(PACKING) PEANUTS: GOOD GRIEF!

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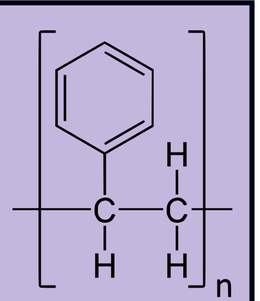
POLYSTYRENE PEANUTS

THE MOST COMMON MATERIAL FOR PACKING PEANUTS IS EXTRUDED POLYSTYRENE FOAM (EPS), A MAN-MADE LOW-DENSITY MATERIAL USED FOR ITS DURABILITY AND LOW COST.

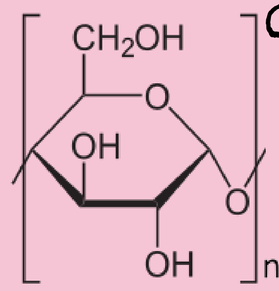


OVERVIEW

PACKING PEANUTS ARE A HUGE MARKET, AND STARTING IN THE 1990S, A BIODEGRADABLE OPTION BECAME AVAILABLE IN THE FORM OF CORNSTARCH-BASED PACKING PEANUTS. THESE PROMISE TO PROVIDE EQUIVALENT PROTECTION WITH SIGNIFICANTLY DECREASED ENVIRONMENTAL IMPACT COMPARED TO TRADITIONAL POLYSTYRENE PEANUTS.

WE SET OUT TO STUDY THESE TWO POLYMERS THROUGH A MATERIALS SCIENCE PERSPECTIVE. THROUGH ANALYSIS OF BOTH POLYMERS AT THE NANO, MICRO, AND MACRO SCALES, WE ANALYZED THE ECONOMICS, MECHANICAL EFFICACY, AND ENVIRONMENTAL IMPACTS OF BOTH PEANUT TYPES, ULTIMATELY CONCLUDING THAT CORNSTARCH PEANUTS OFFER SIGNIFICANTLY REDUCED ENVIRONMENTAL IMPACTS WHILE OFFERING BROADLY SIMILAR MECHANICAL PROPERTIES.

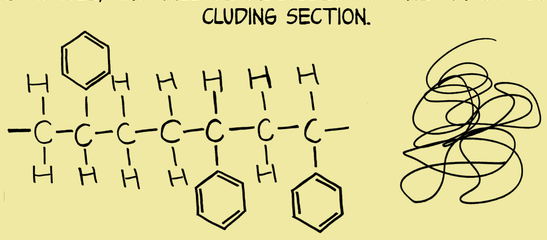
CORNSTARCH PEANUTS



BIODEGRADABLE PACKING PEANUTS ARE MADE FROM CORNSTARCH, A NATURAL MATERIAL MADE FROM A MIX OF AMYLOSE AND AMYLODEXTRIN AND USED FOR ENERGY STORAGE.

POLYSTYRENE STRUCTURE

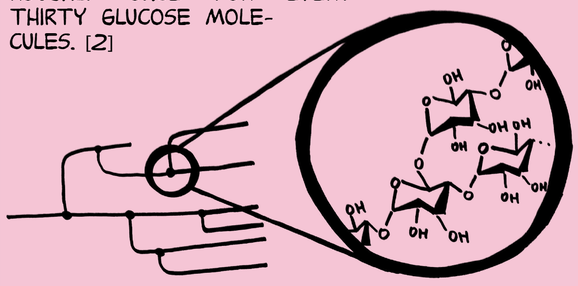
EPS FOAM IS MADE OF POLYSTYRENE, A LINEAR POLYMER OF STYRENE. AS SHOWN IN THE DIAGRAM BELOW (LEFT), IT IS HELD TOGETHER BY SINGLE AND DOUBLE CARBON-CARBON BONDS, MAKING IT STRONG AND NON-POLAR. [1] ITS ATACTICITY MAKES IT CLUMP IN AN AMORPHOUS BUNCH, ALSO SHOWN BELOW (RIGHT). GIVEN TIME, ULTRAVIOLET RADIATION WILL CHIP OFF SMALL PARTICLES OF POLYSTYRENE, LEAVING MICROPLASTICS IN THE SURROUNDING ENVIRONMENT, BUT POLYSTYRENE'S LACK OF POLAR BONDS PREVENTS ALL WATER SOLUBILITY. EPS FOAM IS NOT BIODEGRADABLE, AND WILL BE DISCUSSED FURTHER IN OUR CONCLUDING SECTION.



CORNSTARCH STRUCTURE

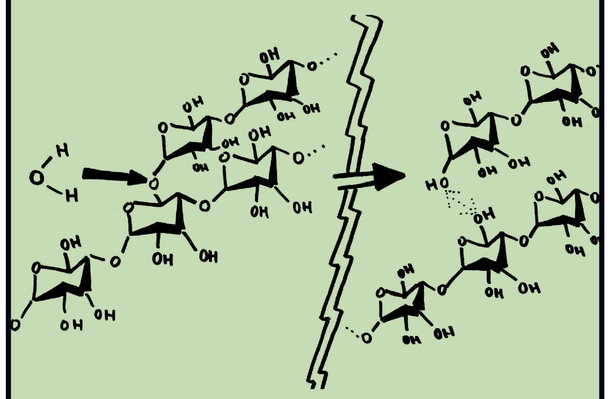
CORNSTARCH, LIKE OTHER STARCHES, IS PRODUCED BY PLANTS FOR LONG-TERM STORAGE OF GLUCOSE MONOMERS. CORNSTARCH IS MADE UP MOSTLY OF AMYLOPECTIN, A BRANCHING POLYMER OF GLUCOSE MOLECULES. [2] ITS POLYMER SHAPE IS SHOWN BELOW.

BRANCHES OCCUR WHEN GLUCOSE SUBUNITS FORM 1-6 CARBON BONDS, AND EMERGE ROUGHLY ONCE FOR EVERY THIRTY GLUCOSE MOLECULES. [2]



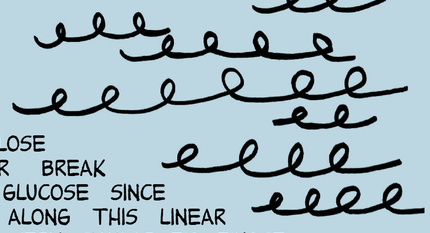
AMYLOPECTIN HYDROLYSIS

WHEN WATER MOLECULES ARE INTRODUCED, HYDROLYSIS CAN OCCUR AT THE BRANCHING POINTS OF AMYLOPECTIN CHAINS, WHICH ARE MOST EXPOSED DUE TO THE SHAPE OF THE MOLECULE. [3]

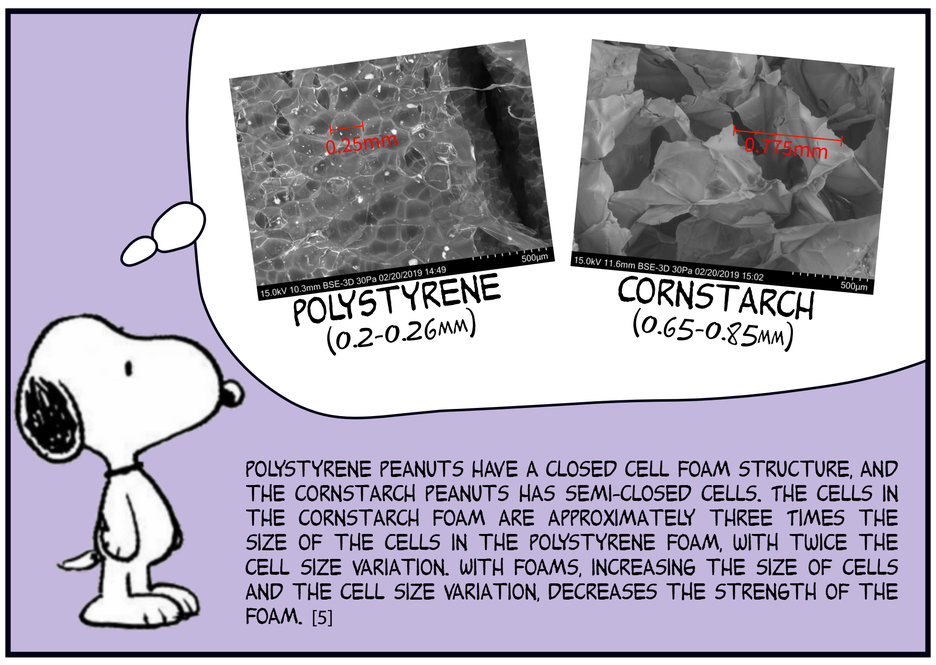


DISSOLVED RESIDUE

AS SUCH, WATER BREAKS DOWN AMYLOPECTIN AT ITS BRANCHING POINTS, LEAVING BEHIND AMYLOSE NANO-POLYMERS. AMYLOSE IS AN UNBRANCHED, CURLING POLYMER OF GLUCOSE, AS SHOWN BELOW.

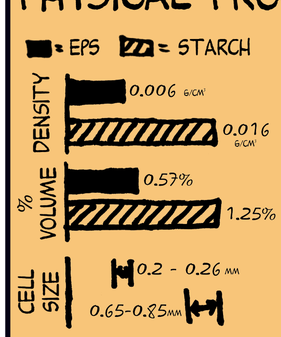


YOU MIGHT EXPECT AMYLOSE TO FURTHER BREAK DOWN INTO GLUCOSE SINCE THE BONDS ALONG THIS LINEAR POLYMER ARE VERY SIMILAR TO THOSE JUST BROKEN. HOWEVER, AMYLOSE'S LOOPING SHAPE RESISTS HYDROLYSIS, AND SO AMYLOSE RESISTS DISSOLUTION. [4] AMYLOSE AND AMYLOPECTIN ARE BOTH BIODEGRADABLE, AND THEIR IMPACTS WILL ALSO BE DISCUSSED FURTHER IN OUR CONCLUDING SECTION.

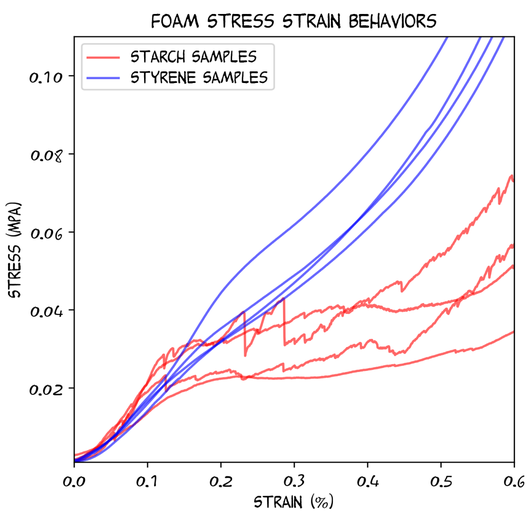


POLYSTYRENE PEANUTS HAVE A CLOSED CELL FOAM STRUCTURE, AND THE CORNSTARCH PEANUTS HAS SEMI-CLOSED CELLS. THE CELLS IN THE CORNSTARCH FOAM ARE APPROXIMATELY THREE TIMES THE SIZE OF THE CELLS IN THE POLYSTYRENE FOAM, WITH TWICE THE CELL SIZE VARIATION. WITH FOAMS, INCREASING THE SIZE OF CELLS AND THE CELL SIZE VARIATION, DECREASES THE STRENGTH OF THE FOAM. [5]

PHYSICAL PROPERTIES

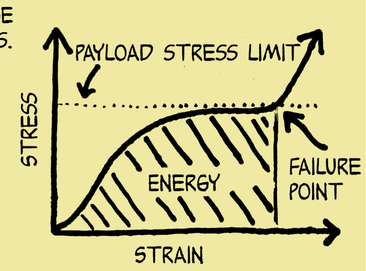


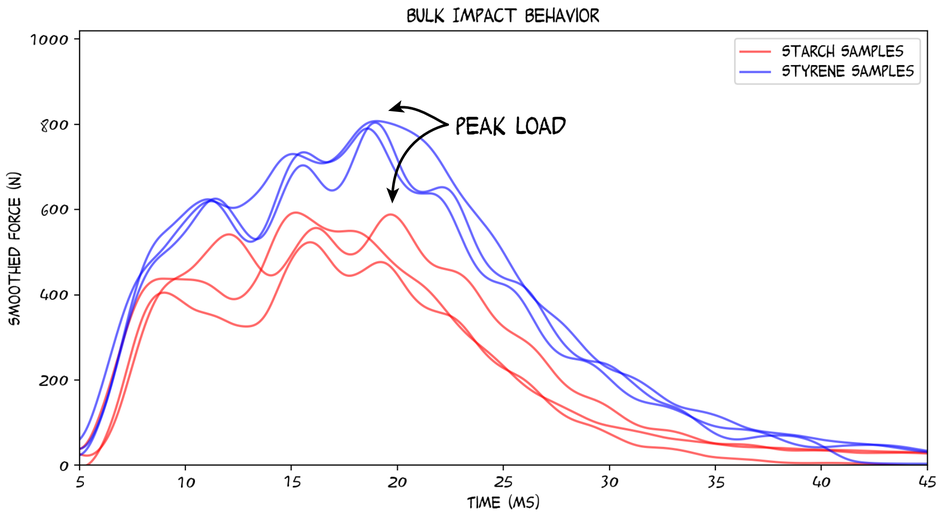
THE BASIC MATERIAL PROPERTIES OF EACH FOAM DEPEND ON MULTIPLE FACTORS, INCLUDING MATERIAL PROPERTIES OF THE BASE MATERIAL, DENSITY OF THE FOAM, AND THE GEOMETRY OF THE CELLS. DUE TO THE SMALLER, MORE REGULAR CELLS OF POLYSTYRENE, THE MICROSTRUCTURE CONTRIBUTES MORE STRENGTH, WHICH EXPLAINS HOW IT CAN ACHIEVE SIMILAR PERFORMANCE TO THE STARCH IN OUR TESTS DESPITE HAVING LESS THAN HALF OF THE DENSITY. IN ADDITION, THE CLOSED-CELL NATURE OF THE FOAM ALLOWS THE ENTRAPPED AIR TO SERVE AS A SUPPORT DURING STRUCTURAL LOAD TESTS.



MECHANICAL PROP.

THE STYRENE LINES ARE SMOOTH, TIGHTLY CLUSTERED, AND MOSTLY LINEAR, INDICATING THAT EPS ABSORBS ENERGY ELASTICALLY FOR THE ENTIRE TESTED RANGE. IN CONTRAST, AFTER A THRESHOLD STRAIN, STARCH FOAMS BEGIN TO ABSORB ENERGY THROUGH CELL WALL FAILURE, AS INDICATED BY SMALL SHARP DROPS IN STRESS. THIS ALLOWS THEM TO ABSORB MORE ENERGY AT A LOWER STRESS THAN STYRENE, BUT DIMINISHES SURVIVAL AFTER MULTIPLE LARGE FALLS.



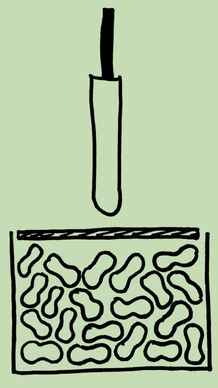


IMPACT TESTING

WE USED AN IMPACT TESTER TO MEASURE THE COMPLICATED INTERACTIONS BETWEEN MULTIPLE PEANUTS IN A BOX.

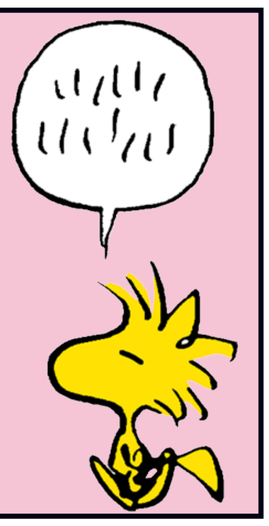
WE SET UP A SCENARIO TO MODEL THE BEHAVIOR OF PEANUTS TRAPPED BETWEEN THE BOTTOM OF A CARDBOARD BOX AND A RAPIDLY DESCENDING CARGO THEY NEED TO PROTECT, SIMULATED IN THIS EXPERIMENT WITH A LARGE ALUMINUM PLATE PROPELLED BY THE IMPACT TESTER.

THE RESULTING DATA SHOWS THE AMOUNT OF FORCE EXERTED BY THE PEANUTS ON THE "CARGO", WHERE LOWER PEAKS INDICATE A GENTLER COLLISION. NOTE THAT THE FIRST 5MS RECORD THE COLLISION WITH THE PLATE, AND HAVE BEEN HIDDEN.



IMPACT TEST RESULTS

AS THE GRAPH SHOWS, THE PEAK DECELERATION INDUCED BY THE STARCH PEANUTS IS 20-30% LOWER THAN THE POLYSTYRENE, INDICATING THAT THE STARCH IS GENTLER FOR THE SPECIFIC IMPACT CONDITIONS WE CHOSE. WE HYPOTHESIZE THAT SEVERAL FACTORS COMBINE TO GIVE THE STARCH THIS SOFTER IMPACT PROFILE, INCLUDING VISCOUS DAMPING FROM AIR MOLECULES ESCAPING THROUGH THE OPEN-CELL FOAM, BUCKLING OF THE CELL WALLS AS INDICATED IN THE UNIVERSAL MECHANICAL TESTER DATA, AND SOFTENING DUE TO THE ABSORPTION OF ATMOSPHERIC MOISTURE. WE BELIEVE THAT MORE CAREFUL MEASUREMENT OF THE UNLOADING CURVES OF THE VARIOUS MATERIALS WOULD ALLOW US TO DISENTANGLE THESE CAUSES MORE EFFECTIVELY.



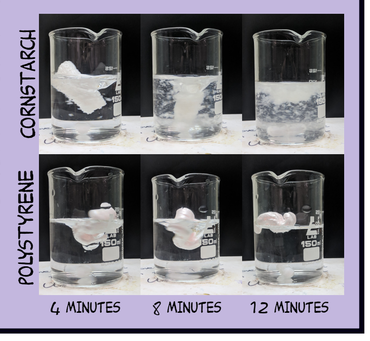
EFFICACY

ADVANTAGES TO USING POLYSTYRENE PEANUTS INCLUDE LESS WEIGHT, HIGH YIELD, MORE REPEATABLE PROTECTION, AND A REDUCTION OF DUST AND PESTS. CORNSTARCH PEANUTS, ON THE OTHER HAND, OFFER A LONGER PERIOD OF GRADUAL FAILURE DUE TO CELL COLLAPSE, THEREFORE ABSORBING ENERGY WITHOUT SUBJECTING THE PAYLOAD TO HIGH STRESSES.

	POLYSTYRENE	CORNSTARCH
PEAK LOAD	850N	580N
DENSITY	.006 G/CM³	.016 G/CM³
PLATEAU STRESS	N/A	~0.03MPA
FAILURE MECHANISM	ELASTIC	BUCKLING

ENVIRONMENTAL IMPACT

CORNSTARCH PEANUTS ARE BIODEGRADABLE AND POLYSTYRENE PEANUTS ARE NOT. CORNSTARCH PEANUTS LEAVE BEHIND AMYLOSE AND AMYLOPECTIN, BOTH OF WHICH ARE DIGESTIBLE FOR MANY COMMON BACTERIA AND OTHER ORGANISMS. THEY DEGRADE IN DAYS TO WEEKS. POLYSTYRENE PEANUTS GET CHIPPED AWAY VERY SLOWLY AND ONLY BY ULTRAVIOLET RADIATION, ALL THE WHILE LEAVING BEHIND HARMFUL MICROPLASTICS IN THE ENVIRONMENT. THEY STAY IN THE ENVIRONMENT FOR OVER 5 HUNDRED YEARS. [6, 7, 8]



ECONOMIC IMPACT

BULK CORNSTARCH PEANUTS COSTS 20-30% MORE THAN BULK POLYSTYRENE. [9] CURRENTLY, BIODEGRADABLE PEANUTS MAKE UP 20% OF PACKING PEANUTS SOLD, AND THAT NUMBER IS EXPECTED TO DOUBLE OVER THE NEXT TEN YEARS. AS CORNSTARCH TECHNOLOGY IMPROVES AND SUSTAINABILITY DEMANDS RISE, WE EXPECT TO SEE MORE AND MORE CORNSTARCH PEANUTS.