Proceedings of the
Junior Scientist Conference 2010
Proceedings of the
Junior Scientist Conference 2010

Vienna University of Technology
Vienna, Austria
April 2010

Edited by
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Cover page design: Bettina Neunteufl

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ISBN 978-3-200-01797-9

Printed in Austria.
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Flame spread on inclined surfaces of solids

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Abstract — Experiments have been carried out to investigate the effect of inclination on the rate of upward flame spread over combustible solids and to receive data for further CFD simulations. Flame spreading characteristics and spreading rates are measured and compared for thin and thick solids. The flame spread rate increased with increasing inclinations because of the flame interaction to the surface. A critical angle was found to be at an inclination of 20-30°. First simulations with the CFD model FDS show too high values for the flame spread rate and the problematic in simulating ignition and sustained burning.

I. I NTRODUCTION

Flame spread over combustible solids is a fundamental and a highly dangerous phenomenon in a fire. Although there are several studies for flame spread in positions like wall, floor, ceiling or corners (e.g.[1-2]) there is little research concerning the flame spread phenomenon on inclined surfaces. It has long been recognized that a critical angle of the burning surface can increase the hazard with regard to fire growth potential than does a floor or wall configuration, [3], but still deeper understanding of the mechanism of flame spread is essential.

Recently more advanced options of fire spread modeling have become available to engineers. CFD models, like FDS, can also be applied to predict flame spread and fire growth [4] but still are in need of validations and further studies. The aim of this study is to provide information for applicability of CFD models with regard to flame spread. The present paper examines the top side upward flame spread in horizontal and vertical orientations as well as several inclinations in between and presents first simulations with FDS.

II. E XPERIMENTS

To test the flame spread rate on thin and thick materials a test apparatus and a new measurement technique has been developed to examine the flame spread behavior and velocity under different inclinations.

Cellulose sheets and PMMA, cut into rectangular shape 300 mm length and of 100 mm in width, were selected as the fuels for the thin respectively the thick material in the current study. PMMA was supplied in 5 mm thickness. The materials where tested in a test apparatus which enables to study the flame spread under different, infinitely adjustable, inclinations.

The flame spread rate can be defined through the burn out front and/or the pyrolysis front, which can be identified through visual observation (reach a defined line), temperature criterion (ignition temperature, maximum temperature) or special material criterion (e.g. “bubbling” surface for PMMA) For the present study a measurement instrumentation was developed to define the flame spread rate with date collection through “conductive-line-measurement”. The disconnection of a conductive line through the pyrolysis front enables the determination of the flame front on the surface. For thick materials as PMMA the transient gas phase temperature above the PMMA surface was used for the determination of the flame spread.

The flame spread rate was also determined by measuring the distance and the elapsed time to pass between different positions on the surface with visual observations and video processing.

III. R ESULTS

The newly developed “conductive-line-measurement” technique was found only suitable for thin materials, but not for thick porous materials and materials which are melting or being conductive itself.

The present study compares the results of different flame spread measurements at different inclinations. Spreading rate measured by temperature based methods versus visual observations differ 2% for horizontal orientation and increase to 28% for vertical orientation. The scattering of the results increase in general with increasing inclinations, for all results independent of the measurement technique and flame spread criterions.

Figure 1 and Figure 2 illustrate the average upward flame spread rate at different angles on Cellulose sheets and PMMA surfaces. With increasing inclina-
tion the flame spread rate increases and the angle between the flame flow and the surface decreases, until the flame is nearly totally attached to the surface.

In the present study the critical angle was found when the inclination angle reached 30°, and results in an abrupt increase of the flame spread rate. In previous studies the critical angle was found to occur at an inclination of 15°-30° [5-6]. Between 30°-50° for Cellulose sheets respectively 30°-60° for PMMA the flame spread rate almost stays constant. It is uncertain and in need of further validation if this “plateau” is a flame spread phenomenon or a test specific in the present study. As assumed the maximum flame spread is at the vertical orientation, but the deviation at 90° reaches 150%.

IV. CONCLUSION

The following observations were made based on the flame spread experiments:

- The “conductive line”-measurement technique for the determination of the pyrolysis front seems only applicable for thin materials, but not for porous materials and materials melting or being conductive.
- The flame spread rate can be defined with different criterions, the scattering between the different criterions increases with increasing inclinations.
- The critical angle was found at 30°, as shown in the abrupt increase of the flame spread rate.
- Within inclinations of 30°-50° for Cellulose sheets respectively 30°-60° for PMMA the flame spread rate was found to be nearly constant, but is in need of further validation.

First simulation with FDS show an overestimated flame spread rate on horizontal PMMA surfaces.

Further work in this study will include FDS simulations of the flame spread over Cellulose sheets and PMMA surfaces in vertical and horizontal orientations as well as on inclined surfaces.

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