MULTISCALE
SYSTEMS

Mechanical Metamaterials

Advanced materials made lighter, stronger, smarter

Solutions

MetaCORE™
MetaCORE-LD™

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Contents

Introduction

Mechanical metamaterials

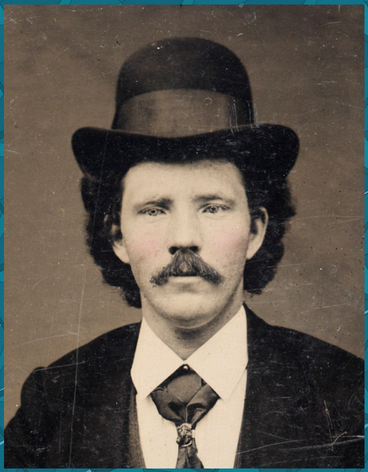
Metamaterials: Advanced Materials Without Chemistry

Mechanical metamaterials are lighter, stronger, and more multifunctional than traditional materials.This enhancement comes from the application of origami-inspired geometric patterns applied to traditional materials such as polymers, metals, and composites.

Similar to honeycomb and corrugated panels, geometric patterning is the key to unlocking new potential from common materials without chemical or molecular engineering. Our approach to material engineering via pattern design enables us to outperform these legacy alternatives and achieve far greater performance.

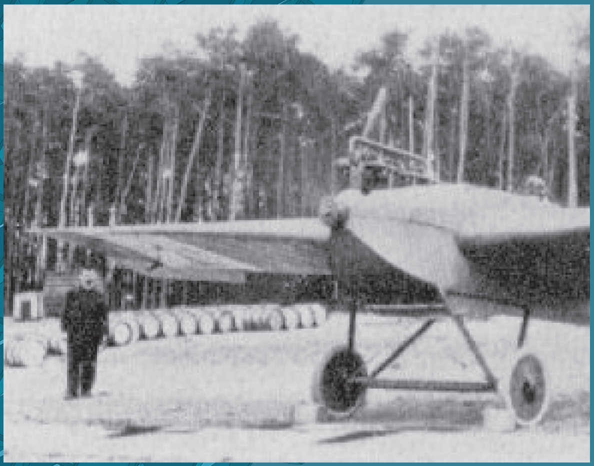
By digitally analyzing billions of possible geometric combinations in a matter of seconds, we can down-select the most promising candidates, prototype the designs, and validate their characteristics. This approach saves time, money, and generates savings for our customers and their end users.

A Concise History of Structured Materials



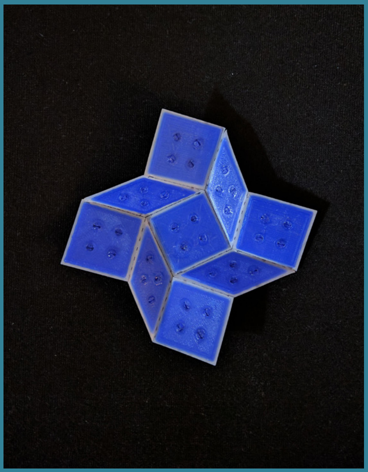
1856

Corrugated paper patented. Used as a liner for tall hats.



1915

Honeycomb cores for aircrafts patented by Hugo Junkers.



2014

Origami inspires mechanical metamaterials.

Technology

Translating basic science to advanced solutions

Design Process

We have a 3-step computational design process[1] that translates origami-inspired geometry into fabrication-ready mechanical metamaterials[2].

Step 1: Origami Math

Our technical team have taken their PhD and postdoctoral research in physics and applied it to engineering next-generation materials. Using math that’s inspired by the geometry of origami, we interface non-linear computational geometry and thin shell elasticity with multi-objective optimization to design our mechanical metamaterials.

Step 2: Develop the Representative Volume Element (RVE)

Taking the parameterized designs of Step 1, we use homogenization theory to create a RVE. This theoretical abstraction allows us to connect structure to function in order to predict how the metamaterial will react in real-life scenarios.

Step 3: 3D Metamaterial Structure

We run high-throughput screens with *Ansys* on parametric RVE models to forecast real-world behavior. The end result is a 3D design that we can fabricate, test, validate, and repeat until the desired outcomes are achieved.

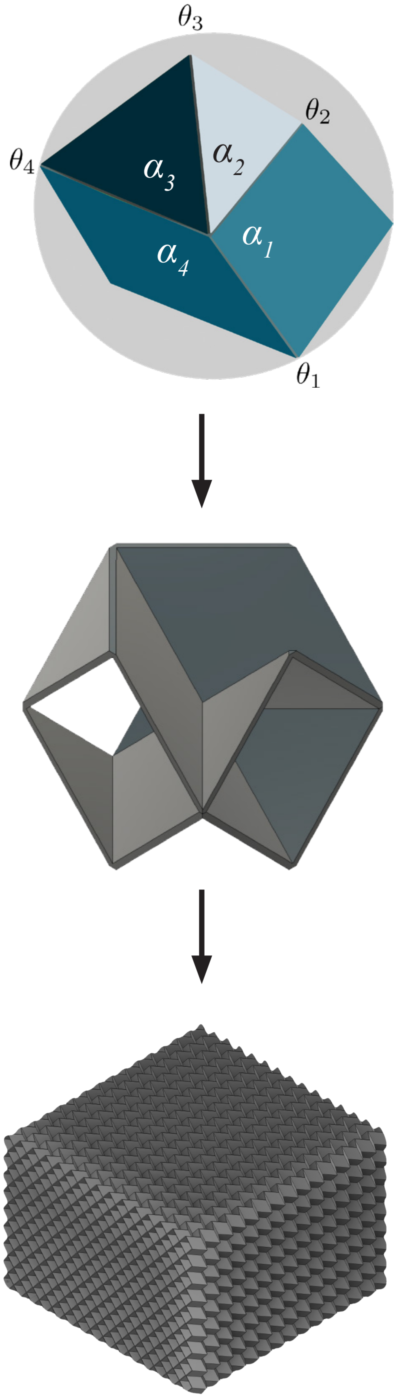


Fig. 1.1: *3-step metamaterial design process*

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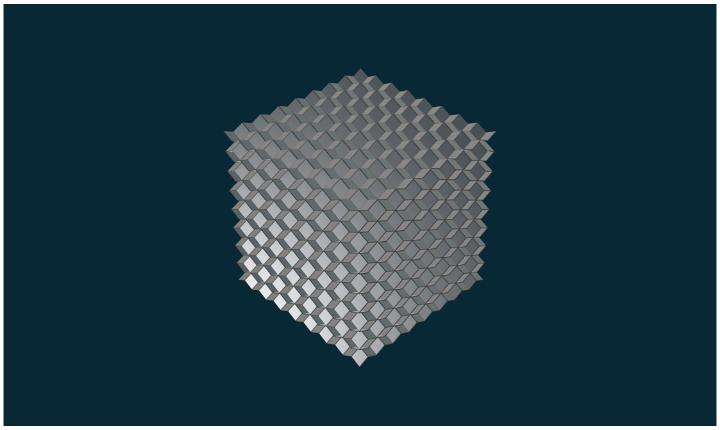
[1] Multiscale Systems, Inc.. Material With Proisotropic Stress Response Structure. USPTO 63/044,646, filed June 26, 2020.

[2] See **multiscalesystems.com/resources** for list of relevant publications.

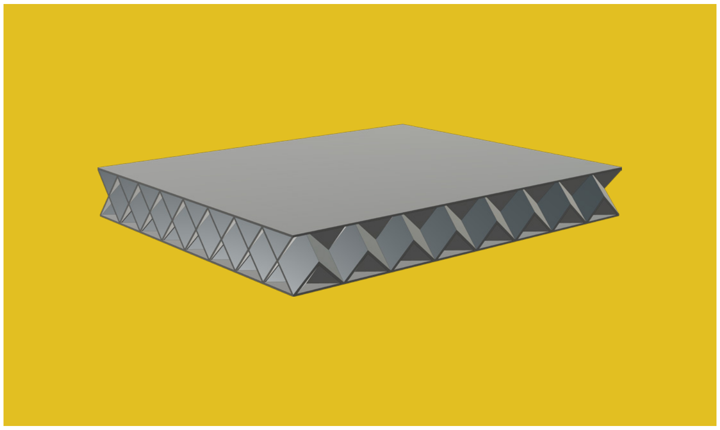
Metamaterial Solutions

With funding from NASA, the US Department of Energy, and the US National Science Foundation, we were contracted to translate our technology into commercial metamaterial solutions. While these Federal agencies are looking to the industries and markets of tomorrow, customers today can gain a competitive advantage by engineering their products with our lighter, stronger, and smarter materials.



MetaCORE™

MetaCORE is a lightweight, impact absorbing metamaterial. Optimized for Crush Force Efficiency and Specific Energy Absorption, its uses span a variety of markets, including transportation, electric vehicles, aerospace, and defense (**pg. 10**).



MetaCORE-LD™

Derived from the innovations of MetaCORE, MetaCORE-LD is a structural panel product optimized for lightweighting in the transportation market. Applications include semi-trailer paneling, urban air mobility vehicles, and electric vehicles (**pg. 17**).

MetaTHERM™ (in development)

MetaTHERM is our metamaterial designed for applications in Enhanced Geothermal Systems (EGS) and is optimized for controlled thermal expansion, holding extreme pressure differentials, and mitigating equipment failure in the downhole environment.

Working With Our Customers

Use **Table 1.1** to select the characteristics you want in your advanced material. If an existing product line doesn't meet your needs, we'll work with you to design a bespoke solution tailored to your application.

Characteristics of Metamaterials

Our approach to engineering advanced materials focuses on impacting outcomes and use cases, meaning metamaterial products are defined by a set of characteristics (Table 1.1) rather than by chemical formulations.

Table 1.1: Characteristics currently available for optimizing metamaterial solutions

Characteristic	MetaCORE	MetaCORE-LD	MetaTHERM
High Crush Force Efficiency (CFE)	X		
High Specific Energy Absorption (SEA)	X		
Pro-Isotropy	X	X	
Low Mass Density (Lightweight)	X	X	
Cost Savings	X	X	X
High Strength		X	
Low Thermal Conductivity		X	
Controlled Poisson Effects			X
Controlled Thermal Expansion			X
Corrosion Resistance	X	X	X
Customer-Preferred Manufacturing Method	X	X	X
Add your custom characteristics here	-	-	-

Descriptions of Characteristics

High Crush Force Efficiency (CFE)

CFE is the ratio of the load (force per unit area) when crushing begins, F_{crush}, to the load during the compression, $F_{\text{compression}}$:

$$CFE = \frac{F_{\text{crush}}}{F_{\text{compression}}}$$

When CFE = 1, the impact decelerations are mitigated. When CFE becomes smaller and approaches 0, sudden changes in acceleration are transmitted through the material, causing trauma (e.g., head and neck injury) or damaing cargo.

High Specific Energy Absorption (SEA)

The SEA is the integrated area under the load-compression curve divided by the mass of the material that’s become crushed. A large SEA (> 20 kJ/kg) means lots of energy has been absorbed by the material on impact or that the material absorbing the impact is very lightweight. Many lightweight, high SEA materials are functional in one direction, meaning they have low SEA in the other two directions. Therefore, off-axis impacts are generally not effectively dissipated. MetaCORE is a pro-isotropic high-SEA metamaterial, which sidesteps the uncertainty of knowing the impacting direction.

Pro-Isotropy

Some materials have special properties in one or two distinct directions, making them anisotropic. Other materials have properties that are independent of direction, making them isotropic. Pro-isotropic materials are materials whose characteristics are enhanced to make them more isotropic.

Low Mass Density (Lightweight)

Mass per unit volume of material is a common metric used to determine the weight of a final product. Because many of our metamaterials are designed with open cellular geometries, their density often reaches 1/10th the density of the base material, making it an ideal choice for lightweight applications.

Cost Savings

Our metamaterials are typically fabricated using widely available raw materials with a value-added design and manufacturing process. This method keeps costs low relative to other advanced materials available in the commercial market.

High Strength

We have a variety of strategies to increase the effective strength of a material. Some are similar to plywood, which uses alternating plies bonded together to prevent fracture propagation. Other strategies use the metamaterial geometry to convert large bulk compression/tension to internal torsion, or conversely large bulk torsion to internal compression/tension. In both cases, we're essentially compensating for the weakest failure mode (typically shear) by forcing the structure to activate a different type of deformation and therefore exhibit a higher effective strength. A third strategy we've introduced is the use of curved surfaces to guide failure-inducing stress away from critical regions and toward "sacrificial structures." This Crack Denial Strategy is inspired by the goals of self-healing materials, but is realized in materials available today.

Delamination: Sandwich panels fail for a variety of reasons related to their design and the loading patterns experienced in applications. The most common problem is delamination. Delamination occurs when the panels separate from the core material, inducing core shear and reducing the panel’s effective thickness. As a result, delamination leads to out-of-plane buckling, collapse from in-plane loads, and complete failure. MetaCORE-LD is engineered to radically shift the bounds of a standard failure mode map, replacing the costly failure of core shear with a no-fuss face wrinkling.

Low Thermal Conductivity

Many of our products are cellular materials whose volume is ~90% or more air. The effective thermal conductivity is governed by the same physics of conventional disordered foams commonly used in applications where thermal insulation is required. What distinguishes our metamaterial products is that they are ordered cellular materials, which means they retain significant structural loading capacity. Most designs, including those for MetaCORE-LD, contain continuous open-air channels that run the full length of the panel for additional thermal engineering, heating, and cooling opportunities.

Controlled Poisson Effect

Most solid materials bulge outward when squeezed or compressed - the volume doesn't want to change, so the material has to find somewhere to go. This effect is quantified by Poisson's Ratio, which is typically positive. In contrast, many metamaterials have a negative Poisson's Ratio, which introduces interesting opportunities for engineering materials with reduced frictional wearing. We can target a specific value for the Poisson's Ratio in each direction, so that some directions have an extraordinary bulging effect when loaded, while others contract, or do not move at all.

Controlled Thermal Expansion

Heating solids typically causes them to expand. We've developed techniques to engineer this effect, and even induce negative thermal expansion. Precise engineering of thermal expansion is useful for multi-material interfaces like plastic caps on metal vessels. When heated, the differential swelling creates thermomechanical stress, fatigue, and eventually the plastic cracks. With metamaterial enhancements to create equal-but-opposite thermally-induced strain, we mitigate the expansion stresses so the two parts can coexist without failure.

Corrosion Resistance

We fabricate metamaterials with a variety of base materials including polymers, metals, and composites. Some of our base materials, like PETG and PEEK, are highly resistant to chemical and environmental corrosion.

Metamaterial Benefits

Bespoke Design

Bespoke metamaterials mean customers can expect a tailored solution optimized for their specific application and delivered on budget. Our design process accommodates a variety of manufacturing methods, ranging from small- to large-run production. Methods our technology is compatible with include:

- 3D printing
- Injection molding
- Thermal/vacuum forming
- Metal stamping
- Roll-to-roll pattern transfer
- CNC milling

Component Simplification

Advanced materials allow engineers to simplify complex multi-component devices into a single part, which not only reduces the cost of assembly, but fewer parts mean fewer things to break, fewer assembly errors, and lower costs.

Multi-Objective Optimization

Customers may want a material with properties and performance characteristics that don’t occur naturally, are too expensive to buy, or are very specific to a niche application. Our solution is to take user-defined needs and translate them into design targets for our multi-objective optimization process.

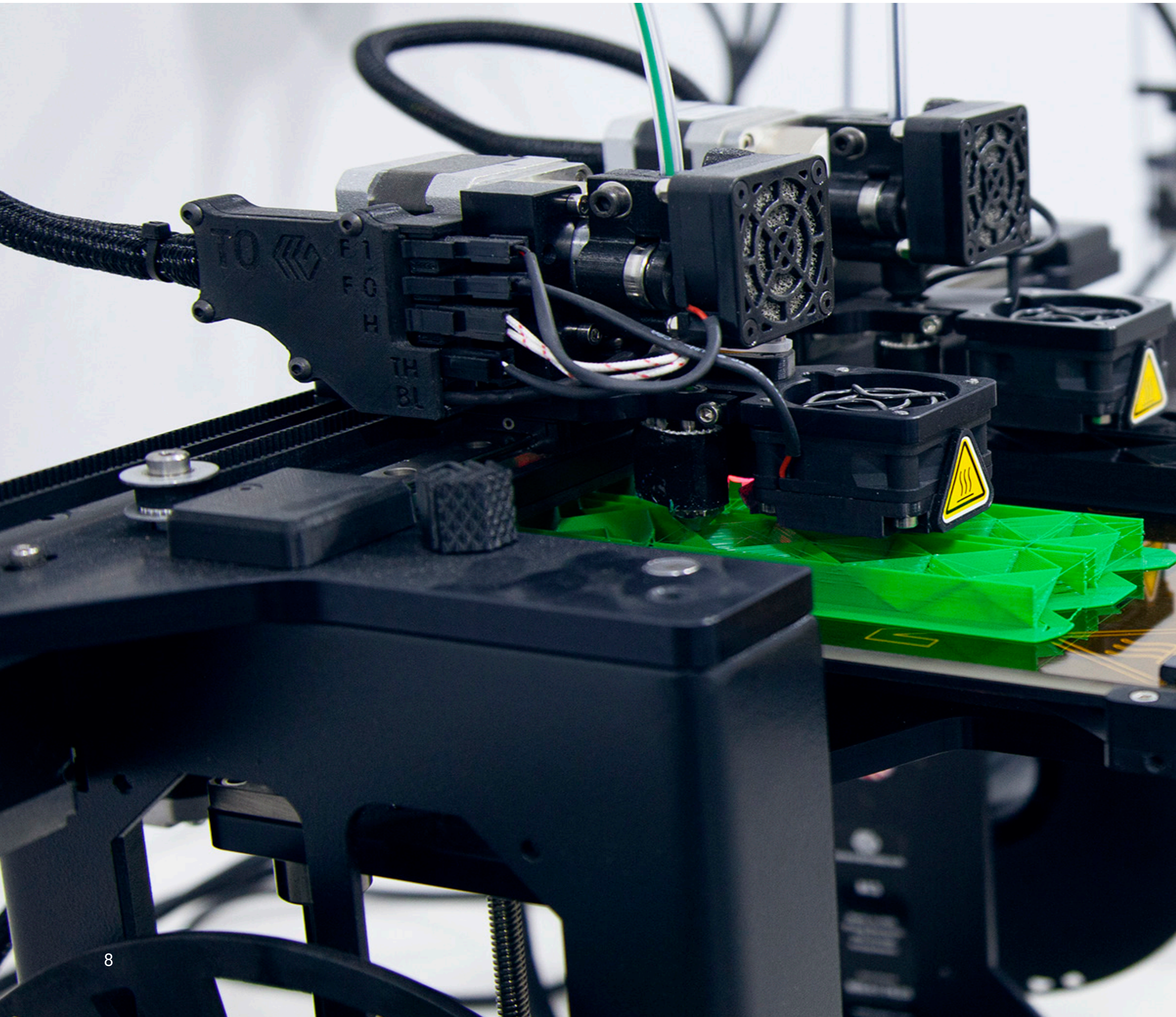
Topological optimization is a familiar two-objective optimization process. It allows an engineered product to maintain structural support and loading capabilities while reducing the amount of material used in its fabrication. Multiscale Systems have developed a range of solutions that go beyond two-objective optimization and enable exotic new functionally previously unobtainable on the commercial market.

Simplified Supply Chains

Supply chains can be simplified by having advanced materials at the time- and point-of-need. With 3D printing, all you need is a printer, stock materials, and a digital library. If something breaks, you just print and replace without the complex and costly logistics of supply chains that currently exist. Because metamaterials get their enhancements through the geometry of structural design, 3D printing metamaterials on-site enables our customers to have advanced materials when they need them, where they need them.

Simplified Certifications

A variety of industries require new materials to be certified before their use in production. Look at aerospace, where nearly an entire generation of engineers invested countless years to get fiber-reinforced composites FAA-certified for use in commercial airplanes. Our metamaterial enhancements are fabricated with customer-defined materials, which means no new chemical or molecular formulations need to be certified, saving our customers time, money, and allowing already-vetted materials to roll into production.



Facilities & Equipment

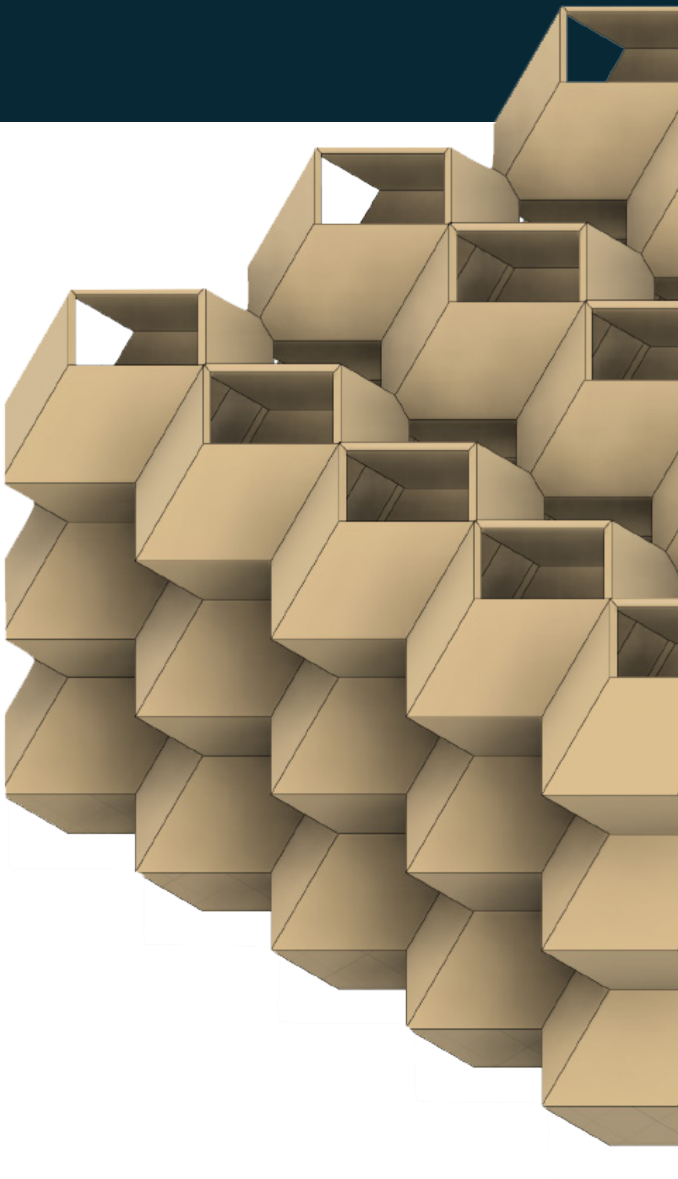
We use a variety of tools for in-house prototyping, characterization, and testing including:

- 3D printing
- CNC milling for mold making
- Laser cutting/engraving
- High-capacity mechanical testing (ASTM)
- High-speed microscopy
- Contact-free thermal imaging

Our design tools utilize modern high-performance computational resources and are integrated with *Ansys*, one of the most advanced engineering software platforms available.

MetaCORE™

Reduce weight without sacrificing strength



About MetaCORE

Our flagship light-weight structural material is engineered with the properties of an ideal impact absorber and can be customized with application-specific crush strength. MetaCORE is produced in flat sheets, blocks, sandwich panels, or can be pre-formed to a smooth curved surface.

MetaCORE's anisotropic geometry is engineered for a pro-isotropic force-displacement relationship with a high Crush Force Efficiency (CFE) and Specific Energy Absorption (SEA). The CFE ensures safety at the moment of impact, and the SEA ensures safety throughout the duration of a collision event.

Target Markets

- Transportation
- Electric Vehicles
- Aerospace
- Defense

Table 2.1: Characteristics of MetaCORE with corresponding advantages

Characteristic	⟶	Advantage
High Crush Force Efficiency	⟶	Mitigates sudden deceleration
High Specific Energy Absorption	⟶	Lightweight protection
Pro-Isotropy	⟶	Multi-directional performance
Low Mass Density (Lightweight)	⟶	Total system weight reduction
Corrosion Resistance	⟶	Increased durability
Cost Savings	⟶	Widely available raw materials
Customer-Preferred Manufacturing Methods	⟶	On-demand customization

Table 2.2: Selected characteristics of MetaCORE compared to honeycomb and foams

Material	CFE		SEA		Pro-Isotropic	
	Low	High	Low	High	Low	High
Honeycomb	X			X	X	
Foams		X	X			X
MetaCORE		X		X		X

Geometric Motifs

Multi-objective optimization rarely produces a single solution. Instead, multiple different solutions with the desired input characteristics can be generated by our process. We embrace the multiplicity especially since some designs excel in unexpected ways.

The MetaCORE product line was conceived as a lightweight impact-absorbing structural material. The geometric motifs shown in Figs. 2.1 to 2.3 all satisfy these criteria, but in slightly different ways (see **Tables 2.3** and **2.4**). More importantly, variations in each motif's geometry (angles, lengths, thicknesses, etc.) allow us to access a different range of material properties.

Having a catalog of motifs means our customers tell us what they want, and we have a shorter lead time to deliver.

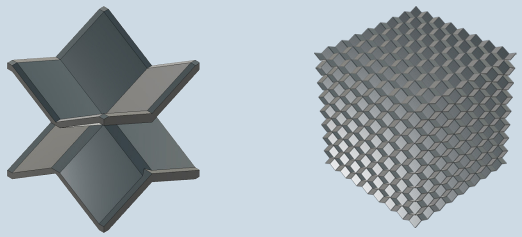


Fig. 2.1: *MetaCORE [EB] motif as single unit cell and tessellation (right).*

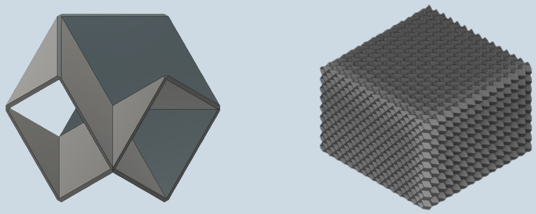


Fig. 2.2: *MetaCORE [MO] motif as single unit cell and tessellation (right).*

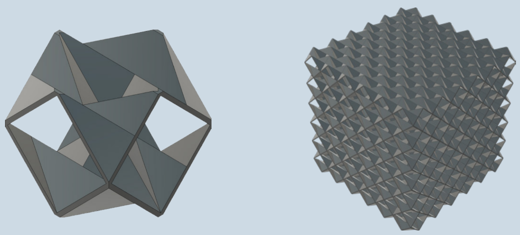


Fig. 2.3: *MetaCORE [WB] motif as single unit cell and tessellation (right).*

Competitive Advantages

Reduce Weight Without the Trade-Offs

Stiffness vs. Density

Stiffness, measured by the Young's modulus *E*, expresses how much a material will deform in response to an applied load. We all intuitively recognize that stiffer materials are generally heavier, and compliant materials are generally lighter. As a result, we're surprised when we find light materials that are very stiff (composites and technical ceramics) or delighted when we find heavy materials that are very soft (memory foam). This intuition is quantified when we plot the density of a material, ρ, against its Young's modulus and observe a generally upward-leaning trend.

MetaCORE Advantage

The highly engineered geometry of MetaCORE has most of its internal volume empty, leading to extremely low densities. The same geometry converts applied external loads to hidden internal deformations giving it a much higher effective stiffness. As a result, MetaCORE exists on the boundaries of what's possible, far exceeding the performance of conventional alternatives.

Better Protection from Impacts

Specific Energy Absoption Min. vs. Max.

A material's Specific Energy Absorption (SEA) tells you how much energy can be absorbed by crushing a given amount of the material. Often, materials reporting high values of SEA only absorb in one direction, while the other two directions offer little-to-no functionality. Plotting a material's maximum SEA vs. its minimum SEA reveals the problem.

MetaCORE Advantage

Honeycomb and foams are commonly used as lightweight energy absorbing materials. Plotting the minimum vs. maximum SEA reveals the strength of MetaCORE over these alternatives (Fig. 2.4). By design, MetaCORE exists as a high performing energy absorber regardless of the impact's direction.

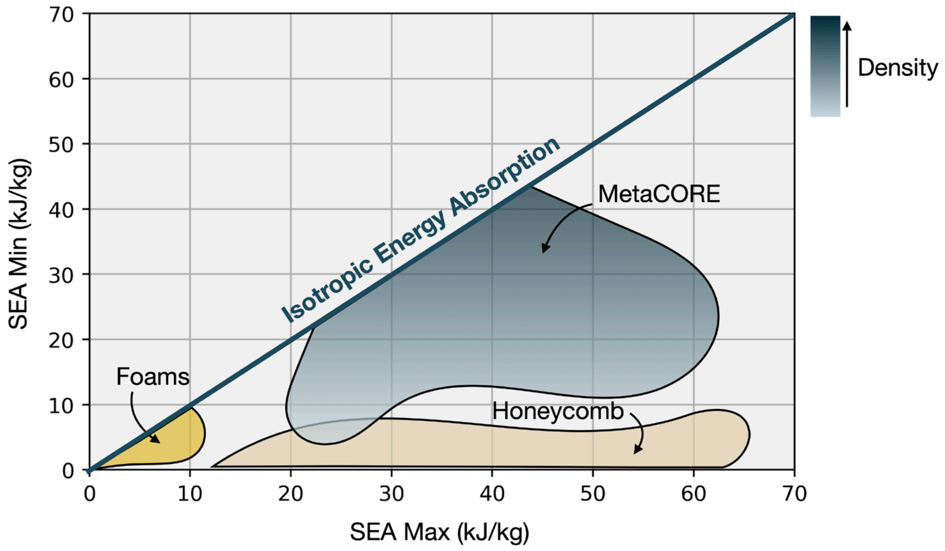


Fig. 2.4: *SEA min. vs. SEA max. of MetaCORE, honeycomb, and foams*

Multi-Objective Optimization

Crush Force Efficiency vs. Specific Energy Absorption

Before there were seatbelts in every car, researchers identified useful metrics for engineering vehicle safety systems. One metric, the Crush Force Efficiency (CFE), is particularly good for quantifying the transfer of force from a collision to a vehicle occupant. While CFE is useful, it doesn't tell you how much energy is ultimately absorbed by the material mitigating impact. This is where the Specific Energy Absorption (SEA) comes in. Some materials, like foams, have a great CFE but absorb very little energy. Other materials like honeycomb have great SEA but allow for undesirable propagation of harmful de-acceleration forces. Plotting CFE versus SEA gives a good high-level perspective on these two critical – and distinct – aspects of crashworthiness (**Table 2.2**, Fig. 2.5).

MetaCORE Advantage

MetaCORE is specifically engineered with the force-displacement relationship of an ideal energy absorber, giving it extremely high CFE values. Our aluminum and carbon fiber reinforced versions of MetaCORE take these high CFEs and build out exceptional SEA, making the functional combination uniquely high-performance.

Simplified Material Choice

Specific Stiffness Min. vs. Max.

By dividing the Young's modulus by the material's density, you derive its specific stiffness (sometimes referred to as "specific modulus" or "stiffness-to-weight ratio"). High specific modulus materials are widely applicable in aerospace applications where low-weight high-stiffness materials are desired since they resist deformation. Consider choosing a material for building an airplane. Aluminum seems obvious because it's less dense than steel, but steel is stronger than aluminum, so maybe we should use a thinner steel plate to save weight without sacrificing tensile strength. However, even if we find the right weight-to-tensile-strength ratios, we end up sacrificing stiffness, which ultimately allows the wings to flex too much during flight. These trade-offs are all too common when selecting engineering materials.

MetaCORE Advantage

Materials advertising a high specific stiffness like honeycomb are only functional in one direction and exhibit low specific stiffness in the other two directions. Directional independence can be achieved with MetaCORE where the minimum and maximum values of specific stiffness are comparable, benefitting customers by simplifying material selection.

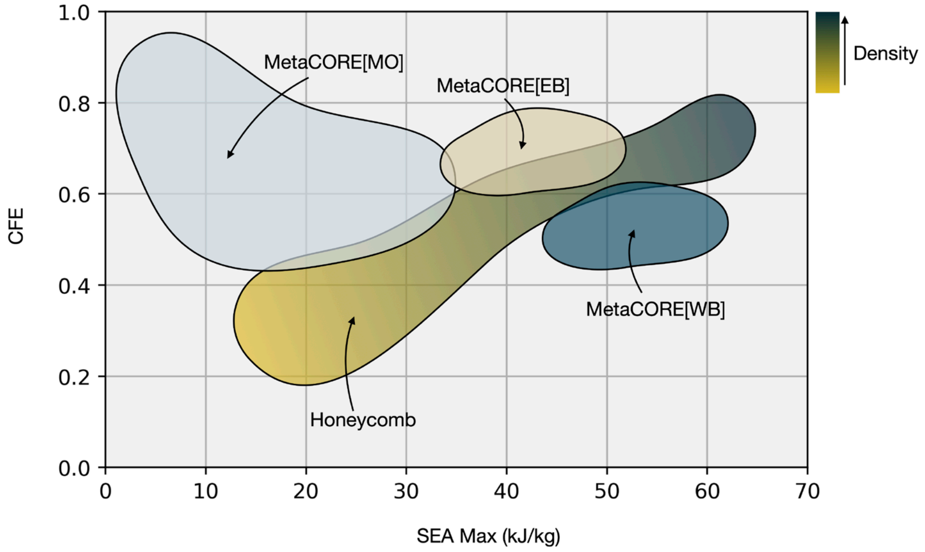
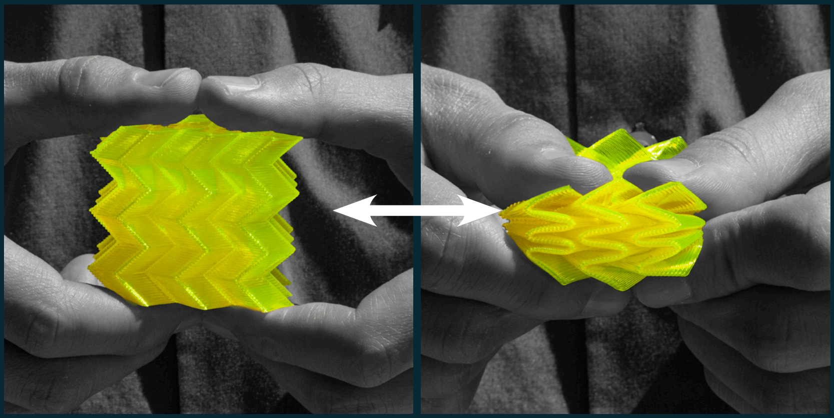


Fig. 2.5: *CFE vs. SEA max. of MetaCORE motifs and honeycomb. Note that large values for honeycomb are only valid in one direction and impacts from any other direction are not effectively mitigated (see Fig. 2.6).*

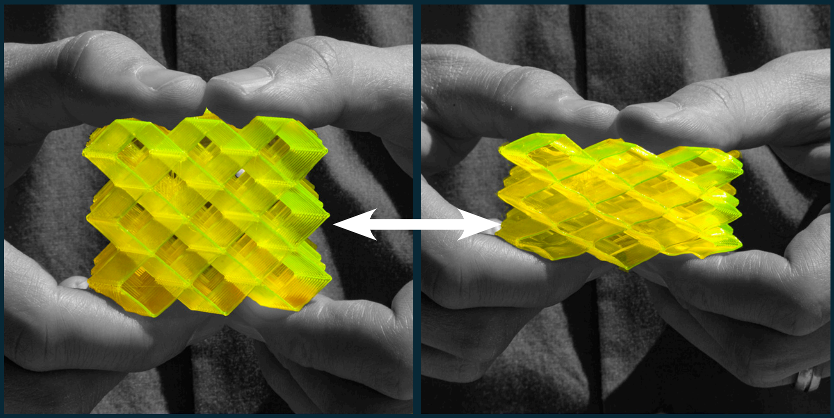
Geometry in Action

If a picture is worth a thousand words, then a demo is worth a million. This particular variation of MetaCORE [MO] illustrates how a molecularly homogeneous polymer can be formed into a metamaterial with unique properties in each direction.



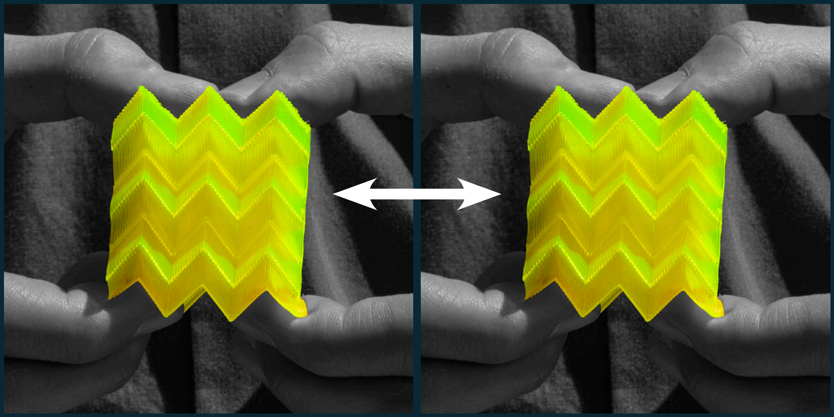
Compression 1: Soft

A small amount of force and the structure collapses. If squeezed between two flat plates, this variation of MetaCORE will flatten into a rectangular disc.



Compression 2: Intermediate

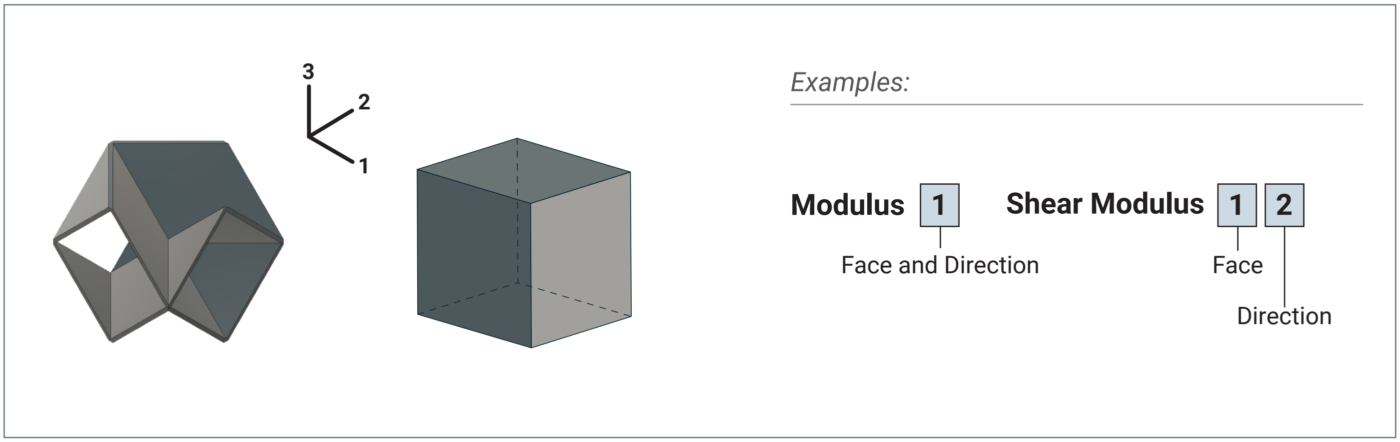
With some additional force, the intermediate orientation will also eventually collapse into a rectangular disc.



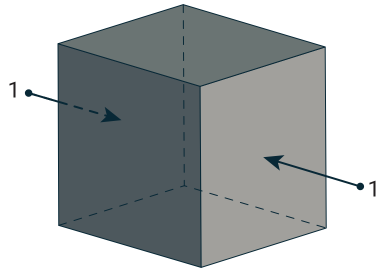
Compression 3: Firm

The internal geometry is engineered to convert **external** compression into **internal** tension, causing the structure to tear itself apart rather than flatten.

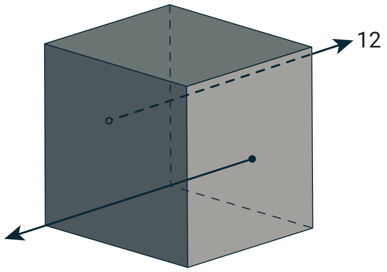
Definitions of Moduli Coordinate System



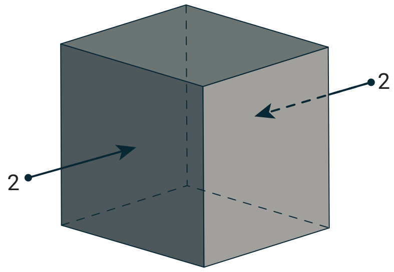
Modulus 1



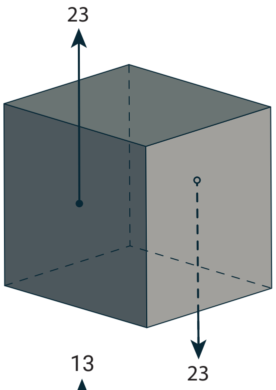
Shear Modulus 12



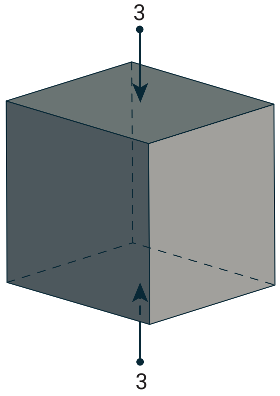
Modulus 2



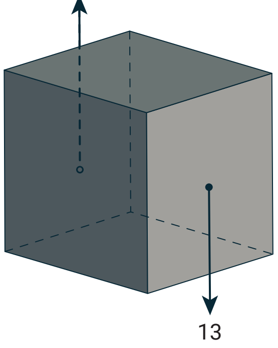
Shear Modulus 23



Modulus 3



Shear Modulus 13



Note: By symmetry, Shear Modulus 12 = Shear Modulus 21; Shear Modulus 23 = Shear Modulus 32; and Shear Modulus 13 = Shear Modulus 31.

Specification of MetaCORE metamaterials

Product - Motif - Material - Cell Length - Relative Density

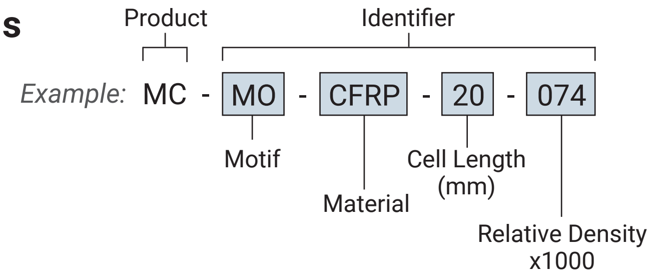


Table 2.3: MetaCORE Density, Typical Modulus, Typical Shear Modulus, and Typical Yield Strength

Metamaterial	Base Material	Density		Typical Modulus 1		Typical Modulus 2		Typical Modulus 3		Typical Shear Modulus 12		Typical Shear Modulus 23		Typical Shear Modulus 13		Typical Yield Strength	
		pcf	**kg/m³**	**kpsi**	**MPa**	**kpsi**	**MPa**	**kpsi**	**MPa**	**kpsi**	**MPa**	**kpsi**	**MPa**	**kpsi**	**MPa**	**kpsi**	**MPa**
General range	CFRP	3-20	50 - 300	0.8 - 10k	1 - 100	1 - 5	1 - 100	1 - 15	1 - 100	0.15 - 15	1 - 100	0.15 - 15	1 - 100	0.15 - 15	1 - 100	0.1 - 0.7	2 - 5
General range	Alunimum	6-30	100 - 500	2 - 250	100 - 2,000	24- 110	100 - 1,000	30 - 300	100 - 2000	40 - 300	300 - 3000	50 - 250	300 - 2000	50 - 450	300 - 3000	1 - 4	10 - 30
EB-CFRP-20-074	CFRP	6	95	0.8	6	1	7	1.4	10	2	13	2	14	7.5	52	0.3	2
EB-AL-20-074	Aluminum	13	200	20	150	24	175	36	250	47	325	50	350	190	1300	1.5	10
MO-CFRP-11-173	CFRP	14	221	3	21	4	30	2.9	20	12	84	10	67	19	130	0.6	4.5
MO-AL-11-173	Aluminum	29	470	76	525	110	750	73	500	300	2100	240	1675	450	3250	3.5	24
WB-CFRP-26-100	CFRP	8	130	10	70	3.5	25	11	76	2	12	2	14	2	14	0.4	2.5
WB-AL-26-100	Aluminum	17	270	250	1750	90	625	275	1900	40	300	50	350	50	350	2	14

Table 2.4: MetaCORE Typical Specific Energy Absorption (SEA) and Typical Poisson's Ratio

Metamaterial	Base Material	Typical SEA Min.	Typical SEA Max.	Typical Poisson's Ratio 12	Typical Poisson's Ratio 23	Typical Poisson's Ratio 13
		kJ/kg	**kJ/kg**	**no unit**	**no unit**	**no unit**
General range	CFRP					
General range	Alunimum	2 - 20	20 - 60	-1.5 - 4	-1.5 - 4	-1.5 - 4
EB-CFRP-20-074	CFRP			0.38	-0.04	0.64
EB-AL-20-074	Aluminum	18	51	0.38	-0.04	0.64
MO-CFRP-11-173	CFRP			0.68	-0.9	0.95
MO-AL-11-173	Aluminum	3	20	0.68	-0.9	0.95
WB-CFRP-26-100	CFRP			-0.45	0.64	0.91
WB-AL-26-100	Aluminum	23	56	-0.45	0.64	0.91

***CFRP** = Carbon Fiber Reinforced Plastic*
***Aluminum** = 6061 aluminum alloy*

MetaCORE-LD

Lighter paneling with increased strength

About MetaCORE-LD

MetaCORE-LD is MetaCORE engineered into a sandwich panel. This composite structure offers substantial weight reduction with a maximum bonding surface area. As a result, delamination of panels from the core material is a problem of the past.

Just like MetaCORE, MetaCORE-LD offers exceptional support to loads in the normal direction. Unlike other products, MetaCORE-LD goes further by providing unprecedented in-plane loading support. This means MetaCORE-LD panels can be manufactured with greater weight-bearing capacity and lower failures rates.

The thermal conductivity of MetaCORE-LD is also exceptionally low due to the amount of hollow internal space. Values of 25 mW/m-K are typical, and lower values are feasible for bespoke applications.

Between the low density, suppressed failure modes, and thermal insulating properties, MetaCORE-LD is an ideal paneling product.

Target Markets

- Transportation
- Electric Vehicles

Geometric Motifs

The MetaCORE product line was conceived as a lightweight impact-absorbing structural material. These geometric motifs (**pg. 11**) have made their way into MetaCORE-LD, which offers our customers a greater access to bespoke solutions.

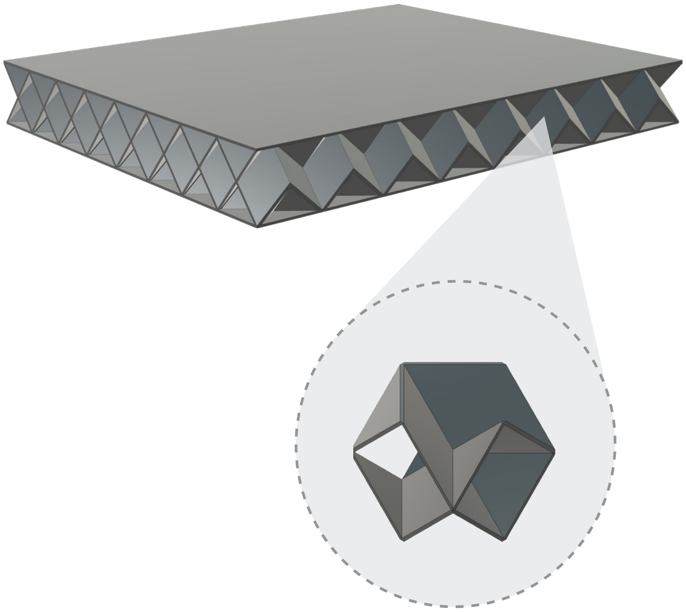


Fig. 3.1: *MetaCORE-LD [MOX] contains a core of MetaCORE [MO] unit cells*

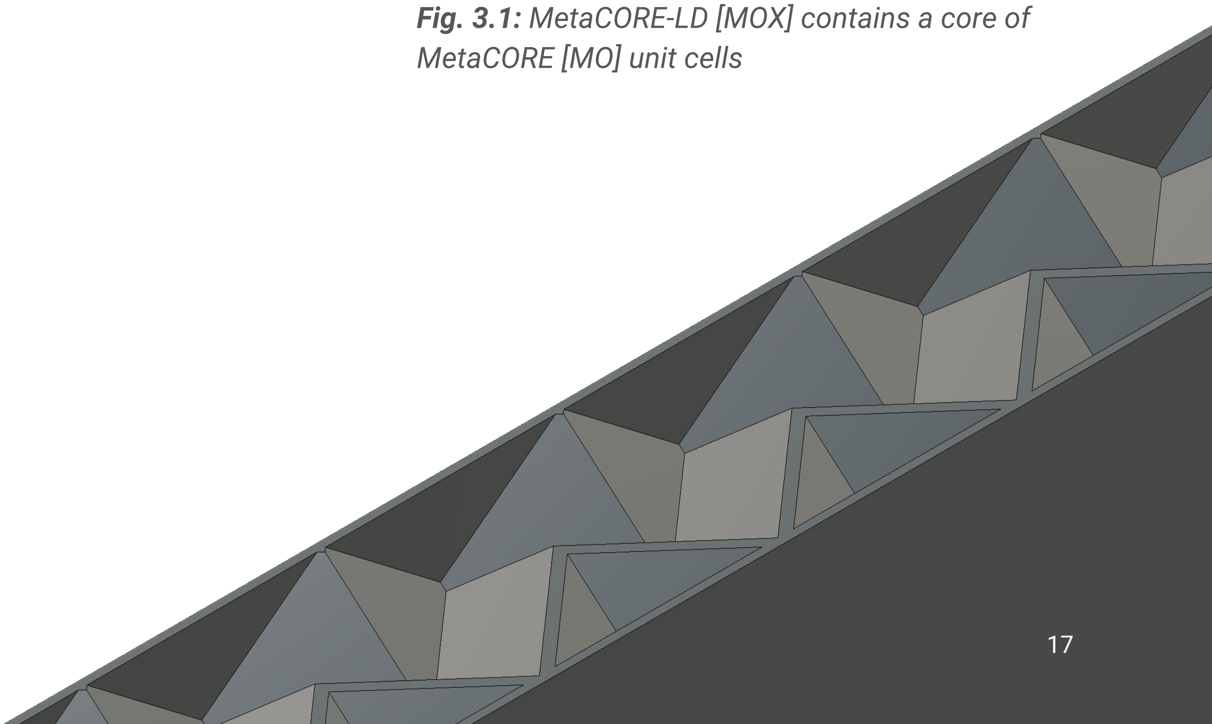


Table 3.1: Characteristics of MetaCORE-LD with corresponding advantages

Characteristic	⟶	**Advantage**
Low Mass Density (Lightweight)	⟶	Reduces total vehicle weight
High Strength	⟶	Mitigates catastrophic failure
Low Thermal Conductivity	⟶	Better temperature control
Pro-Isotropy	⟶	Multi-directional performance
Corrosion Resistance	⟶	Increased durability
Cost Savings	⟶	Widely available raw materials
Customer-Preferred Manufacturing Methods	⟶	On-demand customization

Competitive Advantage

Increased Resilience

MetaCORE-LD vs. HDPE

Lightweight sandwich panels are great for boxing out structures and providing insulation from the elements. Their fabrication is easy enough: one material (often a foam or honeycomb) is sandwiched between two thin panels fabricated from thermoplastics or metals.

It's important when using sandwich panels to understand their strengths and weaknesses, particularly since they're composite structures with failure modes unique to their construction. Whether it be yielding, face wrinkling of the panel, or shear of the core, exactly what happens when excessively loaded depends on the relative densities and dimensions. These possibilities are well-summarized with a failure mode map (Fig. 3.2). Knowing what failure mode to expect is important since face wrinkling may be acceptable whereas core shear could be catastrophic.

MetaCORE-LD Advantage

MetaCORE-LD is engineered to shift the boundaries of a standard failure mode map by offering greater operational range of functionality and resilience to failure. Tolerable aesthetic defects can be substituted for catastrophic failure of the core material.

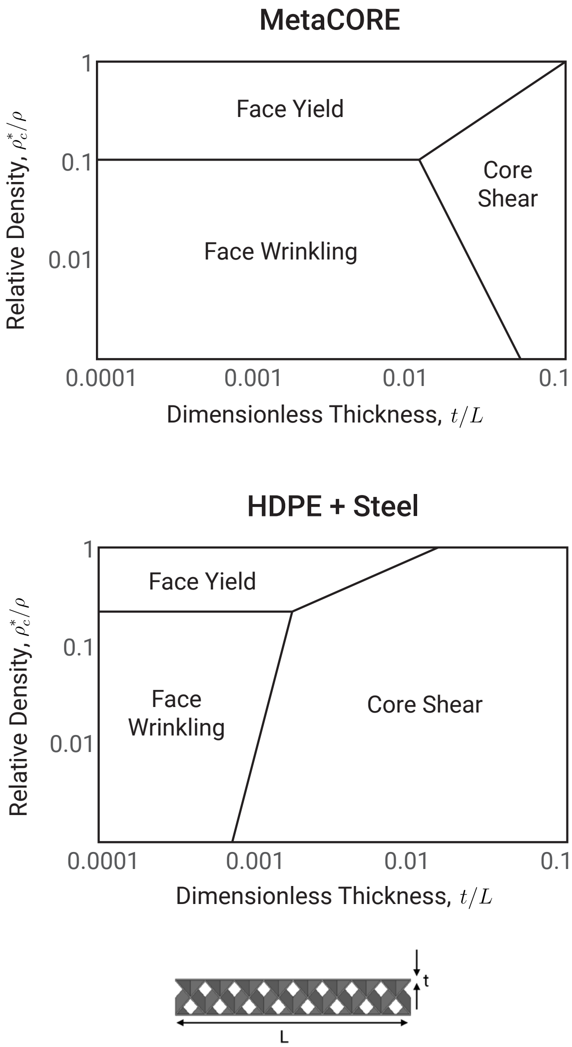


Fig. 3.2: *Sandwich panel failure mode maps of MetaCORE-LD compared to Steel + HDPE. t is the thickness of the face, L is the spanwise length of the panel, ρ_c^* is the effective density of the core, and ρ is the density of CFRP used to construct the core.*

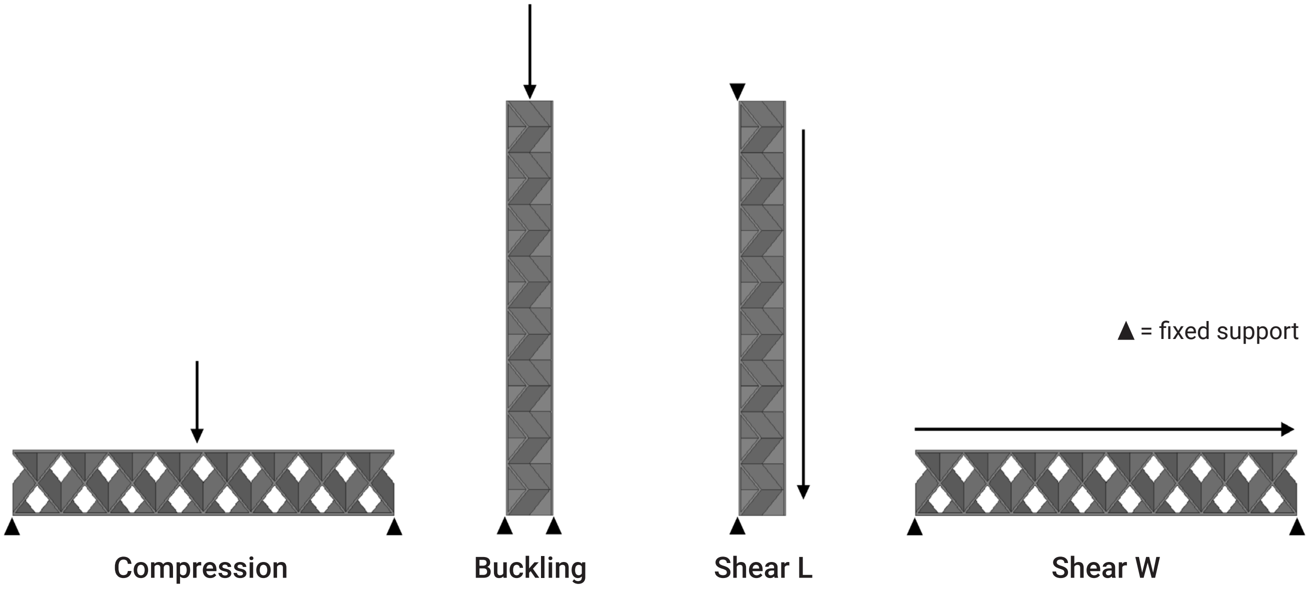


Fig. 3.3: *Definition of loading types of MetaCORE-LD*

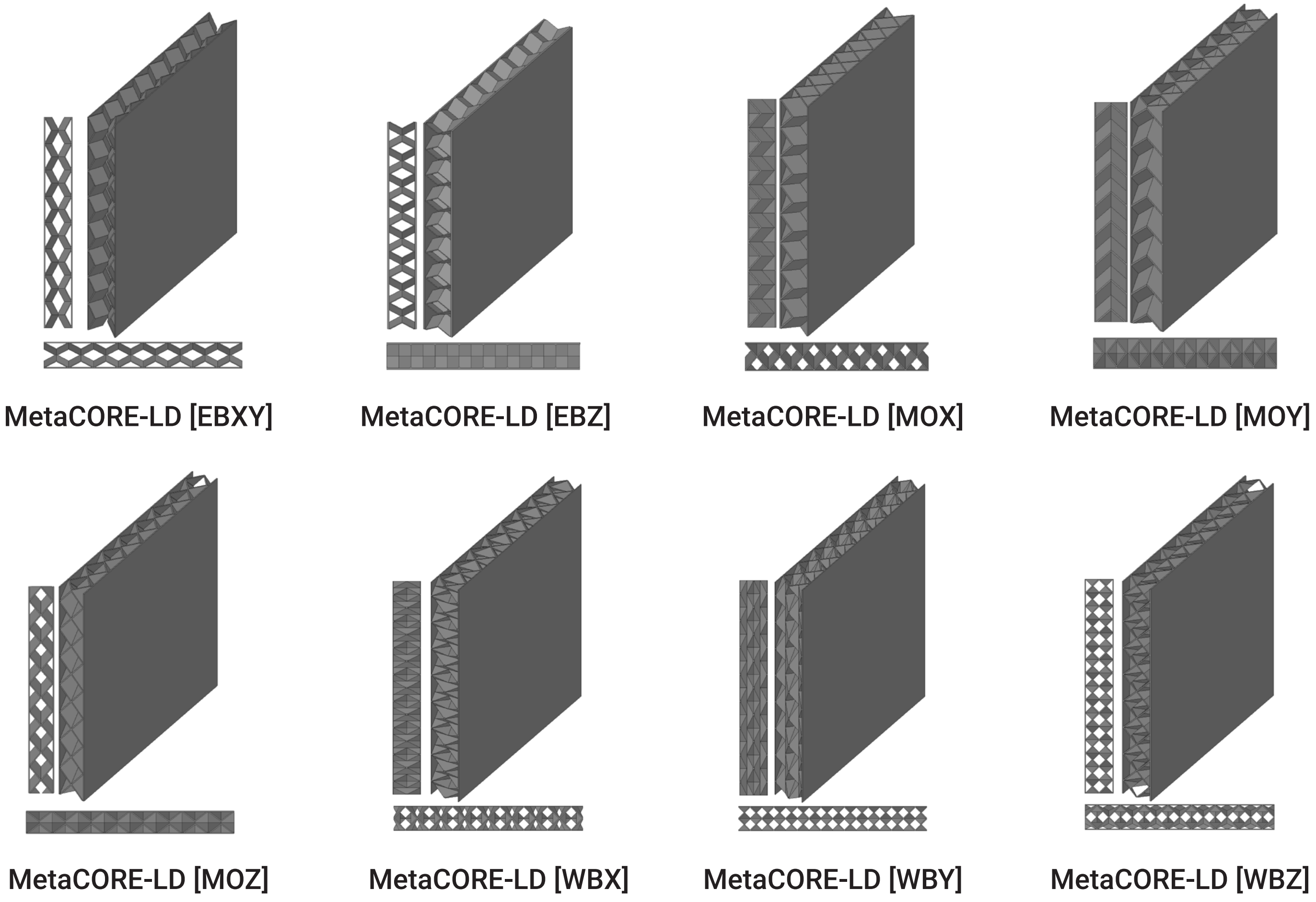

MetaCORE-LD [EBXY]
MetaCORE-LD [EBZ]
MetaCORE-LD [MOX]
MetaCORE-LD [MOY]
MetaCORE-LD [MOZ]
MetaCORE-LD [WBX]
MetaCORE-LD [WBY]
MetaCORE-LD [WBZ]

Fig. 3.4: *MetaCORE-LD motifs relating to Table 3.2*

Specification of MetaCORE-LD metamaterials

Product - Motif & Orientation - Core Material - Skin Material

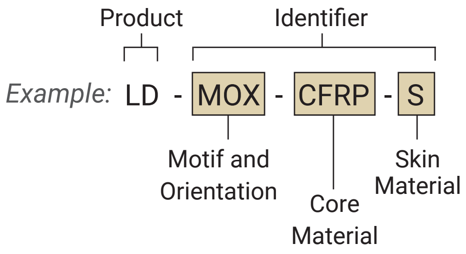


Table 3.2: MetaCORE-LD Density, Typical Compressive Strength, Typical Buckling Strength, and Typical Shear Strengths

Metamaterial	Base Material	Density		Typical Compressive Strength		Typical Buckling Strength		Typical Shear Strength L		Typical Shear Strength W	
	core/skin*	pcf	kg/m³	kpsi	MPa	kpsi	MPa	kpsi	MPa	kpsi	kMPa
EBXY-CFRP-S	CFRP/Steel	50	795	0.25	2	2	14	1.3	9	1.3	9
EBZ-CFRP-S	CFRP/Steel	50	795	0.25	2	4	28	2.3	16	2.3	16
MOX-CFRP-S	CFRP/Steel	57	910	0.4	3	2.7	19	1.5	10	1.5	10
MOY-CFRP-S	CFRP/Steel	57	910	0.3	2	2.1	14	1.7	12	1.3	9
MOZ-CFRP-S	CFRP/Steel	57	910	0.3	2	2.9	20	1.5	10	1.7	12
WBX-CFRP-S	CFRP/Steel	51	825	0.4	3	1.9	13	1.1	8	1.1	8
WBY-CFRP-S	CFRP/Steel	51	825	0.4	3	1.8	12	1	7	1	7
WBZ-CFRP-S	CFRP/Steel	51	825	0.4	3	2.6	18	1.5	10	1.5	10

** Steel thickness ~1mm. Core thickness ~1 unit cell (~10-20mm).*

Aluminum skins and skinless panels also available.

*See **Fig. 3.3** for definition of loading types and **Fig. 3.4** for renders of panel geometry.*

Markets

Mechanical metamaterials driving future innovation

Transportation

Transportation of goods and products is essential for our quality of life. Lighter, stronger materials let carriers haul more cargo per load, lower operating costs, and increase trailer lifetime. Exceptional cellular volume fraction provides superior thermal insulation for temperature sensitive cargo.

***Solutions**: MetaCORE, MetaCORE-LD*

Geothermal & Drilling

Enhanced geothermal systems get so hot, liquid water goes beyond steam and becomes a super critical fluid. Engineered equipment in these extreme conditions demand resilience in order to reduce costly downtime wasted on repairs.

***Solution**: MetaTHERM*

Aerospace

Commercial space flight is now possible. Whether used for low-altitude Urban Air Mobility Vehicles (UAMVs), or in-orbit flight, advanced materials are essential to sustain, expand, and grow this industry.

***Solutions**: MetaCORE, MetaTHERM*

Defense

Since the Cold War, US Military overmatch capabilities have faded. Advanced materials fielded from the domestic industrial manufacturing base are critical dual-use solutions that strategically restore favorable conditions, especially in the era of multi-domain operations.

***Solutions**: MetaCORE, MetaTHERM*

Electric Vehicles

Energy is required to accelerate mass. For EVs, this immutable physical law means lighter vehicles can travel greater distances. Light materials with exceptional crashworthiness are key as we move to zero-emission vehicles.

***Solutions**: MetaCORE, MetaCORE-LD, MetaTHERM*

Request Samples

Contact us to request a package with samples of our metamaterials:

- **info@multiscalesystems.com**
- 1-855-955-7900

MULTISCALE
SYSTEMS

+1-855-955-7900
info@multiscalesystems.com

49 Canterbury Street, Suite 500
Worcester, MA 01610

multiscalesystems.com