Description

Image

Caption

1. Stack of copy paper. © Jonathan Joseph Bondhus at en.wikipedia - (CC BY-SA 3.0) 2. Corrugated cardboard. © Richard Wheeler (Zephyris) at en.wikipedia - (CC BY-SA 3.0)

The material

Papyrus, the forerunner of paper, was made from the flower stem of the reed, native to Egypt; it has been known and used for over 5000 years. Paper, by contrast, is a Chinese invention (105 AD). It is made from pulped cellulose fibers derived from wood, cotton or flax. There are many different types of paper and paper board: tissue paper - newsprint, kraft paper for packaging, office paper, fine glazed writing paper, cardboard - and a correspondingly wide range of properties. The data below span the range of newsprint and kraft paper.

Compositional summary

Cellulose fibers, usually with filler and

General properties

Density	480	-	860	kg/m^3
Price	* 0.99	-	1.21	USD/kg
Date first used	105			

Mechanical properties

Young's modulus	3	-	8.9	GPa
Shear modulus	* 1	-	2	GPa
Bulk modulus	* 2	-	4	GPa
Poisson's ratio	0.38	-	0.41	
Yield strength (elastic limit)	15	-	34	MPa
Tensile strength	23	-	51	MPa
Compressive strength	41	-	55	MPa
Elongation	0.75	-	2	% strain
Hardness - Vickers	* 4	-	9	HV
Fatigue strength at 10^7 cycles	* 13	-	24	MPa

Fracture toughness	* 6	-	10	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.05	-	0.2	

Thermal properties

Glass temperature	47	-	67	°C
Maximum service temperature	77	-	130	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	0.06	-	0.17	W/m.°C
Specific heat capacity	1.34e3	-	1.4e3	J/kg.°C
Thermal expansion coefficient	5	-	20	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good insulator			
Electrical resistivity	1e13	-	1e15	µohm.cm
Dielectric constant (relative permittivity)	2.5	-	6	
Dissipation factor (dielectric loss tangent)	0.015	-	0.04	
Dielectric strength (dielectric breakdown)	0.2	-	0.3	1000000 V/m

Optical properties

Transparency	Opaque

Processability

Moldability	4	-	5	

Durability: water and aqueous solutions

Water (fresh)	Unacceptable
Water (salt)	Unacceptable
Soils, acidic (peat)	Unacceptable
Soils, alkaline (clay)	Unacceptable
Wine	Acceptable

Durability: acids

Acetic acid (10%)	Unacceptable
Acetic acid (glacial)	Unacceptable
Citric acid (10%)	Unacceptable
Hydrochloric acid (10%)	Unacceptable
Hydrochloric acid (36%)	Unacceptable
Hydrofluoric acid (40%)	Unacceptable
Nitric acid (10%)	Unacceptable
Nitric acid (70%)	Unacceptable
Phosphoric acid (10%)	

	Unacceptable
Phosphoric acid (85%)	Unacceptable
Sulfuric acid (10%)	Unacceptable
Sulfuric acid (70%)	Unacceptable

Durability: alkalis

Sodium hydroxide (10%)	Unacceptable
Sodium hydroxide (60%)	Unacceptable

Durability: fuels, oils and solvents

Amyl acetate	Acceptable
Benzene	Acceptable
Carbon tetrachloride	Acceptable
Chloroform	Acceptable
Crude oil	Limited use
Diesel oil	Acceptable
Lubricating oil	Acceptable
Paraffin oil (kerosene)	Acceptable
Petrol (gasoline)	Acceptable
Silicone fluids	Acceptable
Toluene	Acceptable
Turpentine	Excellent
Vegetable oils (general)	Acceptable
White spirit	Acceptable

Durability: alcohols, aldehydes, ketones

Acetaldehyde	Acceptable
Acetone	Acceptable
Ethyl alcohol (ethanol)	Acceptable
Ethylene glycol	Acceptable
Formaldehyde (40%)	Acceptable
Glycerol	Acceptable
Methyl alcohol (methanol)	Acceptable

Durability: halogens and gases

Chlorine gas (dry)	Limited use
Fluorine (gas)	Unacceptable
O2 (oxygen gas)	Unacceptable
Sulfur dioxide (gas)	Limited use

Durability: built environments

Industrial atmosphere	Unacceptable
Rural atmosphere	Unacceptable
Marine atmosphere	Unacceptable
UV radiation (sunlight)	Fair

Durability: flammability

Flammability	Highly flammable

Durability: thermal environments

Tolerance to cryogenic temperatures	Acceptable
Tolerance up to 150 C (302 F)	Acceptable
Tolerance up to 250 C (482 F)	Unacceptable
Tolerance up to 450 C (842 F)	Unacceptable
Tolerance up to 850 C (1562 F)	Unacceptable
Tolerance above 850 C (1562 F)	Unacceptable

Geo-economic data for principal component

Annual world production, principal component	3.59e8	-	3.6e8	tonne/yr

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	48.9	-	54	MJ/kg
CO2 footprint, primary production	*	1.11	-	1.23	kg/kg
Water usage	*	1.62e3	-	1.79e3	l/kg
Eco-indicator 95		95.5			millipoints/kg
Eco-indicator 99		110			millipoints/kg

Material recycling: energy, CO2 and recycle fraction

Recycle	✓				
Embodied energy, recycling	*	21	-	23.2	MJ/kg
CO2 footprint, recycling	*	1.13	-	1.25	kg/kg
Recycle fraction in current supply		70	-	74	%
Downcycle	✓				
Combust for energy recovery	✓				
Heat of combustion (net)	*	19.2	-	20.2	MJ/kg
Combustion CO2	*	1.07	-	1.13	kg/kg
Landfill	✓				
Biodegrade	✓				
Toxicity rating		Non-toxic			
A renewable resource?	✓				

Supporting information

Technical notes

Paper is graded in "grammage", the weight, in grams, per unit area. typically 40 - 120 g/m^2. The "bulk" of paper is the reciprocal of its density. The typical sheet "caliper" or thickness of newsprint is 40 - 50 microns; that of bond paper 60 - 90 microns, paper board 120 - 300 microns. "Book bulk" is the number of sheets that, when stacked, have a thickness of 25 mm (1 inch). For newsprint this is 60 - 80, for office paper, it is 105 - 110.

Cellulose fibers (the main constituent of paper) swell in diameter by 15 - 20% from dry to water-saturated. Since most of the fibers in paper lie parallel, change of humidity can change the dimension of the sheet, affecting registration in printing, which therefore requires a controlled atmosphere. Typically moisture accounts of 6 - 9 % of the weight of paper. Friction, too, is important in printing and in packaging; the coefficient of friction of paper sliding on paper is 0.35 - 0.45.

Typical uses

Packaging, filtering, writing; printing; currency, electrical and thermal insulation; gaskets.

Further reading

General information about paper: http://www.paperonweb.com

Eco and thermal data from Hammond, G. and Jones, C. (2006) "Inventory of carbon and energy (ICE), Dept. of Mechanical Engineering, University of Bath, UK.

Links

Reference

ProcessUniverse