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Research TMD

Advancements in Metal-Plastic Hybrid Structures: Experimental Analysis and Design Optimization of 3D-Printed Honeycomb Frameworks

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Abstract

The exploration of metal-plastic hybrid structures has gained significant attention due to their potential for lightweight, high-strength applications across industries such as aerospace, automotive, and construction. This study investigates the experimental and design enhancements of a metal-plastic hybrid structure utilizing a honeycomb architecture produced through 3D printing. By integrating metals with plastic polymers in a honeycomb configuration, this hybrid approach aims to combine the high strength and stiffness of metals with the flexibility and lightweight nature of plastics. Various experimental tests, including compression, tensile, and impact tests, were conducted to evaluate the mechanical properties of different metal-plastic hybrid combinations and identify the optimal material blend for structural resilience and durability. The study also explores design improvements in honeycomb cell geometry and thickness, examining how these factors influence load distribution, energy absorption, and weight efficiency. Advanced simulation models were developed to predict structural behavior, validate experimental results, and guide design optimization. Findings demonstrate that specific metal-plastic hybrid compositions can achieve a 20-30% reduction in weight while maintaining comparable strength to all-metal counterparts. These insights offer valuable guidelines for designing metal-plastic hybrid structures with enhanced performance, furthering the potential for 3D-printed honeycomb frameworks in sustainable and high-performance applications.

Keywords: FEA analysis, Stress, 3D Printing, composite materials, etc.

INTRODUCTION

In the late 1980s, an idea of plastic/metal hybrid technology came into existence. This technology's name is derived from the Greek term "hybrid," which describes the materials' varying origins and characteristics. General Motors created a prototype display panel support framework by leveraging our experience. LANXESS Plastic/Metal Hybrid technology is being utilized by automakers including Audi, Ford, and Nissan to manufacture a variety of pieces, including seating and front-end structures. It reduces weight for fuel efficiency while providing strength, rigidity, and force absorption [3–5].

As a relatively novel material, composite materials currently lack a widely recognized definition. Two or more distinct materials are put together to create composites. While the compound presents a totally new material, their primary constituents separately have unique features and characteristics. The qualities of this material are entirely new, distinct, and different from those of its constituent parts. Enhancing structural, tribological,

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thermal, chemical, or other material features is the goal of this material compounding process. There are two or more phases in a composite substance because the constituent parts do not mix and dissolve among others [6].

The reverse of subtractive assembly, which involves hollowing out a piece of plastic or metal using a machine like a router, is 3D printing. Compared to conventional manufacturing procedures, 3D printing allows you to create intricate forms with less material. As the number of companies that have not yet incorporated additive manufacturing into their supply chains continues to decline, the use of 3D printing has attained a critical mass. In the beginning, 3D printing was only appropriate for one-off manufacturing and prototyping, but it is currently quickly evolving into a production strategy (Figure 1).

Figure 1. Radiator.

LITERATURE REVIEW

"Energy absorption on metal-composite hybrid structures: Experimental and numerical simulation" by Gang Zheng, Zhen Wang, Kai Song [7].

The mechanical behavior of hybridization constructions under quasi-static axial loading is examined in this work. The quasi-static axial compression tests are first carried using hybrid tubes that utilize various construction schemes, stacking orders, and foam fillers. Additionally, as a comparison of the hybrid tubes, the aluminum, carbon fiber reinforced plastic (CFRP), and aluminum foam tubes are investigated as well. The aluminum/CFRP hybrid tubes, both empty and loaded with foam, were found to exhibit superior mechanical behavior features. Experiments have validated findings based on the mathematical models used. This study experimentally and numerically investigated the influence of the configurational scheme, the clearance size, the stacking sequence, as well as the foam filling on the mechanical behavior of aluminum/CFRP hybrid tubes under the quasi-static axial compressive loading conditions. "Separation and reclamation of automotive hybrid structures made of metal and fibre-reinforced plastic" by Swetlana Schweizer, Anna Becker-Staines, Thomas Tröster [8].

Methods for the divide of CFRP and metal hybrid constructions are presented in this paper along with the corresponding procedures windows and boundary necessities. The separation is performed by the introduction of thermal heat through furnace heating, induction heating, resistance heating, and infrared heating. The current study describes a technique that uses a thermal procedure to separate hybrid building plans (metal and CFRP) for independent recycling. Several heating methods, including inductive methods, resistance, infrared, and furnace, were used to study the thermal process on the hybrid structures. The current work examines appropriate process windows and the boundary conditions for the corresponding heating methodologies. Using microscopic data, the impact of different heating methods on the separation process is demonstrated.

"Process combinations for the manufacturing of metal-plastic hybrid parts" by W-G Drossel, C Lies, A Albert, R Haase, R Müller and P Scholz [9].

Four creative manufacturing methods for the creation of metal-plastic-hybrid parts are presented in the article. Light and extremely strong substances are used in the automotive and aerospace sectors to improve product performance by lowering weight and energy consumption. Reinforced plastic composites are of extreme importance. Although they provide reinforced polymers as a substitute, it is still not cost-effective. A promising method for the cost-effective realization of compact buildings with a high achievement potential is the use of hybrid metal-plastic constructions based on the idea of "using the right material at the correct place."

“Laser-based surface pre-treatment for metal-plastic hybrids using a new process strategy” by C. Wunderling, L. Mayr, S.P. Meyer, M.F. Zaeh [10].

In order to thermally combine brass samples with a carbon-fiber reinforced thermoset, RAC was used as a before treatment in this work. Circular laser beam oscillation was used in a new process design for this purpose. Surface enlargement and roughness measurements were used to examine the topography. In this work, a design criterion was developed mathematically and verified experimentally by analyzing the metal's resulting topography in relation to surface roughness. likewise, the strength derived from traditional beam trajectories was contrasted with the joint toughness. Steel substrates were connected using a thermoset reinforced with carbon fiber for checking. In comparison to traditional straightening trajectories, the laser-based pre-treatment employing the circularly oscillating led focal point produced a comparable joint strength & was more effective when paired with on-the-fly processing. As a result, processing time can be greatly minimized.

“Metal-plastic hybrid 3D printing using catalyst-loaded filament and electrolessplating” by Jing Zhan, Takayuki Tamura, Xiaotong Li, Zhenghao Ma, Michinari Sone, Masahiro Yoshino , Shinjiro Umezu, Hirotaka Sato [11].

In this study, a plastic 3D printing process involving electrolessplating, a type of chemical metal deposition, is proposed and shown. The technology may metalize specific regions of the acrylonitrile butadiene sty (ABS)-based 3D-printed plastic building materials. This study produced and custom-fabricated an ABS filament that incorporates palladium chloride ($PdCl2$) as a catalyst precursor, suitable for use in a fused filament fabrication (FFF) 3D printer, because electroless plating is initiated by a palladium (Pd) catalyst. There are two nozzles on the 3D printer. One uses an everyday filament to create the primary ABS 3D structure component (i.e., pure ABS without $PdCl2$), while the other uses a bespoke jet to deposit a $PdCl2$-loaded ABS layer onto a chosen area of interest. The 3D-printed component is then submerged straight into an electroless plating slurry of nickel (Ni). “Crash analysis of a passenger car bumper assembly to improve design for impact test” by Mohammed Abdul Basith, N. Chandrashekar Reddy, Sudhakar Uppalapati, S.P. Jani. 2214-7853/ 2020 Elsevier Ltd.https://doi.org/10.1016/j.matpr.2020.08.561 [1].

In this research paper author mohammed abdul basith et al, explain about the crash analysis of the front bumper. Study on the design of the front bumper to improve the performance in impact test. In this study author mainly study this crash test on the three specific speed which is 40, 60 and 80 km/hr. In the recent years the material of the vehicle front bumper is aluminium alloy thermoplastic and mild steel. Front-end incidents account for the majority of passenger vehicle accidents. Therefore, the material and design of the bumper needs to be taken into consideration in order to absorb the impact force and the energy released during a vehicle incident. This will increase passenger safety and lessen the damage to the body pieces. Now with the improved research in the field of design, more affordable and lightweight materials are available at affordable rates and can be used for manufacturing of a passenger vehicle bumper. The reduced weight of the bumper also increases the fuel efficiency of the car and also stability in performance of the car bumper. The repair cost of the material is affordable, more flexible for modification.

"3D printing as an enabling technology to implement maritime plastic Circular Economy" by J. Garrido, J. Saez, J.I. Armesto, A.M. Espada, D. Silva, J. Goikoetxea, A.Arrillaga. Procedia Manufacturing 51 (2020) [2].

In this literature author j Garrido explain about the 3D printing technology. The approach blends the ideas of the Circular Economy with the development of new, environmentally friendly materials from ocean plastic waste and the adoption of 3D printing, a the moment manufacturing technique that is adaptable enough to change with the manufacturing environment to create new, eco-innovative small and medium parts as well as components. The project's ongoing research on how to implement the circular economy in the maritime industry using plastic trash is provided in this document. This paper has presented the results of the research survey about strategies to introduce a Circular Economy in the maritime sector for plastic wastes.

OBJECTIVES

CATIA V5R20 software models of existing components used in the auto industry.

To optimized existing component by using thermoplastics material.

Developing solutions that better satisfy end-user needs by utilizing the greater design flexibility available through 3D printing.

To select suitable material available in 3D printers for manufacturing

To perform static analysis of steel pipe using ANSYS 19 software.

To perform experimental testing of new, optimize model by using UTM

Experimental testing and correlating result Methodology

This study optimizes the hybrid solar-wind energy technique's design using a mathematical model. The energy balance equation, which takes into account the system's energy inputs as well as its results, serves as the foundation for the model. The model also considers system factors including battery capacity, wind turbine capacity, and rooftop solar panel area. To optimize the system design for greatest energy production and minimal cost, the model is solved using simulation technology.

Design and Operation

Using computer systems (or workstations) to help with design development, modification, analysis, or optimization is known as computer-aided design, or CAD. With CAD software, a designer may be happier, produce better designs, improve documentation and communication, and build a database for manufacturing. Electronic files for printing, machining and other production processes are frequently the output of CAD. Another name that is used is CADD, which stands for Computer Assisted Design and Drafting.

Geometry can be edited using a history tree using either explicit or direct modeling. Once geometry is created using a sketch, direct modeling can incorporate relationships between selected models (such as tangency and concentricity) that are not possible with parametric modeling methods (Figure 2-4).

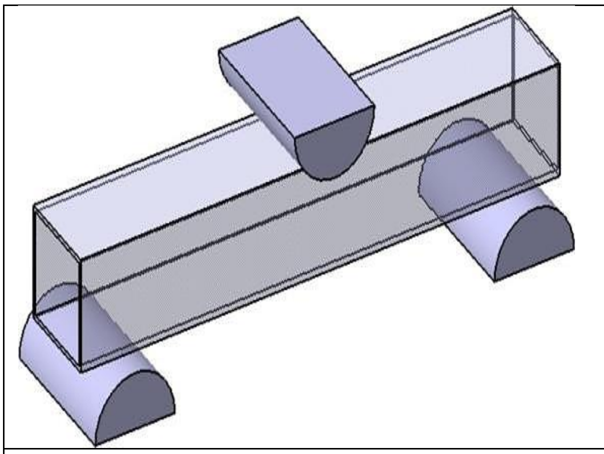

Figure 2. Specimen for dynamic analysis without plastic.

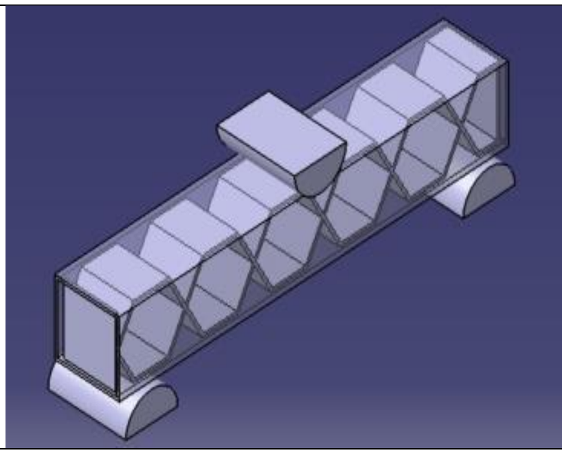

Figure 3. Honeycomb 3D printing structure

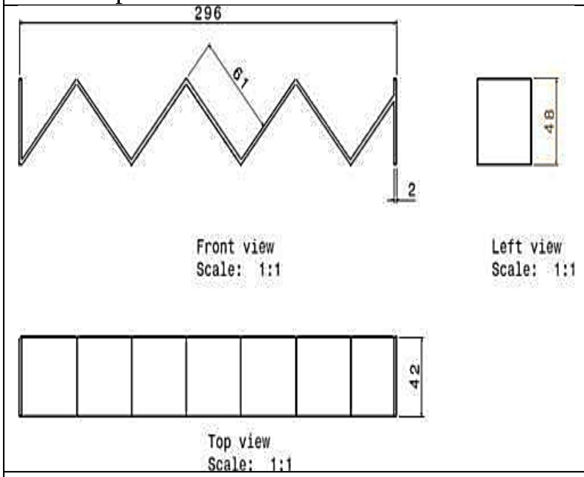

Figure 4. Zig-zag 3D printing structure Analysis With Material Structural Steel and Abs/Pla 3D Printing Material

When analyzing and comparing structural steel with ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic Acid) — two common 3D printing materials — we need to consider several key factors including material properties, performance characteristics, manufacturing processes, and application suitability. Each material is used for distinct purposes, and their capabilities vary significantly depending on the intended use case (Table 1, Table 2).

Table 1. Material used for steel pipe.

Properties of outline row 4: Steel 4340			
	A	***B***	***C***
1	*Property*	*Value*	*Unit*
2.	Material field variables	Table	
3.	Density	7830	Kg m^-3
4.	Specific heat, C	477	J kg^-1C^-1
5.	+ Johnson cook strength		
14	Bulk modulus	1.59E+11	Pa
15	Shear modulus	8.18E+10	Pa

Table 2. Material used for 3D printing structure.

Properties of outline row 3: ABS			
	A	***B***	***C***
1	*Property*	*Value*	*Unit*
2.	Material field variables	Table	
3	Density	1040	Kgm^-3
4.	- Isotropic elasticity		
5.	Derive from	Young's modulus and poisso….	
6.	Young's modulus	2390	MPa
7.	Poisson's Ratio	0.399	
8.	Bulk modulus	3.9439E09	Pa
9.	Shear modulus	8.5418E+08	Pa
10	- Bilinear isotropic hardening		
11.	Yield strength	45	MPa
12.	Tangent modulus	700	MPa

RESULTS
FEA Analysis

When performing FEA (Finite Element Analysis) on a cross-structured 3D printed component, several factors need to be considered to evaluate its structural performance, including material properties, geometrical configuration, boundary conditions, load conditions, and printing orientation. FEA helps determine the stress distribution, strain behavior, and deformation of the structure under real-world conditions, which can provide valuable insights into the component's functionality and reliability (Figures 5, 6).

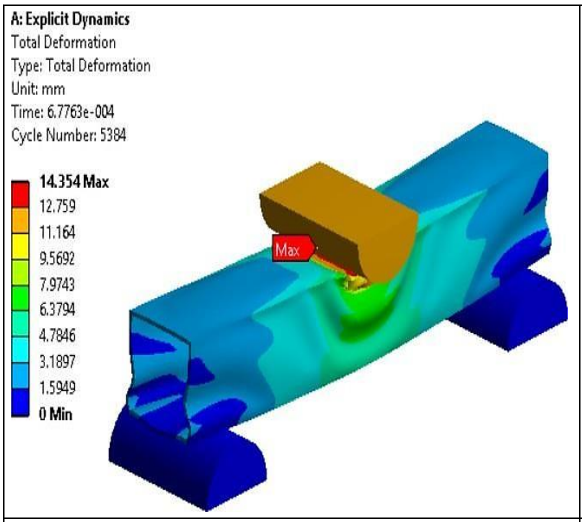

Figure 5. Total deformation

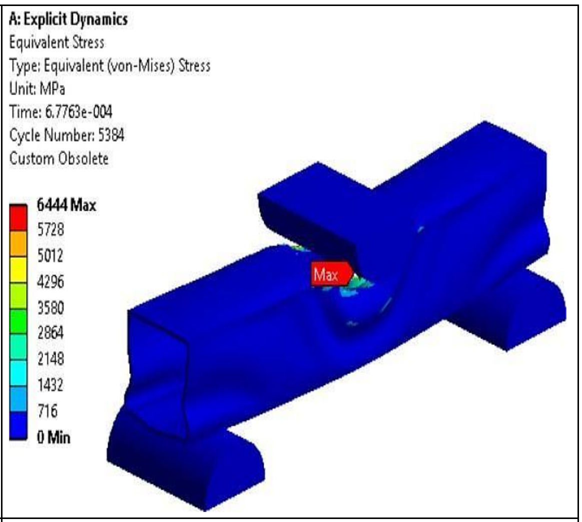

Figure 6. Equivalent stress.

For this example, we will assume a cross-shaped 3D printed structure as the subject of analysis. This could be a part used in mechanical, aerospace, automotive, or structural engineering applications. The cross structure could be a support frame, bracket, or a lattice structure (Figures 7-9).

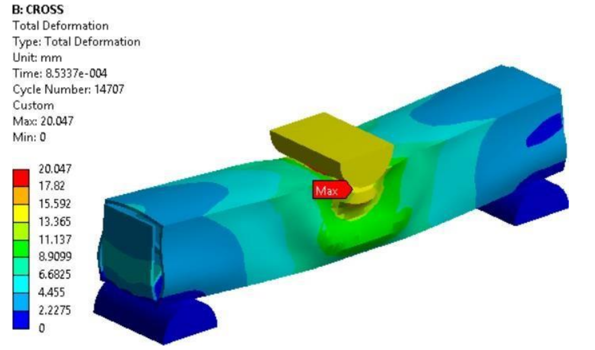

Figure 7. Total deformation

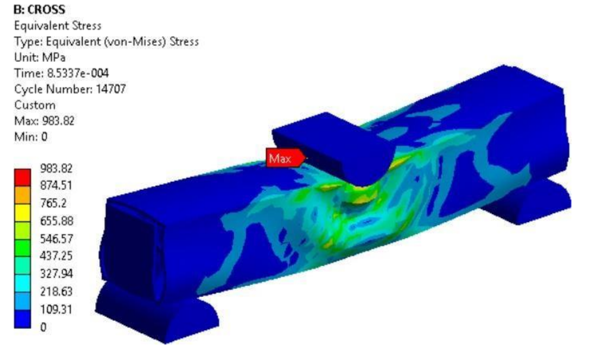

Figure 8. Equivalent stress Experimental Testing.

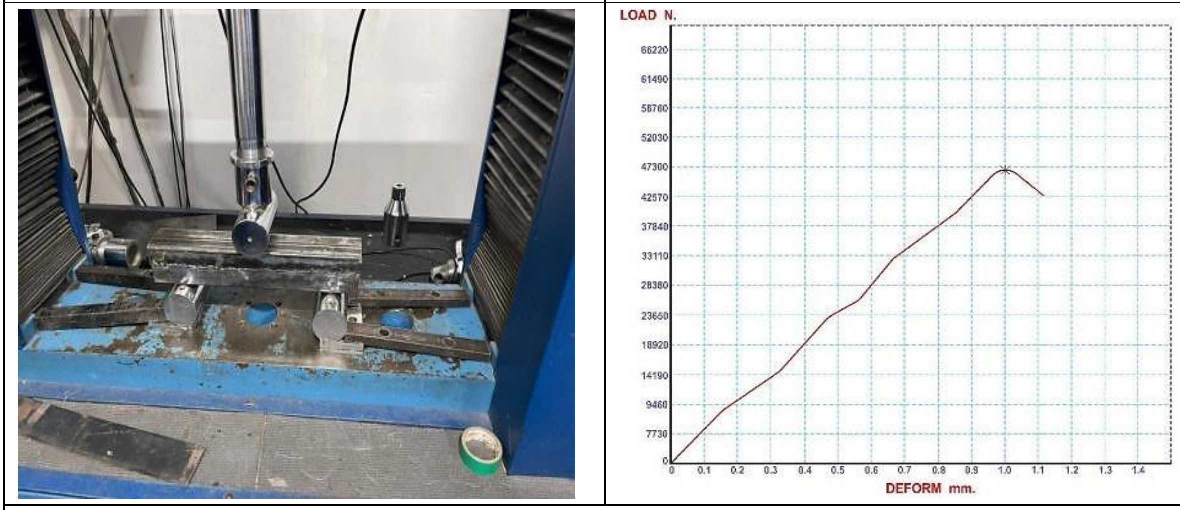

Figure 9. FEA analysis of cross 3d printing structure

FEA Analysis Results

After performing the Finite Element Analysis (FEA) of the cross-structured 3D printed component, the results typically cover several key parameters that help assess the component's structural performance under specific load conditions. These results can be visualized and interpreted using stress, strain, displacement, and safety factor plots, which are generated during the simulation process. (Table 3, Table 4)

Table 3. Experimental Testing with FEA Analysis Results.

S.N.	Structure type	Total deformation (mm)	Reaction force (kn)
1	ZIG ZAG	17.63	87.97
2	Cross	20.04	88.556
3	Honeycomb	23.68	153

Table 4. Experimental Testing with FEA Analysis Results.

S.N.	Validation type	Reaction force (n)
1	FEA	49153
2	EXPERIMENTAL	47300

CONCLUSION

Study on crash test and types of crash test perform in global NCAP.

Study on metal plastic hybrid technology to reduce impact of accident on human body.

Perform dynamic analysis on singular metal part to find out maximum deformation and equivalent stress generated on specimen.

Design three types of 3D printing structure zig zag, cross and honeycomb to find out better structure.

Perform dynamic analysis on the all three structure and find out total deformation, equivalent stress and reaction force using ansys software.

3D print better reaction force structure which is honey comb structure.

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