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Proceedings Paper:

Mustafa, BG, Mat Kiah, MH, Andrews, G et al. (2020) Toxic Gas Emissions from Plywood Fires. In: Osvaldova, LM, Markert, F and Zelinka, SL, (eds.) WFS 2020: Wood & Fire Safety. 9th International Conference on Wood & Fire Safety 2020, 01-04 Nov 2020, Strbske Pleso, Slovakia. , pp. 50-57. ISBN: 978-3-030-41234-0.

https://doi.org/10.1007/978-3-030-41235-7

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Toxic Gas Emissions from Plywood Fires

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Abstract. Toxic emissions from four construction plywoods were investigated using a freely ventilated cone calorimeter with raw predilution hot gas sampling. Each plywood sample was exposed to the conical heater of the cone calorimeter radiating at 35 kw/m^2. Rich mixtures occurred in some of the tests, these rich mixtures produced high concentrations of toxic gases. The 4 samples had different peak heat release rate HRR, but similar steady state HRR. The elemental analysis of the four samples showed that they had different nitrogen content, indicating different glues were used. Plywood B had the highest N content of 6.43%, which resulted in the highest HCN concentration. The most important toxic species were CO, HCN, acrolein, formaldehyde and benzene on both an LC_{50} and $COSHH_{15min}$ basis.

Keywords: Toxicity, Wood Fires, FTIR.

1 Introduction

Wood products are extensively used in building construction, furniture and interior furnishing. Commonly used construction wood products include: plywood, MDF, Oriented strand board (OSB) and chipboard. However, despite these products being in common usage little information has been published on their toxic hazards in fires. This work is concerned with plywoods and uses four commercially available types, where the thickness and number of wood layers differ. These processed wood products generally use glues as a binder and these contain organically bound nitrogen which can give rise to HCN in the fire products and so the burning of these potentially pose a greater health hazard in fires than for unprocessed wood. The authors have shown [1-3] for pure construction pine wood crib fires in a confined 1.6 m^3 enclosure that the main toxic gases were CO, acrolein, formaldehyde and benzene. In most of these pine wood compartment fires HCN was not significant, apart from during the early stages of one fire where HCN had a significant contribution to the toxicity [3]. It will be shown in this work that for all four plywoods that HCN and NO_2 emissions were very significant additional toxic gases to those for pure pine wood.

The majority of deaths and injuries from exposure to fire smoke are as a result of inhalation of toxic effluents [4]. Wood as the most dominant fire load accounts for

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approximately 65 % of CO emissions [5]. Survivors of fires often describe toxic gases as acidic and/or irritant gases, and these slow the movement of people eventually leading to their death [6-9] through the impairment of escape. There is currently no legislation that requires toxic gas measurements from fires for any material used in buildings. Only light obscuration by smoke in standard fire tests is required to be measured for building materials. The main toxic products in most fires were shown by Purser [6] to be CO, HCN and irritant or acidic gases. The concentration of each depends on the type of fuel and on the thermal decomposition products of the materials when heated in a fire, which also depends on the fire temperature and ventilation.
The most common method of assessing the toxicity of fire products is the LC_{50} 30 min exposure concentration which aim at predicting the concentrations at which 50 % of the people will die in the fire if exposed to the gas concentration for 30 minutes [7]. COSHH [10] is the European statutory law on occupational exposure limits equivalent to the US short term (10 mins.) exposure limits AEGL2. The $COSHH_{15\ min}$ toxic gas concentration represents a safe condition for 15 minutes for escape not to be impaired. The USA Acute Exposure Guideline Levels [7] AEGL 2 10 mins. exposure are equivalent to the $COSHH_{15min}$ levels for disabling and impairment of escape. This work used the $COSHH_{15\ min}$ and the LC_{50} to assess the toxicity of gases emitted from plywood fires based on impairment of escape and lethality.

2 Material and Methods

Four types of construction plywood were investigated as shown in Table 1: plywood A (PWA), plywood B (PWB), Dark plywood (DPW) and Light Plywood (LPW).

Table 1. Fuel Characteristics

Parameter	PWA	PWB	LPW	DPW
Proximate Analysis (Wt. %) (daf)				
Volatile Matter	79.47	80.81	82.64	84.23
Fixed Carbon	20.53	19.19	17.36	15.77
Ultimate Analysis (Wt. %) (daf)				
Carbon	52.00	47.39	50.03	45.88
Hydrogen	6.56	6.22	6.66	5.94
Nitrogen	0.38	6.43	3.51	1.74
Sulphur	0.00	0.00	0.00	0.00
Oxygen	41.06	39.97	39.80	46.45
Stoichiometric A/F by carbon balance	5.35	4.83	5.35	4.50
Gross Calorific value (MJ/kg)	18.80	18.30	18.40	18.60
Moisture (as received) (%)	6.68	6.91	5.02	4.58
Ash (as received) (%)	3.42	1.68	3.30	3.27

The standard cone calorimeter (ISO 5660) was modified for raw fire smoke toxicity measurements by adding a cone heater exit chimney and gas sampler [9]. The oxygen analysis from the chimney was used to determine the primary HRR. The 100 mm square wood samples had a thickness of 20 mm (PWA), 18 mm (PWB), 11 mm (DPW) and 11 mm (LPW). Each plywood sample was exposed to 35 kw/m^2 radiant heat with free ventilation. The ignition delay for the four samples was 54 s (Plywood A), 53 s (Plywood B), 73 s (Dark Plywood) and 49 s (Light Plywood). The fire continued until flaming combustion ceased and there was only char burning. It will be shown that this transition from flaming combustion to char smouldering combustion was associated with a change in the release of toxic gases. A modified N-gas model for toxicity assessment was used for the total toxicity of the gases produced by the fires. This was obtained by taking the ratio n of the concentration of the species measured by the FTIR and dividing by either the LC_{50} values or the $COSHH_{15\ min}$ values. These ratios were added to give the total toxic gas N.

3. Results and Discussion

3.1 Mass Loss, Equivalence Ratio and Heat Release Rates (HRR)

The mass loss rate, shown in Fig. 1a, at steady state for all the samples was about 0.06 g/s, with a much slower burn rate during the char burning phase. The equivalence ratios (from carbon balance) in Fig. 1b showed that rich mixtures occurred in some of the tests, indicating that some features of confinement occurred even though the fire was freely ventilated. Most of the samples had rich mixtures in the initial stage of the combustion except for Plywood B which was only rich in the second burning phase. These rich mixtures produced high concentrations of toxic gases. The four samples had different peak HRR, but similar steady state HRR as shown in Fig. 2. The primary HRR in Fig. 2a was significantly lower than the mass loss HRR in Fig. 2b, indicating significant post cone fire combustion. This is why the cone calorimeter diluted sample cannot be used for toxic gas assessment.

3.2 Toxic Gas Concentration

The most important toxic gas emissions are shown in Fig. 3. All plywood samples had an almost zero concentration of CO during the steady state burning phase. The highest concentration of each of the toxic gases released occurred during the early

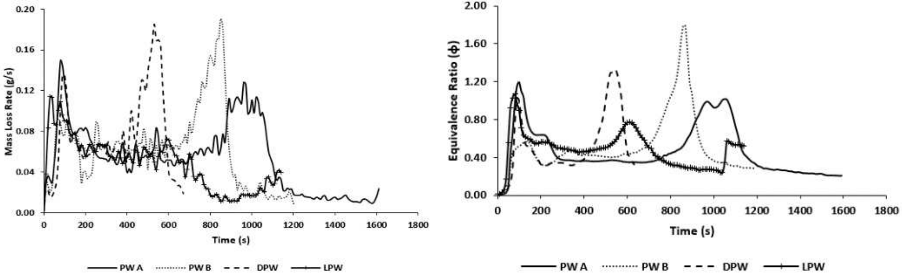


Fig. 1. Mass Loss Rate (a) and Equivalence Ratio (b)

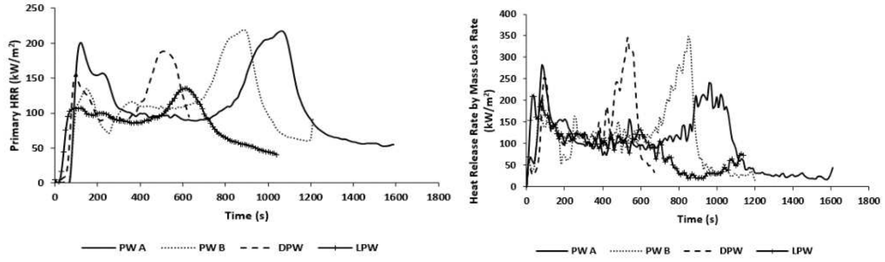


Fig. 2. Primary HRR (a) and HRR based on Mass Loss Rate (b)

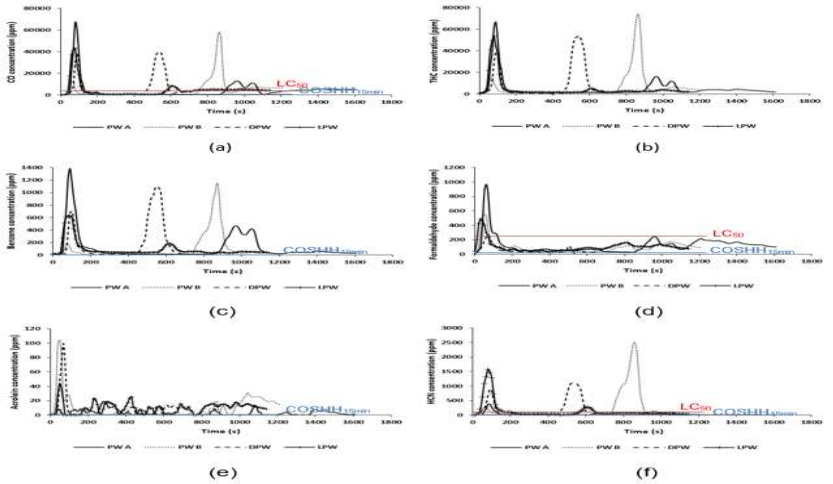


Fig. 3. Toxic gas concentrations; CO (a), Total Hydrocarbon (b), Benzene (c), Formaldehyde (d), Acrolein (e) and Hydrogen Cyanide (f)

rich combustion, indicating that entrainment of air into the fire gases was not sufficient to produce overall lean mixtures, even though the experiments were freely ventilated. The highest concentration of benzene was released by plywood A, followed by the dark plywood, plywood B and the light plywood. There were significant differences in the concentration of the toxic gases (CO, Benzene, Formaldehyde, Acrolein, HCN), both in terms of the magnitude and the time the peak concentrations occurred. The toxicity was higher for richer fires, and the toxicity peaked at maximum HRR. Plywood B had the highest Nitrogen content of 6.43%, which resulted in the highest HCN concentration by a factor of 2-4. All toxic gas concentration levels were considerably higher than the LC_{50} limit except for acrolein and benzene, but all the toxic gas emissions were above the $COSHH_{15min}$, with each plywood with different concentrations.

3.3 Total Fire Toxicity N on an LC_{50} and $COSHH_{15min}$ Basis

The most important toxic species were CO, HCN, acrolein, formaldehyde and benzene on an LC_{50} and $COSHH_{15min}$ basis. Figure 4 shows that the peak **N** for LC_{50} toxic assessment were all >20 and were different for each plywood, both in terms of the magnitude and the time when the peak N occurred. The peak **N** on a $COSHH_{15min}$ basis was > 900. This means that the toxic gases need to be diluted with fresh air by a factor of about 900-1500 before escape is not impaired and it has to be diluted by a factor of > 20 before it doesn't kill anybody in 30 mins. The two methods of deriving **N** show that the dependence of **N** on time were similar for all plywoods.

The major contribution to the total toxicity is shown on an LC_{50} and $COSHH_{15min}$ basis in figs. 5 and 6 for the 4 plywood fires. For PWA the toxicity was dominated by CO, followed by formaldehyde, HCN and acrolein on an LC_{50} basis and formaldehyde, acrolein, benzene, CO and HCN on a $COSHH_{15min}$ basis. HCN was the third most important toxic gas, but its contribution never exceeded 10% on an LC_{50} basis.

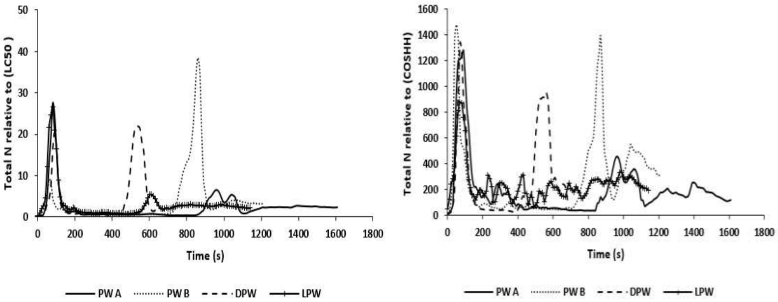
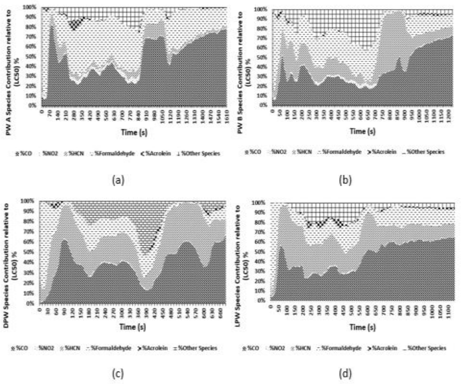


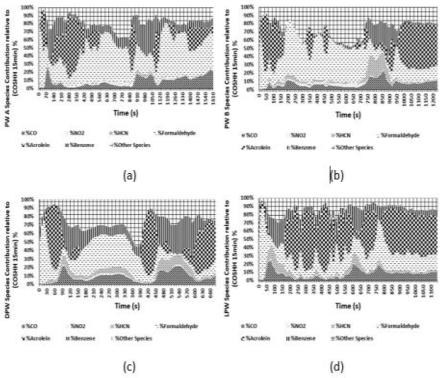
Fig. 4. Total toxicity N relative LC_{50} (a) and relative to $COSHH_{15\ min}$ (b)

For the PWB the toxicity was dominated by CO, HCN, formaldehyde and acrolein on an LC_{50} basis, but formaldehyde was more significant on a $COSHH_{15min}$ basis, followed by acrolein, HCN, benzene and CO. For the DPW the toxicity was dominated by CO, HCN, formaldehyde on an LC_{50} basis, with < 10 % contribution of acrolein. However, on a $COSHH_{15min}$ basis, formaldehyde dominated the toxicity, followed by acrolein, benzene, CO and HCN. The LPW fire was also dominated by CO, HCN, formaldehyde on an LC_{50} basis, with < 10 % contribution of acrolein. However, acrolein was the most important toxic gas on $COSHH_{15min}$ basis followed by formaldehyde, benzene, CO and HCN. The results showed that benzene was also a significant contribution to the toxicity in these plywood fires. The differences between LC_{50} and $COSHH_{15min}$ toxic assessments in these fires show that the relative importance of the four toxic gases for death are different from that of impairment of escape. For these plywood fires CO dominates in relation to death and for impairment of escape the other three gases are more important and each plywood had different toxic gases dominating. These toxic emissions were similar to those for pine wood crib compartment fires [1-3] with the added significance of HCN emissions from the glues used in plywood construction.



(a) (b)

(c) (d)



(a) (b)

(c) (d)

Fig. 6. N-Gas Composition (COSHH$_{15min}$) PWA (a) PWB (b) DPW (c) and LPW (d)

Fig.5. N-Gas Composition (LC$_{50}$) PWA (a) PWB (b) DPW (c) and LPW (d)

4. Conclusions

1. High concentrations of toxic gases that would impair escape were produced in the initial stage of the fire, where escape is occurring in a fire.
2. The 4 plywoods had different compositions indicating that the manufacturing processes were different and hence released different concentrations of the toxic gases. Toxic gas regulation for plywoods should be introduced to control this.
3. The modified standard cone calorimeter is a good technique to use for the realistic determination of toxic gases when used with a heated FTIR.

Acknowledgements. The Petroleum Technology Development Fund, Nigeria and the University of Maiduguri are thanked for sponsoring the PhD of Bintu G. Mustafa. Thanks to Garry Fitzgibbon of Galliford Try for providing some of the test materials.

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