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The Aircraft Composite Integral Fuel Tank Fire Safety Performance Analysis and Shrinkage Ratio Simulation Calculation

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Abstract

Composite materials in specific modulus, specific strength and corrosion resistant properties are better than the metal materials. But as the composite materials thermal conductivity worse than metal, the speed of composite materials temperature rises more than metal. Then it is very necessary that the discussion of the composite material heat-resistant properties and flame retardant performance whether could meet the metal material performance requirements. This paper applied Fluent software to discuss shrinkage ratio aircraft fuel tank experiment method which simulate aircraft fuel tank top plate to accept the sun heat radiation 1 hour. During this time, the test plate center temperature, fuel surface temperature and fuel steam temperature. Comparing with Fluent simulation results and FAA test data, the results are basically the same trend, but there are still some residuals. According to FAA data correction calculation method, simulated a larger percentage or full size composite fuel tank fire experiment provides calculation method.

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Keywords: Composite material, Fire protection, safety performance, Fluent shrinkage ratio simulation.

1. Foreword

In February 2012, Boeing787-"dreamline" composite material application proportion is 50%, and in the development of the Airbus350 advertised that it will make the composite material application ratio up to 51%. Then Airbus350 is going to be used most composite material on the aircraft in the world. Because the composite materials in specific modulus, specific strength and corrosion resistant properties are better than the metal, composite materials now has been widely used in aviation field. In order to further reduce the aircraft weight, increase fuel storage space, the aircraft research next key is the development of composite material integral fuel tank. But as the composite materials thermal conductivity worse than metal, the speed of composite materials temperature rises more than metal. Then it is very necessary that the discussion of the composite material heat-resistant properties and flame retardant performance whether could meet the metal material performance requirements.

2. Fuel tank fire risk factor analysis

Since 1959 there have been 17 fuel tank ignition events, resulting in: 542 fatalities, 11 hull losses, and 3 others with substantial damage[1]. Lead to such tank fire explosion accident reason including: external wing fires, electrostatics, lightning, pumps or wiring suspected, and maintenance action, and so on. From 1990 to today, Boeing aircraft at least three of the plane disintegrated accidents are the Center Wing Tank explosion caused by lighting in the world. The most fatalities accident happened in 1996, B-747 TWA800 took off from New York J.F.K. airport. During taking off the 25 year old airplane B-747-131 exploded and disintegrated in the air, it was 230 fatalities in this tragedy accident. National

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Transportation Safety Board(NTSB) believes the likely energy source was a short circuit outside of the CWT the allowed excessive voltage to enter the CWT through the Fuel Quantity Indication System(FQIS) wiring. Also the NTSB believes that a contributing factor may have been a heat source from the air conditioning systems located below the CWT.

2.1. Fuel tank lighting source analysis

According to the accident investigation conclusion, there are four energy source may lead to fuel vapor mixture was lit or achieve mixture combustion temperature in the fuel tank[2].

(1) Electrical Sparks and Electrical Arcs. Spark and arc is caused by connection problem of high potential to low potential discharge process. Laboratory testing has shown that the minimum ignition energy in an electrical spark required to ignite hydrocarbon fuel vapor is 200 microjoules1. Therefore, for electrical or electronic systems that introduce electrical energy into fuel tanks, such as fuel quantity indicating systems, any electrical arcs or sparks that are created into any fuel tank should be less than 200 microjoules during either normal operation or operation with failures. Electrical transients caused by environmental conditions, such as lightning strikes, with the potential to create electrical sparks and arcs in the fuel tank, should be limited so that the energy from any electrical spark or arc from the electrical transient is less than 200 microjoules[3].

(2) Filament Heating Current Limit. In the resistance heating filaments are appear thermal ion radiation, ion is emitted high speed collision energy transfer, a large number of ion for synthetic movement to form a larger current, it also can produce a large quantity of heat, so as to meet the mixed vapor spontaneous combustion temperature or light. In this process, a proportional to the size of the magnetic field was going to be produced in the heating resistance wire by the current, and the magnetic field can improve the whole ion energy[4].

Analyses and testing indicate a small piece of steel wool will ignite a flammable mixture when a current of approximately 100 milliamperes root-mean-square (RMS) is applied to the steel wool. Therefore, for electrical or electronic systems that introduce electrical energy into fuel tanks, such as FQIS, the electrical current introduced into any fuel tank should be limited.

(3) Friction Sparks. Service experience has shown that pump inlet check valves, inducers, nuts, bolts, rivets, fasteners, lockwire, roll pins, cotter pins, drill chips, and manufacturing debris, etc., have been inducted into fuel pumps and contacted the impeller resulting in the possibility of metallic deposits on rotating and stationary components within the pump. This condition has resulted in creation of friction sparks and should be an assumed failure condition when conducting the system safety assessment.

(4) Hot Surface Ignition. Guidance provided in AC 25-8, as well as the original release of this AC, define surfaces that come within 50 degrees of the auto-ignition temperature of the fuel air mixture for the fluid as ignition sources. The FAA has historically accepted 400℉ for maximum surface temperatures for kerosene type fuels. (Maximum surface temperature considerations for areas outside the fuel tank are discussed later in this AC.) For remote failure conditions of limited duration, it is acceptable to provide substantiation of actual hot-surface ignition temperatures (note that this is different from the auto-ignition temperature of the fuel), and demonstrate a 50℉ margin below these temperatures.

2.2. Composite fuel tank special failure

Aluminium magnesium alloy material thermal conductivity coefficient is 200-236$Wm^{-1}K^{-1}$, and carbon fiber composite material thermal conductivity coefficient is 10-20$Wm^{-1}K^{-1}$, so fire protection, heat conduction performance exist a big difference. Then the composite material is easy to get local overheating. At the same time when the temperature rise to composite glass transition temperature (T_g) can make the structure performance decline, tensile properties basically remain unchanged, but compressive strength will be reduced by 20%-30% and even more. In normal flight process vibration or tank inside and outside pressure difference can cause tank structure deformation (such as, trunk, etc.).

For example: from the materials science point of view, wet/thermal environment conditions, the composite material elastic modulus and strength design allowable value will decline 10% - 20% (or part of the material performance reduce 50%). High temperature conditions have matrix suction wet with easy, moisture penetration into the matrix induce its inflation, making its plasticizing or softening, and at the same time, softening effect may also lead to T_g is reduced, such as used for Airbus 914C material absorption of moisture 4.7%, T_g decline to 158℉[5].

Composite material passes through the long time high temperature baking, ablation or cause composite material surface temperature reached after T_g, in the plane vibration or shaking function, possible part cracking, delamination, degumming, leakage and deformation and failure cause secondary accidents.