Test Protocol for Assessing the Fire Hazard of Ceiling Materials

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Abstract

The US Army wishes to adopt a fire test protocol sufficient to assure the occupants of combat vehicles to be safe from overhead impact protective materials. The process to develop this test and its preliminary design will be described. The framework for the test protocol is based on engineering design principles and the ability to measure material fire properties to model their fire performance. The threat scenarios selected consists of (1) a fire from below attacking the ceiling, and (2) a ceiling fire alone. The fire below is selected to be a significant in its ability to heat the ceiling, but not a significant threat to the occupants. The fire hazard to the crew is twofold: (1) Thermal: associated with the extent of fire growth on the ceiling, and (2) Smoke Toxicity: to not cause occupant incapacitation in a fixed time period. The criterion for an acceptable material is that the material shall not allow flame spread, and the fractional effective dose for incapacitation (FEDI) is not exceeded.

The investigation involved studying the characteristics of the threat scenarios in a small full-scale mockup, measuring ceiling flame heat flux signatures, and modeling flame spread and toxic gas concentrations. The modeling algorithms give the critical property values to satisfy the acceptable values. The specific material properties consists of the following:

1. Critical heat flux for ignition (CHF): governs whether ignition occurs under the design heat flux, and the net flame heat flux. (Related to ignition temperature.)
2. Thermal Responsive Parameter (TRP): governs the time for ignition and the speed of flame spread. (Related to thermal inertia, $k\rho c$, and ignition temperature.)

3. Heat Release Parameter (HRP): governs the rate of energy release rate per unit area under the net heat flux, and whether flame spread will occur. (Related to the energy release per energy needed to burn.)
4. Available Energy Parameter (AEP): governs the burning time. (Related to the energy of combustion available per unit surface area.)
5. Yields of Gas Species (y_i): governs the gas concentration in fire. (Related to stoichiometry.)

All of these parameters are determinable from devices such as the Cone Calorimeter (ASTM E 1354) or the FM Global Fire Propagation Apparatus (FPA, ASTM E 2058). There are ample examples in the literature for simple and complex materials.

The algorithms for determining the critical property values for acceptance will be presented. The result depends on the characteristic scenario heat flux and the measured material properties. For example, the critical heat release rate per unit area (HRR) needed for upward flame spread and in the ASTM E 84 is reported to be 100 kW/m^2 under their respective heat fluxes. The critical acceptance level in the FAA OSU test is 65 kW/m^2. The critical HRR is equal to the applied heat flux minus the CHF, times the HRP. The acceptable HRP values for no wall or tunnel spread, or pass in the FAA OSU test are:

1. Vertical wall spread: HRP < 100/(25-CHF) based on general wall flame heat flux.
2. Tunnel test: HRP < 100/(35-CHF) based on reported tunnel flame heat flux.
3. Aircraft interior cabin: HRP < 100/(35+25-CHF) based on radiant exposure and general turbulent vertical flame heat flux.

Algorithms for the ceiling fire hazard case examined here will be presented.