (least dense here) and slower charring for ipe (most dense here). However, this aspect needs to be further investigated, as some species show a different behaviour, for example beech (~ 710 kg.m<sup>-3</sup>) which has a very similar charring rate as spruce (~ 471 kg.m<sup>-3</sup>).

## Conclusions

- A CE was calculated for each experimental condition. The evolution of the char depth seems to follow a similar trend for all the experiments for a given wood species.
- This is even more remarkable and encouraging given that numerous samples were subjected to two consecutive exposures, which is a step towards more realistic heat sources.
- No clear influence of the other changes in experimental conditions was observed in the analysis presented here. Despite the large volume of experiments, the variability observed in some of the data remains significant.
- **In the future**, char comparisons will be made for experiments with and without oxygen in order to study the char oxidation process.