

Boron Carbide

*Ceramics
and glasses*



Material Properties

Price	73.2	\$/kg
Density	2,520	kg/m ³
Young's modulus	374	GPa
Yield strength (elastic limit)	277	MPa
Thermal conductivity	17	W/m.K
Specific heat capacity	907	J/kg.°C
CO2 footprint, primary production	8.8	kg/kg
Water usage	154	l/kg
Recycle fraction	0.1	%

Boron carbide is nearly as hard as diamond, but much less expensive. It is used in body armor and as an abrasive.

Alumina

*Ceramics
and glasses*



Material Properties

Price	22.3	\$/kg
Density	3,700	kg/m ³
Young's modulus	331	GPa
Yield strength (elastic limit)	196	MPa
Thermal conductivity	24	W/m.K
Specific heat capacity	892	J/kg.°C
CO2 footprint, primary production	2.7	kg/kg
Water usage	58	l/kg
Recycle fraction	0	%

Alumina is a commonly used ceramic due to its low cost and good performance at high temperatures. It is used as insulators for spark plugs.

Sandstone

*Ceramics
and glasses*



Material Properties

Price	0.5	\$/kg
Density	2,440	kg/m ³
Young's modulus	19	GPa
Yield strength (elastic limit)	10	MPa
Thermal conductivity	2.06	W/m.K
Specific heat capacity	875	J/kg.°C
CO2 footprint, primary production	0.1	kg/kg
Water usage	3.3	l/kg
Recycle fraction	1.4	%

Sandstone is consolidated sand particles bonded by natural cementing agents. It is widely used as a building material because of wide availability and ease of working.

Soda-lime glass

*Ceramics
and glasses*



Material Properties

Price	1.5	\$/kg
Density	2,460	kg/m ³
Young's modulus	68	GPa
Yield strength (elastic limit)	32	MPa
Thermal conductivity	0.96	W/m.K
Specific heat capacity	901	J/kg.°C
CO2 footprint, primary production	0.7	kg/kg
Water usage	15	l/kg
Recycle fraction	25	%

This is the mostly widely used glass, as used in bottles and windows. It is cheap, easy to blow and mold, and is optically clear.

Silicon carbide

*Ceramics
and glasses*



Material Properties

Price	17.4	\$/kg
Density	3,100	kg/m ³
Young's modulus	394	GPa
Yield strength (elastic limit)	319	MPa
Thermal conductivity	122	W/m.K
Specific heat capacity	678	J/kg.°C
CO2 footprint, primary production	7.1	kg/kg
Water usage	59	l/kg
Recycle fraction	0.0	%

Silicon carbide is the grit on sandpaper and is made by fusing sand and coke.

Borosilicate glass

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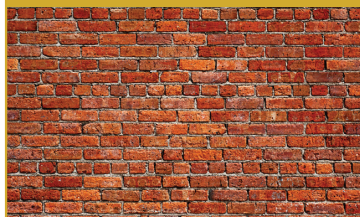
Material Properties

Price	5.8	\$/kg
Density	2,120	kg/m ³
Young's modulus	52	GPa
Yield strength (elastic limit)	24	MPa
Thermal conductivity	1.19	W/m.K
Specific heat capacity	753	J/kg.°C
CO2 footprint, primary production	1.7	kg/kg
Water usage	15	l/kg
Recycle fraction	24.8	%

Borosilicate glass is high in silica and boron trioxide. It has a high melting point and a low thermal expansion coefficient, making it tolerant of thermal shock, hence its use for ovenware.

Brick

*Ceramics
and glasses*



Material Properties

Price	1.0	\$/kg
Density	20,020	kg/m ³
Young's modulus	22	GPa
Yield strength (elastic limit)	9	MPa
Thermal conductivity	0.55	W/m.K
Specific heat capacity	790	J/kg.°C
CO2 footprint, primary production	0.2	kg/kg
Water usage	6	l/kg
Recycle fraction	0	%

Brick of fired clay have been used as a building material for over 5000 year. Unfired earth or mud bricks have an even longer history.

Marble

*Ceramics
and glasses*



Material Properties

Price	0.7	\$/kg
Density	2,780	kg/m ³
Young's modulus	59	GPa
Yield strength (elastic limit)	8	MPa
Thermal conductivity	5.55	W/m.K
Specific heat capacity	904	J/kg.°C
CO2 footprint, primary production	0.2	kg/kg
Water usage	3.4	l/kg
Recycle fraction	1.4	%

Marble is almost pure calcium carbonate. It is used for ornamental building, statuary, ornamental furniture and for electric power panels.

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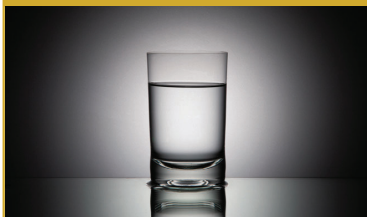
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Silica glass

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Material Properties

Price	8.0	\$/kg
Density	2,190	kg/m³
Young's modulus	74	GPa
Yield strength (elastic limit)	164	MPa
Thermal conductivity	1.32	W/m.K
Specific heat capacity	708	J/kg.°C
CO2 footprint, primary production	2.1	kg/kg
Water usage	3.2	l/kg
Recycle fraction	24	%

Fused silica, a glass of great transparency is nearly pure SiO₂, it has an exceptionally high melting point and resists temperature and thermal shock.

Concrete

*Ceramics
and glasses*



Material Properties

Price	0.0	\$/kg
Density	2,390	kg/m³
Young's modulus	19	GPa
Yield strength (elastic limit)	1	MPa
Thermal conductivity	2.15	W/m.K
Specific heat capacity	921	J/kg.°C
CO2 footprint, primary production	0.1	kg/kg
Water usage	2.8	l/kg
Recycle fraction	13	%

Concrete is a mixture of cement, sand and gravel. Its poor tensile strength is usually countered by adding steel reinforcement bars.

Titanium

*Metals
and alloys*



Material Properties

Price	27.1	\$/kg
Density	4,610	kg/m³
Young's modulus	117	GPa
Yield strength (elastic limit)	844	MPa
Thermal conductivity	7.05	W/m.C
Specific heat capacity	519	J/kg.°C
CO2 footprint, primary production	18.8	kg/kg
Water usage	302	l/kg
Recycle fraction	23	%

Titanium alloys are exceptionally strong for their weight with high melting point and good chemical resistance. However, they are very expensive.

Stainless steel

*Metals
and alloys*



Material Properties

Price	4.4	\$/kg
Density	7,740	kg/m³
Young's modulus	203	GPa
Yield strength (elastic limit)	546	MPa
Thermal conductivity	19	W/m.C
Specific heat capacity	478	J/kg.°C
CO2 footprint, primary production	3.5	kg/kg
Water usage	140	l/kg
Recycle fraction	37	%

Stainless steel is similar to normal steel but contains the alloying element chromium, which gives it good chemical resistance under normal conditions.

Silver

*Metals
and alloys*



Material Properties

Price	786.7	\$/kg
Density	10,500	kg/m³
Young's modulus	74	GPa
Yield strength (elastic limit)	247	MPa
Thermal conductivity	402	W/m.C
Specific heat capacity	231	J/kg.°C
CO2 footprint, primary production	388.0	kg/kg
Water usage	74,000	l/kg
Recycle fraction	17	%

Silver is a shiny precious metal used in jewelry and electronics. Silver salts are photosensitive and enabled the invention of the camera.

Nickel

*Metals
and alloys*



Material Properties

Price	22.7	\$/kg
Density	8,890	kg/m³
Young's modulus	206	GPa
Yield strength (elastic limit)	255	MPa
Thermal conductivity	78	W/m.C
Specific heat capacity	444	J/kg.°C
CO2 footprint, primary production	9.2	kg/kg
Water usage	224	l/kg
Recycle fraction	31	%

Despite its name, the US 5 cent piece is, in fact, only 25% nickel--the rest is copper. Nickel is also used in heating elements and as an alloying element in stainless steel and "superalloys".

Magnesium

*Metals
and alloys*



Material Properties

Price	9.4	\$/kg
Density	1,810	kg/m³
Young's modulus	45	GPa
Yield strength (elastic limit)	128	MPa
Thermal conductivity	82	W/m.C
Specific heat capacity	985	J/kg.°C
CO2 footprint, primary production	12.7	kg/kg
Water usage	964	l/kg
Recycle fraction	37	%

Magnesium alloys are similar to, but lighter than aluminum ones. They are used in aerospace where low weight is important.

Gold

*Metals
and alloys*



Material Properties

Price	54,994.2	\$/kg
Density	19,300	kg/m³
Young's modulus	79	GPa
Yield strength (elastic limit)	188	MPa
Thermal conductivity	317	W/m.C
Specific heat capacity	130	J/kg.°C
CO2 footprint, primary product.	8,300.0	kg/kg
Water usage	2,700	l/kg
Recycle fraction	88	%

Gold is a soft, shiny, yellow elemental metal. Its appearance and chemical stability have led to its use as a monetary standard, jewelry, and in electronics.

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Copper

Metals
and alloys



Material Properties

Price	9.3	\$/kg
Density	8,940	kg/m³
Young's modulus	131	GPa
Yield strength (elastic limit)	133	MPa
Thermal conductivity	264	W/m.C
Specific heat capacity	379	J/kg.°C
CO2 footprint, primary production	3.9	kg/kg
Water usage	308	l/kg
Recycle fraction	44	%

Copper is mainly used for its high electrical and thermal conductivity, although it is also used for roofing and other architectural applications.

Bronze

Metals
and alloys



Material Properties

Price	11.7	\$/kg
Density	8,370	kg/m³
Young's modulus	114	GPa
Yield strength (elastic limit)	253	MPa
Thermal conductivity	49	W/m.C
Specific heat capacity	400	J/kg.°C
CO2 footprint, primary production	4.1	kg/kg
Water usage	367	l/kg
Recycle fraction	42	%

Bronze is a corrosion-resistant alloy of copper and tin. It is used for ships propellers, bells, medals and coins.

Tungsten

Metals
and alloys



Material Properties

Price	87.9	\$/kg
Density	17,700	kg/m³
Young's modulus	334	GPa
Yield strength (elastic limit)	747	MPa
Thermal conductivity	93	W/m.C
Specific heat capacity	138	J/kg.°C
CO2 footprint, primary production	30.1	kg/kg
Water usage	159	l/kg
Recycle fraction	35	%

Pure tungsten has such a high melting point that it is used as filaments for lamp bulbs.

Aluminium (cast)

Metals
and alloys



Material Properties

Price	3.7	\$/kg
Density	2,710	kg/m³
Young's modulus	74	GPa
Yield strength (elastic limit)	169	MPa
Thermal conductivity	133	W/m.C
Specific heat capacity	928	J/kg.°C
CO2 footprint, primary production	7.7	kg/kg
Water usage	1,080	l/kg
Recycle fraction	33	%

Aluminum is the second most important metal in the economy. Its good strength and low density give it uses from drinks cans, cafetiere to aircraft wings.

Bamboo

Hybrids:
composites, foams,
natural materials



Material Properties

Price	1.6	\$/kg
Density	693	kg/m³
Young's modulus	17	GPa
Yield strength (elastic limit)	40	MPa
Thermal conductivity	0.16	W/m.C
Specific heat capacity	1,726	J/kg.°C
CO2 footprint, primary production	0.3	kg/kg
Water usage	703	l/kg
Recycle fraction	1.0	%

Bamboo is an extremely fast growing plant with a hollow structure that makes it strong and light. In some countries it is used for houses, furniture and bridges.

Carbon composite (CFRP)

Hybrids:
composites, foams,
natural materials



Material Properties

Price	40.2	\$/kg
Density	1,550	kg/m³
Young's modulus	104	GPa
Yield strength (elastic limit)	789	MPa
Thermal conductivity	1.8	W/m.C
Specific heat capacity	947	J/kg.°C
CO2 footprint, primary production	51.5	kg/kg
Water usage	1,463	l/kg
Recycle fraction	0.1	%

Carbon reinforced polymers (CFRPs), which is normally called as carbon composite, are very stiff and light, but are expensive, so they are mainly used in aerospace and sports equipment.

Horn

Hybrids:
composites, foams,
natural materials



Material Properties

Price	5.2	\$/kg
Density	1,260	kg/m³
Young's modulus	8	GPa
Yield strength (elastic limit)	34	MPa
Thermal conductivity	0.20	W/m.C
Specific heat capacity	1,359	J/kg.°C
CO2 footprint, primary production	1.3	kg/kg
Water usage	867	l/kg
Recycle fraction	0	%

Horn is made up of a Keratin-based material, sometimes with a bony core. True horn is found ruinsants such as Cows.

Cork

Hybrids:
composites, foams,
natural materials



Material Properties

Price	6.0	\$/kg
Density	196	kg/m³
Young's modulus	0.04	GPa
Yield strength (elastic limit)	2	MPa
Thermal conductivity	0.04	W/m.C
Specific heat capacity	1,928	J/kg.°C
CO2 footprint, primary production	0.0	kg/kg
Water usage	718	l/kg
Recycle fraction	1.0	%

Cork is a natural cellular material, durable and with low thermal conductivity. It is used for flooring, footwear, thermal insulation and as a seal for bottles.

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Glass composite

Hybrids:
composites, foams,
natural materials



Material Properties

Price	35.3	\$/kg
Density	1,860	kg/m³
Young's modulus	22	GPa
Yield strength (elastic limit)	254	MPa
Thermal conductivity	0.47	W/m.C
Specific heat capacity	1,050	J/kg.°C
CO2 footprint, primary production	6.8	kg/kg
Water usage	206	l/kg
Recycle fraction	0	%

GFRPs, which is normally called as glass composite, are made from glass fibers in a thermosetting resin. They have high stiffness and strength at low weight and are cheaper than CFRPs.

Oak (along grain)

Hybrids:
composites, foams,
natural materials



Material Properties

Price	8.5	\$/kg
Density	936	kg/m³
Young's modulus	5	GPa
Yield strength (elastic limit)	5	MPa
Thermal conductivity	0.18	W/m.C
Specific heat capacity	1,662	J/kg.°C
CO2 footprint, primary production	0.4	kg/kg
Water usage	684	l/kg
Recycle fraction	1.0	%

Oak is a hardwood, long used for construction, ship-building and furniture. The properties here are those parallel to the grain.

Leather

Hybrids:
composites, foams,
natural materials



Material Properties

Price	18.6	\$/kg
Density	922	kg/m³
Young's modulus	0.22	GPa
Yield strength (elastic limit)	3	MPa
Thermal conductivity	0.16	W/m.C
Specific heat capacity	1,593	J/kg.°C
CO2 footprint, primary production	4.4	kg/kg
Water usage	11,500	l/kg
Recycle fraction	0	%

Leather is made from tanning animal hides, making it pliable and resistant to decay. It is mainly used in shoes, hats, clothes, furniture and baggage.

Paper

Hybrids:
composites, foams,
natural materials



Material Properties

Price	1.1	\$/kg
Density	897	kg/m³
Young's modulus	3	GPa
Yield strength (elastic limit)	22	MPa
Thermal conductivity	0.25	W/m.C
Specific heat capacity	1,367	J/kg.°C
CO2 footprint, primary production	1.1	kg/kg
Water usage	1,721	l/kg
Recycle fraction	74	%

Paper - one of the oldest and most versatile of man-made materials - is cellulose plant fibers, separated then compacted into sheets.

Pine (along grain)

Hybrids:
composites, foams,
natural materials



Material Properties

Price	0.9	\$/kg
Density	514	kg/m³
Young's modulus	10	GPa
Yield strength (elastic limit)	40	MPa
Thermal conductivity	0.26	W/m.C
Specific heat capacity	1,727	J/kg.°C
CO2 footprint, primary production	0.2	kg/kg
Water usage	723	l/kg
Recycle fraction	1.0	%

Pine is a softwood widely used for construction, furniture and paper-making. The properties here are those parallel to the grain.

Silk (Silkworm silk) fiber

Hybrids:
composites, foams,
natural materials



Material Properties

Price	40.2	\$/kg
Density	1,300	kg/m³
Young's modulus	11	GPa
Yield strength (elastic limit)	490	MPa
Thermal conductivity	0.25	W/m.C
Specific heat capacity	1,374	J/kg.°C
CO2 footprint, primary production	106.9	kg/kg
Water usage	838	l/kg
Recycle fraction	0	%

Silk is the material of balloons, parachutes and the clothing of emperors and film stars. It is the fiber spun by silk worm to wrap and insulate its cocoon.

Butyl rubber

Polymers
and elastomers



Material Properties

Price	2.4	\$/kg
Density	930	kg/m³
Young's modulus	0.001	GPa
Yield strength (elastic limit)	5	MPa
Thermal conductivity	0.10	W/m.C
Specific heat capacity	1,903	J/kg.°C
CO2 footprint, primary production	4.5	kg/kg
Water usage	113	l/kg
Recycle fraction	2.8	%

Synthetic rubbers, such as reinforced styrene butadiene rubber, are used in car tires, gloves, tubing and seals due to their low permeability to air.

PVC

Polymers
and elastomers



Material Properties

Price	2.4	\$/kg
Density	1,370	kg/m³
Young's modulus	3	GPa
Yield strength (elastic limit)	42	MPa
Thermal conductivity	0.18	W/m.C
Specific heat capacity	1,019	J/kg.°C
CO2 footprint, primary production	2.9	kg/kg
Water usage	184	l/kg
Recycle fraction	1.5	%

PVC (Vinyl) is one of the cheapest, most versatile polymers. It can be foamed, reinforced with glass fibers or elastomerized with plasticizers.

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PTFE

**Polymers
and elastomers**



Material Properties

Price	13.4	\$/kg
Density	2,170	kg/m ³
Young's modulus	0.49	GPa
Yield strength (elastic limit)	20	MPa
Thermal conductivity	0.26	W/m.C
Specific heat capacity	1,064	J/kg.°C
CO2 footprint, primary production	16.0	kg/kg
Water usage	465	l/kg
Recycle fraction	0.7	%

PTFE is better known as Teflon. It has excellent chemical resistance and non-wettability. It is used in water proof clothing and non-stick utensils.

PP

**Polymers
and elastomers**



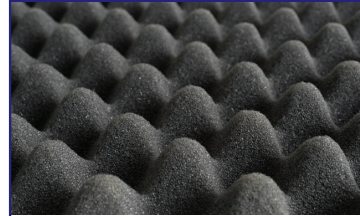
Material Properties

Price	1.7	\$/kg
Density	902	kg/m ³
Young's modulus	1	GPa
Yield strength (elastic limit)	26	MPa
Thermal conductivity	0.19	W/m.C
Specific heat capacity	1,635	J/kg.°C
CO2 footprint, primary production	2.9	kg/kg
Water usage	39	l/kg
Recycle fraction	1.0	%

Polypropylene (PP) is a cheap, tough thermoplastic widely used for household goods, kitchen ware and garden furniture.

Polyurethane

**Polymers
and elastomers**



Material Properties

Price	2.5	\$/kg
Density	1,200	kg/m ³
Young's modulus	0.01	GPa
Yield strength (elastic limit)	43	MPa
Thermal conductivity	0.29	W/m.C
Specific heat capacity	1,616	J/kg.°C
CO2 footprint, primary production	3.3	kg/kg
Water usage	97	l/kg
Recycle fraction	0.1	%

Polyurethane have thermoplastic, elastomeric (e.g. the soft, stretchy fabrics Lycra and Spandex) and thermosetting grades, and they are easily foamed.

Phenolic

**Polymers
and elastomers**



Material Properties

Price	3.1	\$/kg
Density	1,280	kg/m ³
Young's modulus	4	GPa
Yield strength (elastic limit)	37	MPa
Thermal conductivity	0.15	W/m.C
Specific heat capacity	1,444	J/kg.°C
CO2 footprint, primary production	3.7	kg/kg
Water usage	53	l/kg
Recycle fraction	0.7	%

Bakelite is an example of a phenolic resin. Commercialized in 1909, it is stiff, chemically stable, has good electrical properties, is fire-resistant and easy to mold-and cheap.

Polystyrene

**Polymers
and elastomers**



Material Properties

Price	2.5	\$/kg
Density	1,040	kg/m ³
Young's modulus	3	GPa
Yield strength (elastic limit)	34	MPa
Thermal conductivity	0.13	W/m.C
Specific heat capacity	1,281	J/kg.°C
CO2 footprint, primary production	3.0	kg/kg
Water usage	154	l/kg
Recycle fraction	1.8	%

Polystyrene (PS) is an optically clear, cheap, easily molded polymer, familiar as the "jewel" CD case. The largest use of polystyrene is in foam packaging.

PLA

**Polymers
and elastomers**



Material Properties

Price	3.2	\$/kg
Density	1,240	kg/m ³
Young's modulus	4	GPa
Yield strength (elastic limit)	56	MPa
Thermal conductivity	0.14	W/m.C
Specific heat capacity	1,148	J/kg.°C
CO2 footprint, primary production	2.3	kg/kg
Water usage	20	l/kg
Recycle fraction	0.3	%

PLA (polylactic acid) is a biodegradable thermoplastic with properties like polystyrene, made from renewable resources (corn starch or sugarcane), not from oil.

ABS

**Polymers
and elastomers**



Material Properties

Price	2.7	\$/kg
Density	1,040	kg/m ³
Young's modulus	2	GPa
Yield strength (elastic limit)	41	MPa
Thermal conductivity	0.26	W/m.C
Specific heat capacity	1,737	J/kg.°C
CO2 footprint, primary production	3.5	kg/kg
Water usage	172	l/kg
Recycle fraction	3.8	%

ABS (Acrylonitrile butadiene styrene) is a tough polymer which can be molded into complex shapes and colors, hence it is often used in toys.

Natural rubber

**Polymers
and elastomers**



Material Properties

Price	1.7	\$/kg
Density	950	kg/m ³
Young's modulus	0.002	GPa
Yield strength (elastic limit)	24	MPa
Thermal conductivity	0.14	W/m.C
Specific heat capacity	1,918	J/kg.°C
CO2 footprint, primary production	2.5	kg/kg
Water usage	17,849	l/kg
Recycle fraction	0.1	%

Natural rubber made the fortune of Giles Macintosh who devised the rubber-coated coat that bears his name. It is formed from latex, the sap of the rubber tree.

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Standard rules

Material Intelligence:

The Game is for two or more players.

The dealer shuffles the deck and deals one card at a time face down, beginning with the player on the left, using all the deck. Each player holds the cards so only the front of the top card is showing, making sure other players cannot see it.

The player to the left of the dealer starts by reading out a material property - e.g., Density 2320. The other players read out the same property from their top card. The player with the highest value collects all the cards and places them at the bottom of their hand. The winner then picks a property from the next card.

If two or more cards share the highest value, these cards are placed in the middle and the same player chooses a property from the next card. The winner takes the cards from both rounds and places them at the bottom of their hand.

The player who collects all the cards is the winner.

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Alternative rules

Proceed as in the standard rules except for the following.

Players should hold their cards so that they can see all of them, making sure the other players cannot see them.

The player selecting a property reads out that property - e.g., "Thermal Conductivity, 50", and decides whether the winning value should be the highest or the lowest.

To increase the difficulty of the game, this player can also nominate a material family. All players in that round must play a card from the chosen family. If a player does not have a card in the nominated family, they must give one card from their hand to the winner of the round.

The player with the highest value in the nominated material family gathers all the cards placed in the middle and collects these on his/her side of the table.

The player who collects all the cards is the winner of the round. The winner then picks a material family and a property, and so on until all the cards have been played.

Material families

Ceramics and glasses

Ceramics are non-metallic, inorganic solids. They are stiff, hard, and resist abrasion but, unlike metals, they are brittle. Glasses are non-crystalline solids that are hard and remarkably corrosion resistant.

Metals and alloys

Metals are stiff and most, when pure, are soft and easily deformed. They can be made strong by alloying and by mechanical and heat treatment. They are good electrical thermal conductors but are prey to fatigue and they corrode rapidly if not protected.

Hybrids: composites, foams, natural materials

Hybrids are combinations of two (or more) materials in an attempt to get the best of both. They include sandwich and lattice structures, foams, cables and laminates, and almost all the materials of nature - wood, bone, skin, leaf.

Polymers and elastomers

Polymers are mainly based on long chains of carbon atoms. They have low stiffness but can be as strong as metals. Their properties depend on temperature. Elastomers can be stretched to many times their starting length yet recover their initial shape when released.

Material properties

General Properties

Price (\$/kg)

Material prices fluctuate, depending on supply and demand. The values on the cards are approximate.

Mechanical and Thermal properties

Density (kg/m³)

Density is the mass per unit volume of a material.

Young's modulus (GPa)

Materials with a low Young's modulus are bendy; those with a high Young's modulus are stiff.

Yield strength (elastic limit) (MPa)

The loading at which a material starts to deform permanently.

Thermal conductivity (W/m.K)

The rate at which heat flows through a material when one side is hotter than the other.

Specific heat capacity (J/kg.K)

The energy required to increase the temperature of 1kg of a material by 1 Kelvin.

Eco properties

CO2 footprint, primary production (kg/kg)

The amount of carbon dioxide released into the atmosphere during the production of 1 kg of material.

Water usage (l/kg)

The amount of water needed to produce 1 kg of a material.

Recycle fraction (%)

This is the fraction of the current supply of a material that has been recycled.

Material Intelligence the game



Ansys

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