Group 10 Real World Project

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Real World Challenge

A bowling ball is a heavy spherical object repeatedly rolled at high speeds along a hard lane surface with the goal of striking bowling pins with enough force to knock them down. The ball is used thousands of times over its lifetime and regularly experiences high-impact collisions with both the lane and the pins. Therefore, **the material selected for a bowling ball must ensure durability, hardness, and fatigue resistance.**

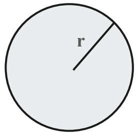
Market Requirements:

- Cost
- Will not crack or deform on impact
- Won't break over prolonged usage
- Won't scratch easily

Material Properties:

- Density & cost per kilogram
- Yield Strength
- Fatigue Resistance
- Hardness

Engineering Problem Statements



r = 10.83 cm

Figure 1: Assumed bowling ball radius of 10.83 cm.

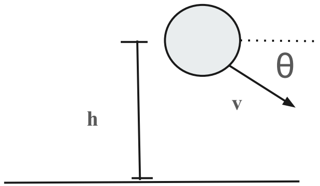


Figure 2: Initial State for Problem 3 where v is velocity, theta the angle from horizontal, and h the height from the ground.

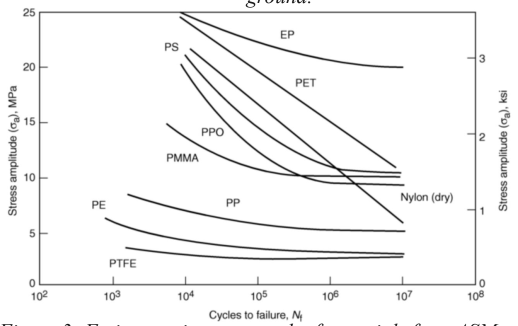


Figure 3: Fatigue resistance graph of materials from ASM handbook

1. Find a material that maximizes weight and minimizes cost. Assume a fixed diameter for your design. Provide a relevant MPI to be used in choosing a material.

2. Assuming the bowling ball acts like a disk and that the ball is dropped from a height of 1 meter, calculate the appropriate stress when dropped if the diameter of the ball is 21.65 cm. Assume a safety factor of 2 and a mass of 6.500kg.

3. Given that a bowling ball weighs 5 kg and is dropped from a height of 1 meter with an initial velocity of 2 m/s directed downward at 30 degrees from the horizontal, calculate the speed of the ball just before impact and the magnitude of the average impact force if the ball stops in 0.05 mm upon contact. Assume the impact area is 10 square centimeters. Neglect air resistance.

4. Assume that a bowling ball that is intended to sustain a total of 100,000 stress cycles with a stress amplitude of 7.5 MPa. Given Figure 3, using a safety factor of 2 for stress amplitude, which materials could be selected?

5. A 5-kg bowling ball impacts a rigid floor with an average normal force of 11.8 kN. At maximum compression, the ball undergoes an elastic indentation of 0.5 mm, and the contact patch formed between the ball and the floor has an effective area of approximately 10 cm². Assume the ball behaves as a linearly elastic, homogeneous sphere with radius 0.108 m, and assume a Poisson's ratio of 0.35. Using Hertzian elastic contact theory for a sphere on a rigid flat: Determine the minimum yield strength required to avoid plastic deformation.

Engineering Models

Cost per Kilogram (Ashby)

$$C = \frac{C_{\text{kg}}}{\rho}$$

Fractural Stress on Bowling Ball when Dropped

$$\sigma_f = \frac{1.5(mgh)^{1/3}E^{2/3}R^{-2/3}}{0.49\pi}$$

Uniform Compressive Stress on Disc

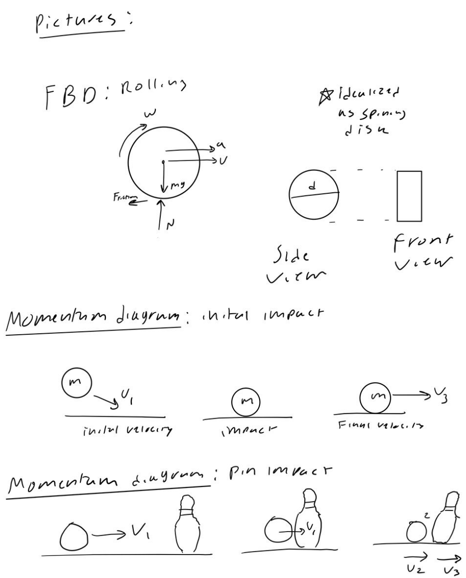
$$\sigma_{\text{max}} = \frac{F_{\text{max}}}{A} = \frac{2mgh}{\delta\, A} = \frac{2mgh}{\delta\, \pi \left(\frac{D}{2}\right)^2}$$

Von Mises Stress from Hertz Contact

(for comparison with each material's Yield Strength)

$$\sigma_{vm} \approx 0.45\, E \sqrt{\frac{\delta}{R}},$$

Force Body Diagrams



Ideal Material: Polystyrene

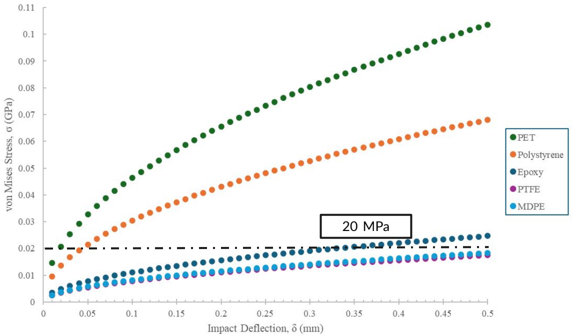


Figure 1: von Mises Stresses acting over a series of deflections of a bowling ball with the expected applied stress in black.

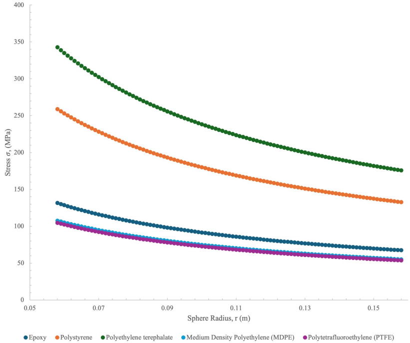


Figure 2: Fracture Stress experienced by a ball with a mass of 6.5 kg dropped from a height of 2 m, using average Young's Moduli for various materials over change of ball radii.

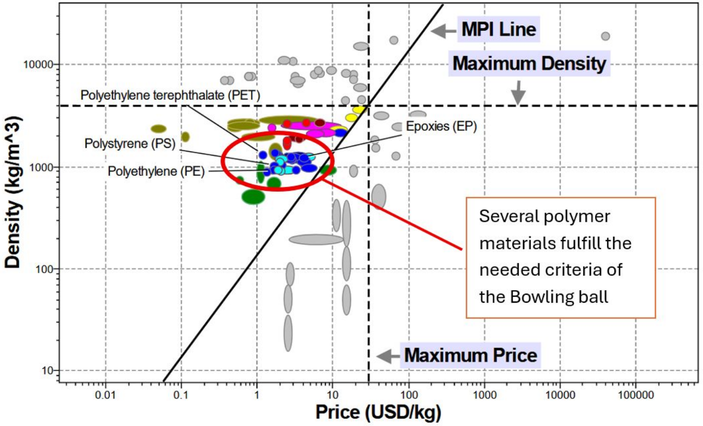


Figure 5: Ashby Chart relationship between Density and Price. Chart generated using Granta EduPack Software.

Table 1: Material performance indexes. Cost data from Materials Science and Engineering textbook.

Material	Ultimate Tensile Strength, σ_{max} (MPa)	Cost per Kilogram ($)
Polystyrene	32	0.11
Epoxy	93	37.06
Polytetrafluoroethylene	173	0.11
Medium Density Polyethylene	21	9.11
Polyethylene terephthalate	426	11.22

Table 2: Number of cycles and hardness. Data from matweb and specialchem.com

Material	Number of Cycles (Stress Amplitude (σ) = 12.5 MPa)	Hardness (Shore D)
Epoxy	1.00×10^7	65.1
Polystyrene	2.00×10^5	87.5
Polyethylene Terephthalate (PET)	1.00×10^6	80.8
Medium Density Polyethylene (MDPE)	3.00×10^4	61.4
Polytetrafluoroethylene (PTFE)	0	57

Table 3: Max stress based on velocity and material density compared to material compressive stress range

Material	Epoxy	PET	PTFE	MDPE*	Polystyrene*
Velocity (m/s)	Max Compressive Stress σ (MPa)				
1	12.46	14.24	21.68	9.82	10.3
2	12.93	14.78	22.49	10.19	10.69
3	13.72	15.67	23.86	10.81	11.34
4	14.81	16.93	25.77	11.68	12.25
5	16.22	18.54	28.22	12.79	13.42
6	17.95	20.51	31.22	14.15	14.84
7	19.99	22.84	34.77	15.75	16.53
8	22.34	25.53	38.86	17.61	18.47
9	25	28.58	43.49	19.71	20.68
10	27.98	31.98	48.68	22.06	23.14

Real World Answers

Environmental:

- Non-biodegradable, non-recyclable
- High energy cost to produce from petroleum

Social:

- Low chance of health concerns working with styrene

Economic:

- Low cost material
- Easy to manufacture

Summary:

While there is an environmental concern with using a petroleum based polymer, the ease of manufacturability, which wasn't accounted for in the model, means that **polystyrene** is still a **good choice given real world considerations.**

Real Material Choice: Polystyrene

References

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