Theme 3-1: Polymers and Composite Materials - 2023

Title	Name of the PI	List the Names of the Co-Is	Department	Abstract	Starting Date	Ending Date	Funding	Amount of Funding
Nickel-Titanium Shape Memory Strut-based Sandwich Panel Core for Blast Mitigation Applications	Zied Bahroun	Noha Mohamed Hassan Hussein	INE	Sandwich panels portray superior mechanical properties due to their specific stiffness and strength which made them more desirable in different industries especially automotive and aerospace. The core of the sandwich structures plays a major role in ensuring that. Increasing the load-bearing capabilities of sandwich panels can widen the horizon for several high-performance applications that would revolutionize their use in the industry. From the explored literature, many authors have researched the development of novel complex geometries that would enhance the properties of the panels. This has been done in terms of core geometry, material, and reinforcement. Complex cellular structures, however, are hard to manufacture and can have high costs. Additive manufacturing has been explored for complex geometries; however, it has not been explored in terms of shape memory material. Since shape memory materials have exceptional mechanical properties, they can be used in sandwich panels to obtain the desired results. In this research, investigators aim to develop a novel sandwich panel with a strut-based structural core made of nickel-titanium shape memory alloy. The main goal of the project is to optimize sandwich panels in terms of core structure and volume fraction. Through introducing the new sandwich panel using additive manufacturing, all parts of the sandwich panel will be manufactured as a single layer and reduce the complexity in manufacturing structural elements. The additive manufacturing process parameters will be optimized to eliminate any damage to the strut that occurs during printing. Conventional manufacturing methods will then be compared to the additive manufactured core in terms of cost and performance. After selecting and fine tuning the manufacturing process, physical and numerical experiments will be used to study the effect of shape memory strut-based core structure on the behavior of sandwich panels under various loading conditions including blast load. Moreover, all controllable design factors of the sandwich panels will be investigated for the purpose of optimizing the design parameters. This will be done through the aid of mathematical optimization techniques to obtain the best core design that maximizes panel impact resistance at minimum cost.	01/06/2023	31/05/2025	FRG	337700
Developing a Low-Cost Process for Manufacturing Reinforced Application-Tailored 3D Printing Thermoplastic Filaments	Maen Alkhader	none	MCE	Fiber reinforced polymer (FRP) composites, with both thermoset and thermoplastic matrices, have become popular in marine, aerospace, and structural applications due to their high specific stiffness and strength as well as their ability to conform to complex shapes without the need for intensive subtractive machining. Until recently, thermoset FRP composites have been considered as superior to their thermoplastic counterparts as they exhibit lower temperature sensitivity and higher stiffness and strength. However, the advent of new thermoplastics that offer high melting temperatures and reduced temperature sensitivity motivated the industry to move towards thermoplastic FRP composites. This shift was also encouraged by thermoplastics' higher ductility and toughness as well as better aptitude to satisfy current sustainability objectives as compared to their thermoset counterparts. Thermoplastic FRP composites are mendable and amendable, do not produce harmful emissions during their consolidation, and can potentially be recycled. Two major hurdles slow the fabrication of thermoplastic FRP composites: preparation of freeform and forced consolidation at elevated temperatures and pressures in closed molds. The former is time and labor intensive process, while the latter is an energy consuming process. To overcome these hurdles and to automate the fabrication processes of thermoplastic composites, automated tape laying (ATL) coupled with in-situ consolidation has been proposed. During this process, composite tapes are simultaneously heated, layered, and consolidated following a layer-by-layer build-up process that resembles filament based 3D printing. This process is fast, efficient, and energy conserving. However, the inter-laminar bond strength in consolidated laminates produced using the in-situ curing ATL process is often inferior to that of laminates produced using regular closed mold processes. Improving the bond strength requires optimizing the material dependent consolidation process parameters relevant to the in-situ curing ATL process. These parameters comprise consolidation pressure, temperature, and laying rate or consolidation time. This work aims to experimentally quantify the individual and synergistic effects of the aforementioned process parameters on the inter-laminar bond strength in thermoplastic FRP laminates produced using the coupled ATL-In-situ curing process. Results will determine the material dependent conditions required to realize a sustainable manufacturing process that produces structurally reliable thermoplastic FRP	01/06/2023	31/05/2024	FRG	124850
Designing an impact resistant hybrid fiber reinforced composite using nanofillers and carbon nanotubes.	Noha Mohamed Hassan Hussein	Zied Bahroun, Mahmoud Awad, Rami Asad	INE	There is a growing interest to replace conventional metallic components by lightweight composite structures especially in high performance aerospace, naval and automotive applications. Composite structures offer superior strength, stiffness and fatigue properties. However, they fall short when it comes to their impact resistance. The heterogeneous structure of the material results in a complex distribution of stresses and strains that makes it difficult to predict the damage behavior. Various failure modes including fiber/matrix debonding, fiber breakage, matrix cracking and delamination may initiate concurrently at one or more location in the composite. Researchers investigated the influence of modifying the composite structure to maximize its energy absorption. Hybrid structures based on mixture of different fiber materials were proposed, various fiber/ metal laminates were examined, sandwich cored structures were designed and nanofillers were added to improve load-bearing capacity of the structure. In spite of the improvements achieved, most of the reviewed literature experimentally investigates effect of one design variable at a time, such as constituents' properties, on the composite structure failure response. During loading, all design variables interactively affect the load bearing capability. Designing a composite structure that suppresses localized damage from propagating further requires controlling all major design attributes at the same time. The objective of this research is to design a hyprid reinforced composite with carbon nanotubes added in specific locations to limit damage propagation. Designing a structure with enhanced load bearing capability opens door for new high performance applications that requires an impact resilient structure whether to sustain a crash or a blast.	01/06/2019	31/05/2021	FRG	140000
Enabling the development of high fidelity 4D printed metamaterials with novel and tunable mechanical properties	Maen Alkhader	none	MCE	Shape memory polymer-based lattice metamaterials have been gaining interest due to their ability to deliver tunable and adaptive unique properties unobserved in nature. Their exceptional abilities stem from having a well-designed lattice geometry fabricated from a shape memory polymer (SMP). Their lattice geometric features can be designed to give rise to unique properties unseen in nature, while their active constituent materials allow them to exhibit tunable and adaptive properties. Developing lattice metamaterials has been made possible by recent advances in additive manufacturing technologies, particularly fused deposition modeling (FDM). These developments have made 3D printing complex lattice structures using shape memory polymers a reality. This reality is called 4D printing: the classical 3D acronym representing the fabrication process is modified to represent a fourth dimension (4D), to symbolize tunability stemming from using SMP constituents. To design 4D printed lattice metamaterials that capitalize on the great potential of their unique properties and tunable characteristics, it is instrumental to have constitutive models that can accurately describe the thermo-mechanical behavior of 3D printed shape memory polymers under complex loading scenarios. This would allow for utilizing computer aided design and analysis tools such as finite element models to design 4D printed lattice metamaterials with repeatable and predictable unique properties and tunable characteristics. However, accurate constitutive models for 4D printed SMPs are currently lacking due to the insufficient understanding of the effects of 3D printing process parameters on the properties of 4D printed SMPs.This proposed work aims to address this issue by experimentally characterizing the effects of 3D printing process parameters on the thermo-mechanical characteristics of SMPs. This investigation will cover the critical aspects of shape fixity, shape recovery, residual stresses, recovery rate, recovery force, and dimensional stability of 4D printed SMPs. Obtained results will be used to develop constitutive models that accurately describe the thermo-mechanical behavior of 4D printed SMPs. These models will enable engineers to design 4D printed polymeric lattice metamaterials with unique and tunable properties.Relevance of this work extends to beyond 4D printed SMPs as it can help understand and model the behavior of 3D printed polymers at large.	01/06/2023	31/05/2025	FRG	557050
Novel Sandwich Panel Core Design with Polymeric Foam and Structural Reinforcement	Noha Mohamed Hassan Hussein	Zied Bahroun	INE	Composite structures are manufactured either as laminates which are stacked and bonded fiber-reinforced sheets or as a sandwich panel where a low-density core is adhesively bonded to face sheets. Laminates offers the benefit of a balanced structure with high in-plane stiffness. In cases where a low weight but large bending stiffness is required, the core of sandwich panels plays a major role. The ability to increase the load-bearing capability of those panels will open the door for more high-performance applications. From the surveyed literature several authors researched developing new complex geometries to enhance the impact resistance of the composites, while others considered reinforcing the core structure with different materials. None of the surveyed literature considered examining a composite core with structural elements for reinforcements. With the advancement of additive manufacturing, a new reinforcement type can be introduced to a composite core that is neither a dispersed particle nor a fiber. This project proposes a novel composite structure that integrates advantages of a structural core and a polymeric foam core enhancing the performance of sandwich panels. Similar process could be used to develop composites in general. The ability to use 3d additive manufacturing and printing different layers with different structures and volume fractions as one body might revolutionize the way composites are designed, perform and fail.	01/06/2021	31/05/2023	FRG	310500
Optimizing manufacturing process of a novel porous Aluminum Matrix Composite Foam with Graphene reinforcement	Noha Mohamed Hassan Hussein	Mahmoud Awad, Sathish Kannan	INE	Metal foams has drawn an increasing interest especially in applications where weight and energy absorption are critical. Extensive studies have been performed on the fabrication techniques and characterizations of metal foams while few researchers examined the manufacturing of porous metal matrix composites. Although the first attempt to develop metallic foams date back to the 1950s, there is still a lack of understanding of the basic metal foaming mechanism. During processing, it is difficult to control the macroscopic shape, density and distribution of the pores, simultaneously. For metal matrix composites it is also difficult to disperse reinforcement homogenously. Both constituents could react with the environment degrading its superior properties. To properly design the material, the impact of all process parameters has to be investigated and new synthesis methodologies have to be developed accordingly. In this project, two new synthesis techniques are proposed to tackle those issues that involve powder metallurgy and melt infiltration. To avoid challenges associated with the low wetting ability of the graphene by aluminum and to avoid formation of non-desired phases like Aluminum carbide, Al4C3, Graphene homogenised with nanoparticles of Nickel/Copper/Zinc in the ratio of (5:5) is used. The effect of the space holder material, graphene type, particles size, sintering temperature, time and pressure are studied using design of experiments, modeling and optimization techniques. The purpose of this research is to recommend an optimal manufacturing technique and settings to produce metal matrix composite foam with desired properties maximized while minimizing manufacturing cost and time. Results support several industries from military, automotive, medical and aerospace in developing this innovative material with superior properties and coping with their need for advanced applications.	01/06/2018	10/03/2019	FRG	75000
Developing a low-cost process for manufacturing reinforced application-tailored 3D printing thermoplastic filaments	Maen Alkhader	none	MCE	Low-cost desktop-sized fused deposition modelling (FDM) printers have been widely embraced by small to large scale institutions and individuals. To further enhance their utility and add another dimension to the range of materials that desktop they can process, multiple efforts originating from within the desktop FDM community have tried to create low-cost desktop-sized solutions capable of fabricating customized filaments. These attempts utilized short single screw extruders and did not have the mixing abilities provided by industrial multi-stage twin-screw extruders. Therefore, low-cost solutions were not effective in fabricating filaments reinforced with particles. This work develops a solution that enables low-cost extruders to fabricate filaments comprising reinforcing particles. In the proposed solution, particles are heated and deposited on thermoplastic pellets to form a coating. Coated pellets are subsequently extruded using a low-cost desktop single-screw extruder. Dispersing the particles through coating the pellets minimizes the need for the mixing process that takes place in industrial extruders. The viability of the process has been proven by the PI in a very recent work in which Polylactic Acid filaments reinforced with dune sand were fabricated. Early results showed that filaments' stiffness and strength depend nonlinearly on the content of reinforcing sand particles. Microstructural microscopic images showed that the suggested process can produce filaments with effectively dispersed reinforcements. Although the early results support the viability of the proposed process, their remain lingering questions regarding: its applicability to other materials, its effects on the property of filaments it produces, the level of reinforcement volume fraction that it can achieve, and its optimum process parameters. This work aims to answer these questions by investigating experimentally the ability of the process to fabricate reinforced filaments from different thermoplastics and a range of reinforcements. In addition, the sensitivity of the produced filaments to process parameters will be investigated. Experimental assessment of the filaments' quality will emphasize on their mechanical properties and microstructure. The success of this work will provide the community of desktop FDM 3D printers with a low-cost enabling platform that allows for creating in-house application-tailored filaments.	01/06/2023	31/05/2024	FRG	124850