Innovative FRP Composite Panel System for Helipads and Runway Parking Ramps

Introduction

Composite materials are increasingly being used in all aspects of our society, from transportation (highway decks, airplanes, airfields) and civil engineering (bridges, wall reinforcement, carbon-fiber reinforced concrete) to expeditionary platforms for the heavy equipment involved in oil and gas field exploration [2]. Composites differ from traditional materials: their combination of distinctly different material components can make new high-strength, lightweight substances with corrosion resistance, long-term durability and low maintenance requirements. Composites also offer design flexibility, good vibrational damping, and resistance to fatigue and temperature extremes. In comparison to that of steel or aluminum, the principle advantages of composites include a higher stiffness to weight, endurance under cyclic loading, and corrosion resistance [4].

Erallo's focus in composite materials is to provide innovative Fiber Reinforced Polymeric (FRP) modular composite panel solutions for applications such as helipads and runway parking ramps. Our Innovative Composite Panels (ICP) is lightweight, strong, durable, and resistant to extreme temperatures and harsh environmental conditions. The ICP system will reduce both the cost and deployment burden, as well as, employ innovative joining mechanisms with embedded, smart sensor monitoring to ensure a secure and stable system regardless of uneven subgrades.

The team of Erallo Technologies (Erallo) and CFC-WVU, has extensive experience in design, analysis and manufacturing of polymer composites. CFC-WVU has developed thermally resistant, modular composite panel systems for a vertical take-off and landing (VTOL) pad system for Marine Expeditionary Airfields and durable, FRP/epoxy resin panels for Highway Decks under a grant from the West Virginia Division of Highways (DOH). In addition, panel systems have been designed and deployed for use in Alaskan oil field environments: where heavy loads from steel-wheels and extreme temperature swings must be tolerated on soft subgrade, support conditions. Smart sensor monitoring systems have been employed (using strain gages, LVDTs & accelerometers) to provide information on the integrity of the modular system and individual panels.

The team of Erallo and WVU intend to modify the existing panel system such that they are design specific for the military programs of **Helipad Landing Platforms and Runway Parking Ramp Expansion (RPRE)**; however, the current panel system already meets or exceeds many of these design aspects without modification. The following are key design aspects for the modified ICP panel systems.

Durability/Performance:

- Lightweight – only two personnel required to lift a panel
- Durable and strong – capable of handling loads of present and near-future cargo and fighter aircraft while operating on a low strength subgrade (CBR6); able to handle 44 kip wheel loads and withstand braking and turning stresses resulting from taxiing aircraft
- High weatherproof capability – UV penetration resistance, capable of being cleared of snow/dirt with standard equipment.
- High frictional and abrasion resistance (in comparison to steel)
- Protective – prevents brownouts from whirling sand/debris and damage to rotors/engines
- Temperature resistant – dissipates heat and maintains integrity, even when hotspots occur: 650°F to 1000°F

Installation/Transportation:

- Efficient assembly and disassembly – requiring few tools (and no special tools); interchangeable for easy re-use at different sites and quick switch-out for replacement

- Easy installation – manual (requiring no Material Handling Equipment (MHE)) to minimize airframes for transport
- Secure anchoring system -- restrains movement under normal operating conditions, including uplift forces caused by winds, jets or propeller blasts
- Quick deployment in the field -- re-useable connections built into panels with an emphasis on shear transfer and thermal stress fluctuations
- Convenient transportation – Loads easily onto C-130s, C-17s and CH-47s

Additional Features:

- Intelligent Monitoring – identify installation defects or weak points (to prevent accidents) and ensure proper subgrade anchoring
- Standard manufacturing processes -- pultrusion, compression molding and affordable “off the shelf” raw materials

Next Generation Helipads and Runway Parking Ramps

New composite systems are needed to meet upcoming (and current) landing/takeoff and parking requirements of aircrafts (both rotary and fixed-wing) in expeditiously situated forward locations. The US military’s current operational scenarios require the agility and flexibility to quickly position land forces, equipment, supplies and medical evacuations at forward locations in a matter of hours – rather than days or weeks, and most often in harsh terrain. In order to achieve these needs, novel advancements in modular composite landing system, for both rotary and fixed wing aircraft, are required.

Following Operation Desert Storm, the Airborne Divisions of the Army and Navy incurred tremendous expense replacing helicopter rotor blades and engines due to foreign object debris (FOD) caused by the rotor-wash from helicopters landing and taking off. Serious crashes and fatalities were also suffered by brownout conditions from helicopter operations on un-surfaced helicopter landing zones. The military conducted initial research [12] to determine the requirements and basic characteristics of an ideal matting system. The next generation of landing pad systems must have “a logistically small footprint, be installed quickly and easily, need minimal special installation tools and material handling equipment (MHE), reduce foreign object debris and damage, and be durable, easily reconfigured and reused.” A new landing mat for landing zones at forward airfields landing -- that is lightweight, strong, and highly heat resistant -- is needed to meet the requirements of current and advanced VTOL aircraft.

In addition, the Air Force AM2 panels used for Rapid Runway Parking Expansion (RPRE) have been known to be insufficient for many years, and although advancements have been made with the development of AM-X composite panels, there is still room for improvements. “The Department of Defense estimates that there are more than 1,200 airfields worldwide that have potential use during contingency operations. The state of these airfields ranges from extremely austere dirt strips to commercial airports and fixed military installations. Many of these airfields do not have adequate aircraft parking aprons to support large contingency operations [13].”

Issues with Current Technology

Brownouts: Fixed wing aircraft require landing materials that are heat and skid resistant; while rotary wing aircraft require a landing zone with materials that can manage and prevent the environmental phenomenon called brownouts. A brownout condition occurs when the helicopter’s rotor downwash creates a whirlwind of dust and foreign objects. Brownouts can blind pilots to visual references and cause spatial disorientation and loss of situational awareness, erode helicopter rotor blades, and affect helicopters’ engines, filters and electronic equipment. Numerous helicopter accidents in Southwest Asia have been caused by brownouts [12].

Lightweight landing pads have been used to suppress dust. These landing pads are composed of semi-permeable mats that allow the dust and sand to fall between holes in the mesh but prevent the sand from coming back up [1]. The mats have been very effective in preventing brownouts and accidents, however, these types of mats fall short in two areas: 1) the mats can become un-staked and the mat material can be swept up by turbulence into the rotor blades, and 2) the mats will not be able to handle the increased downward thermal loads that are anticipated with recent advances in helicopters and VTOL aircraft.

VTOL Turbulence: Recent advances in aviation technology have impacted the landing pad requirements for rotary wing VTOL aircraft and next generation aircrafts like the V-22 Osprey. The technology used for landing pads today cannot withstand the high thermal loads and strong turbulence that the latest versions of VTOL aircraft generate. The stronger turbulence has the potential of turning particles and small rocks into the rotor blades or engine air intake at tremendous speeds and un-staking panels from the ground. Blow-out due to hot gases and increased downward thermal loads generated by the aircraft can also reenter in engine air intake and cause damage [12].

Safety: The use of helipads is crucial for personnel safety and helicopter serviceability as a proper helipad will provide a stable landing surface, better load distribution and prevent brownouts caused by dust picked up by rotor wash. Although flexible woven polyester-based matting systems have been proven effective, their flexible nature does not provide a stable landing surface necessary for helicopter operations or provide the heat and vortex resistance that is now required [1].

Heat and Vortex Resistant: Existing matting products were not designed to handle the advances in the next generation of rotor craft: specifically, the strong vortex created by VTOLs aircrafts as well as the thermal effects due to extremely hot downdrafts from engines [1].

AM-2 Panels: As of 2003, the AM-2 airfield mat system had been in use for over 40 years and had begun to outlive its usefulness due to increased demand for lightweight and quicker installation needs. "The AM-2 is a 1 ½" thick aluminum panel fabricated from an extruded main section and extruded end connectors. The sides of the panels are manufactured to interlock in a rotating motion [13]." The AM-2 panel is heavy, cumbersome to handle, has low durability and is extremely time consuming to transport and install. The Air Force has been seeking advanced ("AM-X") composite panels to replace the AM-2.

Fig 1: AM-2 matting requires a 16-person team to deploy [13]

Innovative Solutions: Design Considerations for Helipads and Runway Ramps

The ICP panel system (described in paragraph 2) will meet many military based criteria for RPRE and portable helipad landing surfaces; hence, improvements to the ICP system would focus on modifying aspects of the panels to be more competitive over current AM-X panel designs and aircraft runway and ramp solutions. The four primary failure modes [7,9] of currently available composite panels will also be addressed:

1. The collapse of ribs under severe local load conditions (a very common phenomenon during hard-landings),
2. Delamination of the top laminate from the ribs when an inadequate amount of fabric reinforcement interconnects the top laminate with the rib,
3. Braking and accelerating forces induced from the wheels generate large in-plane shear forces leading to delamination within a laminate, and

4. Improper designs of joints/connectors on the modular unit result in joint-shear failure, especially when the contact of the mat is highly uneven with the ground.

Enhancing composite panels to resist these common failure modes would include the following considerations and design modifications:

Design and Analysis: Design and analysis models using Abaqus or ANSYS software can be used to simulate conditions and develop better panels. Strength and stiffness prediction equations using in-plane shear and bending energy capacities of the composite laminates can be developed to verify that the proposed mat configuration withstands design limit states. Issues such as delamination of face laminates from ribs should be a prime focus area during design analysis. Computer based modeling can also be used to determine the maximal permissible design loads to accommodate soil pulls and pushes.

Heat Resistant Composite Materials: Further evaluations of current helipads and proposed composite materials and coatings should be conducted to determine the best solution for developing a highly heat-resistant, light-weight and modular panel system. Based on initial analysis, the following glass reinforced resin composites will be used for manufacturing the modified panels: Polyimide Resin Composite, High Reactivity Thermoplastic Modifier Composite, High Temp Resistant Epoxy.

To withstand surface temperature of up to 1000°F under jetting and blasts of hot air, a variety of commercially available coatings and materials should be analyzed for use, including coatings and materials that provide heat diffusion within the plane of the panel -- as opposed to penetrating through the panel thickness [3]. Conductive wire mesh, bonded onto the composite, could aid in reducing hot spot damage by quickly absorbing and dissipating heat. Suitable conductive materials as well as bonding techniques should be reviewed. All heat resistance options should be studied and tested with regard to performance, weight and cost [3,9].

Secure Interlocking/Joining System: A number of different interlocking mechanisms have been evaluated on both scaled and full-size versions of composite panels. As a result of this research, several mechanical interlocking systems have been field tested and found to satisfactorily transfer large magnitudes of shear force while still being easy to field implement. The interlocking joints are variations of tongue-groove mechanisms; the panels are secured to the subgrade with special auguring techniques. These variations have also shown to be inexpensive, resistant to thermal fluctuations, and easy to assemble (requiring only a few simple tools); but further analysis and testing should be performed to optimize the joining mechanisms' ability to withstand the wheel load intensity and frequency of load application required by military and civilian sectors applications. The three types of fasteners evaluated and tested for quick and reliable field assembly/disassembly include:

a. Built-in shear key mechanisms with tongue and groove joining systems integrated in production
b. Mechanical shear transfer devices connecting two contiguous modules, and
c. Special chemical bonding (thermo-plastic polyurethane) mechanisms to transfer in-plane shear but which require local heating for disassembly

Installation and Maintenance: Common logistical factors considered for installation and maintenance include: delivery, unloading, transferring, equipment, ability to be air dropped, and the ability of the installation personnel to quickly dismount and install the modular system in a minimum amount of time. Current panel designs should be evaluated with regard to optimizing logistics for a given application. For example, the size of the unit delivered must easily fit into standard ISO containers. In addition, factors such as unloading, installation, breakdown and re-loading factors must be identified in terms of their limit state of tensile-compression, bending anchor and pull-out strength.

Embedded Sensor Design/Architecture: The addition of a smart, sensor-based system -- to verify that a secure installation has been achieved and to trigger an alert if a module becomes loose -- would be greatly beneficial. Structures like helipads and runway ramps are subjected to damage when exposed to excessive load, use, and harsh weather. It is imperative that a self-monitoring system be employed (whenever a given application permits) that can trigger alerts when there is structural weakness in pegs, excessive tension on cables and composite panels. A low cost, easy to install sensor system that can be attached to critical safety components of the ICP modular system should be developed. The sensor system should be composed of simple, self-powered sensors such as strain gages and vibration sensors. Varied levels of user interface could also be made available; including systems as simple as a blinking LED warning lights or wireless graphical interfaces.

Special Design Considerations – Helipad Panels

Depending on the final design and structural system configuration for helipads, the ICP panel system is estimated to weigh between 1.25 – 4 lbs/sq.ft. The intent is to size the modular units so that two military personnel can handle and assemble a 50' x 100' helipad (or larger) without the use of equipment or exceeding lifting limits (41 pounds to 87 pounds per person). The final size of each modular panel would depend on its actual density, lifting levels and installation form factors. By design, the installation will be intuitive, require minimal time, and remain secure -- while meeting high heat and vortex requirements.

Panel Design: The helipad panel thickness would range from 2” to 4”, with a foam core in the middle varying from 1” to 2” thick, and top and bottom laminates of ¼” to $^{3}/_{8}$” thick. The design focus would be to optimize the strength under rolling loads and impact load conditions as well as creating sufficient joint flex (of the joining mechanism) to minimize local shear and punching effects due to uneven subgrade.

Design for Brownout: The helipad panel would withstand current and next generation rotor craft vortex, rotor wash and extremely hot downdrafts created by VTOLs. The rotor-wash from helicopters landing and taking off on un-surfaced landing zones cause foreign object debris (FOD) and brownout conditions, resulting in costly damage to the rotor blades and engines and unsafe conditions [10, 11]. The approach would be to design a solid contact between the modular panels and subgrade and minimize holes or seams to decrease the chances of dust and FOD when strong vortex and rotor washes occur.

Special Design Considerations - Runway Parking Ramp Panels

Two versions recently developed FRP composite panels are strong candidates for AF runway ramp materials: a 1” thick, single-layer versus a grating-core, with top/bottom mats. The grating-core panel has better fatigue resistance and can withstand heavier loads and load repetitions, while the single-layer panel is quicker to install. Both panel types have interlocking systems capable of transferring substantial shear forces and have loading strengths of 800 kips (~ 44 kips per wheel). Extensive 3D, FE modeling will be performed, with a focus on analysis of CBR6 subgrade interactions, delamination stresses and deployment logistics. Performance testing will be performed with an emphasis on fatigue and force transfer between panels, shear connectors, in-plane friction, durability and temperature testing; up to 1000°F.

1. ***Single-Layer Panel* --** 1” thick FRP panel, weighing between 7-8 lbs/sq. ft., with a cost of approximately $15-18/sq. ft. This panel system is currently being used as a VTOL pad system for Marine Expeditionary Airfields in Alaska (see Figure 2).

2. ***Grating-Core Panel*** – A FRP grating with a top and bottom mat. This panel has a 1” x 1.5” FRP grate sandwiched between two ¼” thick mats. The grating weighs approximately 2.5 lbs/sq. ft. and is reinforced by top and bottom mats weighing between 7-8 lbs/sq. ft. It costs between $17-19/sq. ft. This super strong panel was installed under roadway pavement by West Virginia’s Department of Highways (DOH) in an on-going multi-year study (see Figure 3).

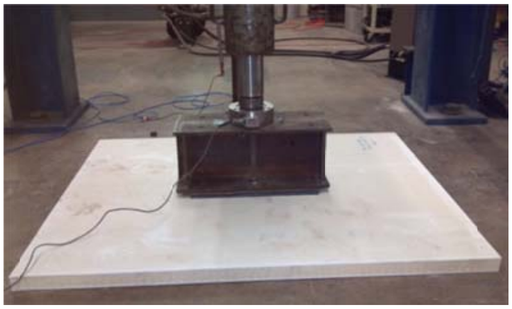

Fig. 2: Single-layer panel (under testing at the WVU-CFC lab)

Fig. 3: FRP grate sandwiched between FRP mats

Manufacturing and Testing Considerations

The following section describes considerations in manufacturing and testing the proposed composite panels.

Manufacturing and Performance Testing: Pultrusion and high temp infusion can be used to manufacture sample and full-scale composite panels [1,8]. The prototype panels should also be tested for mechanical, thermal, impact and abrasion resistance. Strength and stiffness prediction equations, using in-plane shear and bending energy capacities of the composite laminates, can be used to determine if the panel configuration withstands design limit states. Full scale performance testing should be conducted with an emphasis on fatigue and force transfer between panels. Shear connectors and in-plane frictional forces should be evaluated at a system level. Additional testing should also include: static loading, fatigue loading using MTS actuator and moving wheel loads simulating a real time field scenario [3, 5, 6].

Thermal Testing: Prototype and sample coupons should be tested in the laboratory for temperature resistance, including the ability to withstand temperatures of between 650°F and 1000°F for a minimum of 20 minutes. Per appropriate ASTM standards, the prototype and samples should be tested for Heat Distortion Temperature (HDT), at a rate of 1/1000 of an inch per minute at elevated temperatures. As per ASTM D4065, the glass transition temp should be tested in addition to ASTM D 2583 for barcol hardness and ASTM E2092 for heat distortion temperature [9].

Durability Testing: The prototypes should also undergo testing for durability; including weather resistance, puncture strength, tensile strength, tear propagation, shock, stretch and deterioration. Varying temperatures (-30 to 150°F), pH (3 to 11) and moisture and a combination of the above three independent variables [9, 10] should be tested on the prototype samples. At a coupon level, testing should focus on stress versus strain behavior under tension, compression, bending, fatigue, and in-plane as well as interlaminar shear. Impact tests should be conducted on test samples using an Izoid impact testing machine. Any weight loss evaluations or other forms of deteriorations could be carried out using chemical balance, Scanning Electron Microscope (SEM), Optical Microscope and XRD.

Fig 4: Rolling Load/Moving Cart Platform in WVU-CFC lab

Field Testing and Sub-grade Preparation: The modular panel systems should also be field tested as a 200’ x 200’ runway parking ramp and as a helipad landing system. Specialized dump trucks with rear axle loads of 80kips will be used to simulate the 40 kips wheel loads of C17 aircraft. Additional simulations will be designed for the helipad landing system.

Soil below the proposed FRP panel systems should be prepared to satisfy the requirement of CBR6. A number of sensors could be mounted at different locations of the panel to measure strain deformations and establish Dynamic Load Allowance factors, limit states on distortions between contiguous panels, and shear transfer capability of joining mechanisms; both under static and dynamic load conditions.

Applications

As discussed previously, the ICP panel system can be directly applied to the military Helipad Landing System and the Runway Parking Ramp Expansion program, as well as other military and commercial applications. There is a large military market for tough, fire resistant and lightweight composite panels. For example, elevated deck tiles that are lightweight, structurally rigid and extremely fire resistant are used in the Navy. Ships utilize these elevated deck systems to permit communication, electrical and HVAC systems to run underneath the false deck [2]. Army uses include panels for fire resistant portable shelters to support housing, medical and storage facilities.

One of the primary characteristics of the ICP panels is that they have a high degree of temperature and corrosive chemical resistance. Commercial applications range from fire resistant flooring tiles to building materials for decking, fire resistant doors, room dividers and nonstructural wall partitions. Additional uses include flooring tiles for hazardous environments such as chemical plants and for use the support of heavy equipment in harsh environments.

Conclusion

The US military's current operational scenarios require the agility and flexibility to quickly position land forces, equipment and supplies at forward locations in a matter of hours – rather than days or weeks, and most often in harsh terrain. The expeditious configuration of landing sites is one piece of the operation: rapid response times to set up sites provide warfighters with increased flexibility for landing zones and medical evacuations. Both fixed wing and rotary wing aircraft have their own requirements for landing zones and materials used at forward airfields. For example, fixed wing aircraft require landing materials that are heat and skid resistant; while rotary wing aircraft require a landing zone with materials that can manage and prevent the environmental phenomenon called brownouts.

The Erallo and WVU-CFC team have existing composite pad technology that has been field tested under harsh environments and extreme loading conditions. With minor design modifications, this composite pad technology could meet and exceed the challenges of Helipad Landing Systems and Rapid Parking Ramp Requirements program. In addition, our current and proposed composite panel technology could be readily modified to suite a wide variety of both military and civil applications.

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