

Comparative Analysis of Mechanical Properties of Additive Manufacturing Materials



Additive and Traditionally Manufactured Components: A Comparative Analysis of Mechanical Properties (Additive Manufacturing Materials and Technologies)

by Joshua Pelleg

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Additive manufacturing, also known as 3D printing, has revolutionized the manufacturing landscape. This transformative technology allows for the production of complex geometries, customized designs, and intricate components with unprecedented precision. At the core of this technological advancement lies the selection of materials that determine the mechanical performance of the resulting parts. This comprehensive analysis aims to shed light on the mechanical properties of various materials employed in additive manufacturing, empowering engineers and designers to make informed choices for their projects.

Mechanical Properties in Focus:

The mechanical properties of materials are crucial indicators of their ability to withstand external forces and stresses. In the context of additive manufacturing, these properties include:

- **Tensile Strength:** Resistance to breaking under tensile stress
- **Yield Strength:** Point at which a material begins to deform permanently
- **Ductility:** Ability to deform under stress before breaking
- **Fracture Toughness:** Resistance to crack propagation
- **Fatigue Strength:** Resistance to repeated loading and unloading

Material Categorization:

Additive manufacturing materials encompass a wide spectrum of categories, each with distinct properties:

1. **Polymers:** Thermoplastics and thermosets known for their lightweight, flexibility, and ease of processing
2. **Metals:** Alloys with high strength, stiffness, and thermal conductivity
3. **Ceramics:** Inorganic materials characterized by high hardness, wear resistance, and thermal stability
4. **Composites:** Combinations of different materials to achieve tailored properties

Comparative Analysis:

Polymers:

Polymers, namely thermoplastics like ABS and PLA, offer a balance of strength and flexibility. Their lightweight nature and low cost make them suitable for prototyping and consumer products. However, their mechanical properties are generally lower compared to metals and ceramics.

MECHANICAL PROPERTIES OF POLYMERS

Polymers as materials need to be "strong" or "tough" or even "ductile"

How can we define these Mechanical Properties?

How do we measure how "strong" a polymer is?

What is the difference between a "strong" polymer and a "tough" one?

1) **STRENGTH** is easiest to relate to, but there is more than one kind of strength. 1a) **tensile strength**. A polymer has good tensile strength if it is strong when one pulls on it in tension, stretching it (eg. fibres):



The tensile strength is the highest load applied before it snaps in two

Metals:

Metals, such as aluminum, titanium, and stainless steel, exhibit superior strength, stiffness, and durability. Their high thermal conductivity also enables efficient heat dissipation. However, metals can be more challenging to process in additive manufacturing due to their higher melting points and potential for defects.

Typical Mechanical Properties

Metals in annealed (soft) condition

Material	Yield Stress (MPa)	Ultimate Stress (MPa)	Ductility (EL%)	Elastic Modulus (MPa)	Poisson's Ratio
1040 Steel	350	520	30	207000	0.30
1080 Steel	380	615	25	207000	0.30
2024 Al Alloy	100	200	18	72000	0.33
316 Stainless Steel	210	550	60	195000	0.30
70/30 Brass	75	300	70	110000	0.35
6-4 Ti Alloy	942	1000	14	107000	0.36
AZ80 Mg Alloy	285	340	11	45000	0.29

Tensile strength and yield strength for different metal alloys

Ceramics:

Ceramics, including zirconia and alumina, possess remarkable hardness, wear resistance, and thermal stability. They find applications in medical implants, cutting tools, and high-temperature environments. However, ceramics are typically brittle and require careful handling during processing and post-processing.

MECHANICAL PROPERTIES OF CERAMICS

Tabulation of Flexural Strength (Modulus of Rupture) and Modulus of Elasticity for Ten Common Ceramic Materials

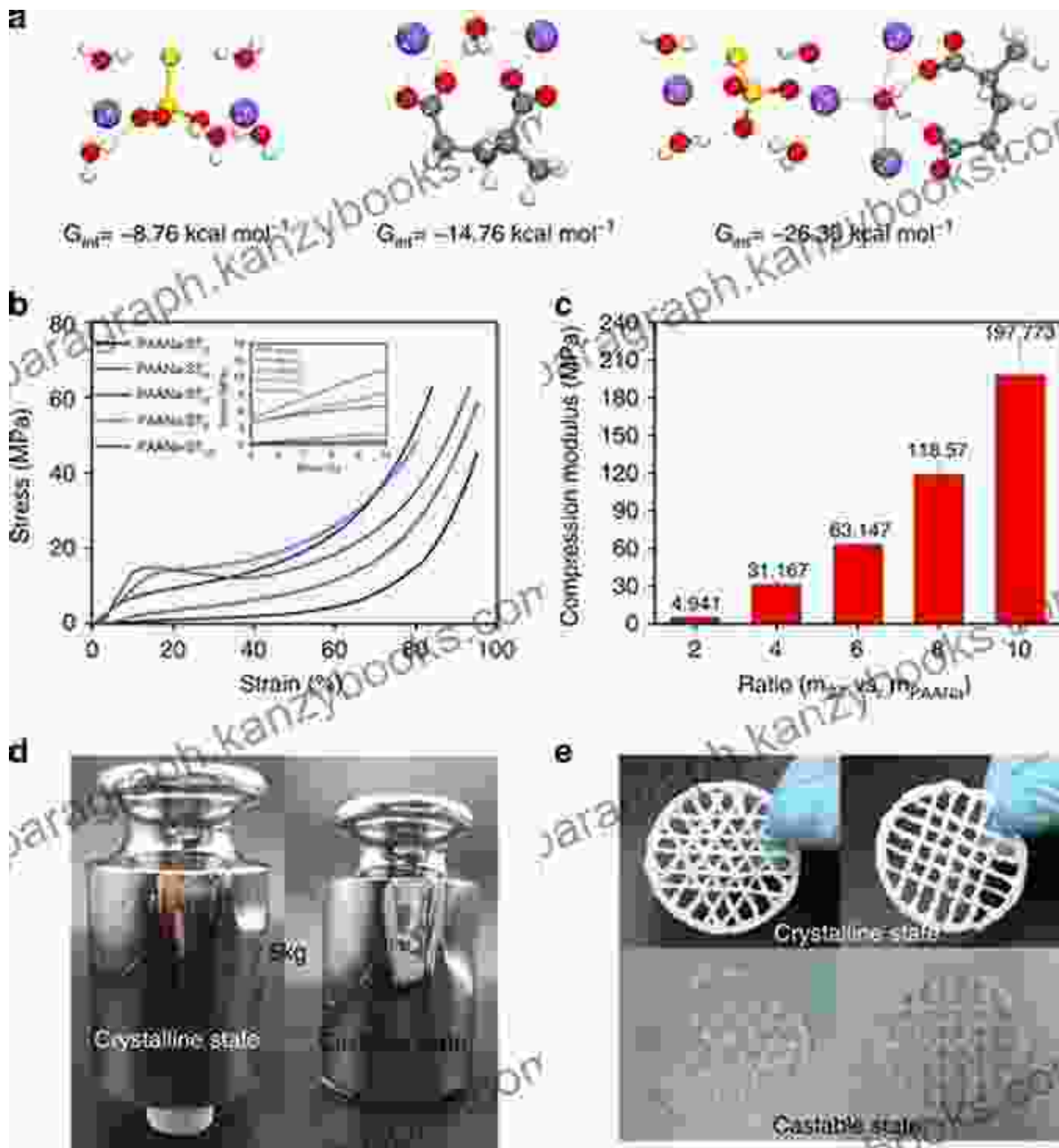
Material	Flexural Strength		Modulus of Elasticity	
	MPa	Ksi	GPa	10^6 psi
Silicon nitride (Si_3N_4)	250-1001	35-215	304	44
Zirconia* (ZrO_2)	800-1500	115-215	206	30
Silicon carbide (SiC)	100-870	15-120	345	50
Aluminum oxide (Al_2O_3)	275-700	40-100	391	57
Glass-ceramic (Pyroceram)	247	36	120	17
Mullite ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$)	185	27	135	21
Spinel (MgAl_2O_4)	110-245	16-35.5	260	38
Magnesium oxide (MgO)	105 ^b	15 ^b	225	33
Fused-silica (SiO_2)	110	16	71	11
Soda-lime glass	60	10	60	10

* Partially stabilized with 3 mol% Y_2O_3

^b Sintered and containing approximately 5% porosity

Composites:

Composites combine different materials to achieve tailored properties. For instance, fiber-reinforced polymers enhance strength and stiffness while maintaining lightweight characteristics. Composites offer versatility in design and can be optimized for specific applications.



Tensile strength and modulus of elasticity for composites with varying fiber orientations

Factors Influencing Mechanical Properties:

The mechanical properties of additive manufacturing materials are influenced by several factors:

- **Printing Parameters:** Temperature, layer thickness, and printing speed
- **Post-Processing:** Heat treatment, surface finishing, and infiltration
- **Material Composition:** Alloying elements, reinforcement fibers, and additives
- **Design Features:** Geometry, orientation, and internal structures

Applications and Considerations:

The selection of additive manufacturing materials depends on the specific application and performance requirements. For instance:

- **Automotive:** Lightweight polymers for interior components, metal alloys for structural parts
- **Aerospace:** High-strength metals for aircraft components, ceramics for heat-resistant tiles
- **Medical:** Biocompatible polymers for implants, porous ceramics for bone regeneration
- **Consumer Products:** Durable plastics for toys, flexible elastomers for wearable devices

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The comparative analysis of mechanical properties of additive manufacturing materials provides valuable insights for engineers and designers to make informed decisions. By understanding the strengths and limitations of different materials, it becomes possible to optimize designs, improve performance, and push the boundaries of innovation. As additive

manufacturing technology continues to evolve, new materials with tailored properties will emerge, further expanding the possibilities for groundbreaking applications.



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