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Burn-Through Responses of Aero-Engine Nacelle using Fiber Metal Composites by ISO2685 Propane-Air Burner

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Abstract*: The paper presents experimental investigation on the behavior and burn through responses of a flat plate composite of fiber-metal laminates composites of aluminum alloy 2024-T3 with carbon and natural fibers subjected to environmental conditions in fire designated zone of an aircraft engine exposed to fire. The main purpose of this study is to know the different burn through time responses of different forms of aluminum alloy with synthetic and natural fibers. The composites were designed and developed to improve the flame fire resistance in a fire designated zone of an aircraft engine in near future for prolonged burning through time that will at least withstand the fire flame for 15 minutes according to the ISO 2685 standard. The composites are fabricated by hand lay-up method in a mold of 300 mm x 300 mm and compressed by compression machine. Based on the obtained results, some of the composites are indicated to be fireproof while some others are fire resistant. It is shown that the carbon fiber reinforced aluminum alloy laminate with only aluminum at top and bottom (CF+AA) of the composites can resist more flame temperature than the carbon fiber reinforced aluminum alloy laminate with alternate layers of aluminum and carbon fiber (CARALL) with 7.86%, the sandwich of carbon fiber with flax with 18.2% and the sandwich of carbon fiber with kenaf with 23.43%. In conclusion, the study reveals that aluminum alloy 2024-T3 with carbon fiber and some types of natural fibers composites possess good properties of resisting high temperature of fire designated zone of an aircraft engine nacelle.

***Keywords*: aluminum alloy, composites, fire designated zone, natural fiber, synthetic fiber**

I. INTRODUCTION

The use of aluminum alloys with reinforced fiber has been gradually increased in several different industrial applications due to its lightweight structure. Among others, it finds several applications in structural design such as in aircraft, light rail, marine crafts and also bridge deck [1]–[2]. Aluminum alloy is a strain-hardened alloy material that primarily depends on the grain refinement for the strengthening mechanism due to its micro structure. At an elevated temperature of about 250ºC to 350ºC, the mechanical properties of aluminum alloys in fire designated zones are degraded, where its strength is reduced as a result of the re-crystallization by annealing [3]–[5]. High temperature exposure of components causes further strength reduction and precipitation growth [6]–[9].

Fiber-metal laminate (FML) is another material used in the aerospace industry. Demands of such materials have quickly become necessary in this industry for constructing aerospace components based on their good performance and lightweight properties, subsequently FMLs have become one of the most used structural components in aerospace industry [10]–[11]. In short, FMLs are hybrid composite materials that are made up of mingling layers of thin metals and also fiber reinforced adhesives. The flight simulation test on the carbon reinforced laminates and aramid fiber reinforced laminates has already been conducted and the results have shown improvement in aircraft structures [12]. Fiber-metal laminates are developed to replace monolithic aluminum alloys in fatigue prone areas in the primary aircraft structures. Fiber metal laminates have the superior properties in terms of the fatigue crack initiation behavior and growth [13].

A main concern in design of aircraft aluminum structures is the fire safety, which is caused by the reduction of mechanical properties due to high temperatures. Thus, a special research is conducted for design considerations on aluminum alloy on aircraft structures and other components that are heat resistant in order to ensure structural integrity at very high temperature [14]–[16]. The composites used in this fire test are immersed fully in the flame fire, and the burning through time for each of the composites is noted. The surface temperature of the test sample is associated with the fire-resistance limit of the tested material, which is being influenced by the temperature of the flame. Likewise, the heat flux is influencing the initial thermal response of the tested materials. This phenomenon makes it necessary to calibrate the flame temperature and the heat flux produced at every test location as stated by the International Organization of Standardization (ISO) in order to be certain that the environment for the fire test meets the requirement to simulate real life situation that could affect an aircraft engine nacelle.

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II. METHODOLOGY

This present study is on a standard ISO 2685 propane-air burner that is made up of burner face, burner head and plenum chamber. Propane gas and air are mixed in the small chamber before reaching the plenum chamber, where combustion takes place. The mixture passes through 3.18-mm copper tubes with a drilled 1.8-mm bore that is serving as a fuel nozzle, which is connected to upper part of the burner. Secondary air (cooling air) moves to the burner head through a 2.6-mm hole to stabilize the flame and maintain the burner's temperature at constant. In the meantime, the burner head is made up from two plates that are used to stabilize the flame and also to prevent backflow of the combustion mixture into the plenum chamber. The upper part of the burner is a plate containing 373 copper tubes that are fixed at gridiron, separated at a distance of 7.93 mm between each other. There are four holes at the top of the burner where the secondary (cooling) air is introduced to the burner. The cooling air cools the copper tubes and there are 332 holes with a diameter of 2.6 mm in the burner plate that prevent flashback [17]–[18].

Four different types of composites have been fabricated by the hand lay-up method in a mold of 300 mm x 300 mm. Table I depicts fabricated composites. For CAKRALL, CAFRALL and CF + AA composites, the aluminum alloy is at the top and bottom of each composite. On the other hand, for CARALL, the aluminum is in alternating form with carbon fiber. Epoxy resin/hardener in the ratio of 2:1 is used as the polymer. The fabricated composites are then compressed in a compression machine for 24 hours in a room temperature and post cured in the oven at 80ºC. Five samples of each type of the composites are fabricated.

The burner is calibrated using an R-type thermocouple for temperature calibration and SBG01 heat flux meter for heat flux calibration as illustrated in Fig. 1. Seven thermocouples that are separated at one-inch distance from one another in the thermocouples housing, which is three inches from the burner face and also the SBG01 heat flux meter. All samples of the composites undergo 15-minute fire test in a pool of fire using a propane-air burner at a temperature of 1100 ± 80ºC and heat flux of 116 ± 10 kW/m^2 at three inches from burner face. The average result of each sample is obtained using three K-type thermocouples on each sample at the center, one inch above the center and also one inch right to the center, as indicated in Fig. 2. The data logger is used in reading flame temperature and heat flux.

Table-I: Specifications of the fabricated composites

Composite type	Number of layers / thickness of aluminum alloy 2024-T3	Number of layers / thickness of carbon fiber	Number of layers / thickness of kenaf fiber	Number of layers / thickness of flax fiber
CAKRALL	2L / 0.6 mm	4L / 0.8 mm	1L / 1.4 mm	-
CAFRALL	2L / 0.6 mm	5L / 1.0 mm	-	2L / 1.2 mm
CARALL	5L / 1.5 mm	6L / 1.2 mm	-	-
CF + AA	2L / 0.6 mm	11L / 2.2 mm	-	-

(a) (b)

Fig. 1.Temperature and heat flux calibrations

(a) (b)

Fig. 2.Temperature and heat flux calibrations

III. RESULTS AND DISCUSSION

The research study of using FMLs composites is focused on developing the new lightweight, greener and user-friendly composites for aircraft components in fire designated zones for continuing certification process of fireproof/fire resistant according to the standard [18]. Table II tabulates the average burn-through responses for each of the considered types of composite after undergoing the fire test in a pool of fire.

Table-II: Specifications of the fabricated composites

Sample No.	Specimens	Burn through time (sec)	Observations
1	CAFRALL	> 900	Fireproof
2	CAKRALL	622	Fire resistant
3	CARALL	> 900	Fireproof
4	CF + AA	> 900	Fireproof

Three of the composites shows fireproof properties, that is the ability to withstand 15 minutes in a pool of fire according to the standards. On the other hand, the CAKRALL sample is shown to burn before the fireproof time but after 5 minutes. According to the standard specifications, this indicates a fire resistant property of the CAKRALL sample [18, 19]. Fig. 3 shows the fire test result against the burn-through time.

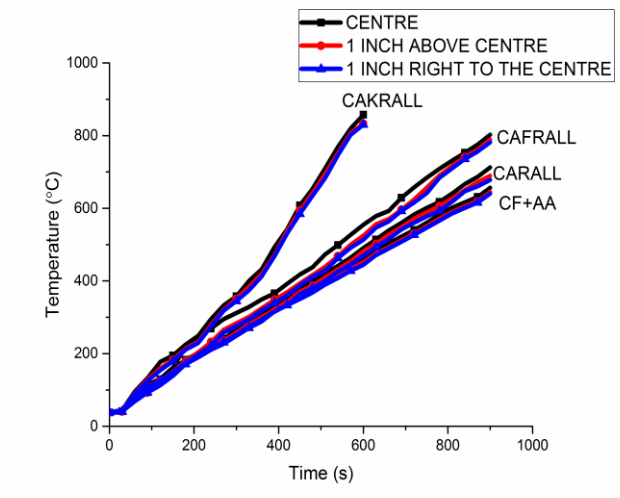

Fig. 3.Fibre-metal laminates on fire test

In the test, a linear relationship exists between the heat of conduction and the time. The burn through time observed for all of the considered types of composites has conformed with the burn-through time obtained in the previous researches as in [6] and [7], where the aluminum melting is observed before flame penetration. In the case of the FMLs, the flame is visible through the woven of the carbon fiber and the melt is observed at the last layer of the composite material (aluminum alloy). Decomposition of epoxy is observed, which is then followed by char formation and, as the composites are further exposed to the higher temperature, the reinforced fibers react and also decomposed. This forms a char that is later oxidized, which is closely similar to the phenomenon observed in [20]. For the four composites that have been considered in this study, three of them are shown to be fireproof (CAFRALL, CARALL and CF+AA) while CAKRALL is a fire resistant composite. The carbon fiber reinforced aluminum alloy using aluminum alloy at top and bottom has been shown to have the least percentage of flame penetration. In similar manner, the hybrid composite (natural fibers and carbon fiber) can be used to substitute the synthetic fibers in the aerospace industry as the flax competes with the synthetic fibers in resisting the flame penetration.

The penetration through the composites and its melting are observed by normal visual observation. The flame appears to penetrate the top layer of aluminum alloy within a short time of the burning. Nevertheless, the flame is then retarded by the combination of the fiber layer with epoxy resin and hardener for some time before the second layer is burned. The process is continued until the whole composite is in flame. Ambient airflow changes the temperature of the flame as observed in [21] and [7]. The result clearly shows that application of fiber to metal alloy helps to retard the rate of heat releases and also increases the rate of smoke, as also observed in [22].

IV. CONCLUSION

All in all, the objective of this study is achieved, where new composites of synthetic/natural fibers have been developed for high temperature application in fire designated zones of an aircraft engine. The samples of the composites undergo fire test for burn-through responses in a flame fire of 1100 ± 80ºC and 116 ± 10 kW/m^2 temperature and heat flux, respectively. The result obtained shows an increase of fire resistance. In the FMLs considered in this study, carbon fiber with aluminum alloy at the top and bottom resists more than other composites considered. The aluminum alloy at the top and bottom of the carbon fiber composites resists more flame penetration with 7.86%, 18.20% and 23.43% than CARALL, CAFRALL and CAKRALL, respectively. Also, a hybrid composite (flax and carbon fiber) is a fireproof composite, which shows that some natural fibers can resist the high temperature. Therefore, it is recommended that natural fiber research on high temperature composites should be encouraged.

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