“Good and Bad Materials”

Trinity College Dublin
The University of Dublin

Joe Linogao

Good Material: Tungsten Carbide for the Ball of a Ballpoint Pen

Figure 1: Selection of BIC Ballpoint Pens

For my first material, I decided to look for materials found in everyday objects we take for granted. After much consideration, I settled for tungsten carbide (WC) which the ink ball in most ballpoint pens is made from *(e.g. BIC).* Tungsten carbide is known for its high hardness, as well as high wear resistance. [1] The sturdy nature of the material suits the ball since it wears down as the pen is used.

Despite the low force we apply while we write, the small cross-sectional area of the ball *(i.e. a circle* πr^2*)* means that the material is under high stress during use. WC is also manufactured in powdered form, making it easy to manufacture a large number of balls through methods such as *compressing, grinding etc.* [2]

Using tungsten carbide as an ink ball reduce the chances of deformity over time. Thus, the lifetime of the pen does not reply on the ink ball, but rather on ink capacity or other parts of the pen. If the ball were to deform, even slightly, this could make the pen dispense ink unevenly leading to a poor writing experience for the user.

Figure 2: Close Up of Ballpoint Pen Tip

Figure 3: WC Ball Bearings

Analysis: Comparison with Other Materials

To show the superiority of tungsten carbide, we can observe how it performs as an ink ball in comparison to other metals, such as steel and brass. For our analysis, I assumed a perfectly smooth sphere with a cross-sectional area of πr^2. For simplicity, we will apply a force of 1N and assume that no form of necking can occur.

With these assumptions, we can calculate the engineering stress generated on an inkball with diameter 1mm (0.001m).

$$\frac{1}{(\frac{\pi}{4} * 0.001^2)} = 1273239Pa = 1.273\ MPa$$

Above, we calculated the constant stress that we will use for our comparison.

Although a ballpoint pen is most likely not undergoing ~ 1.3MPa regularly, it will work for our comparison. Using this, we can compare the strain between *tungsten carbide, steel and brass (UNS C28000 brass alloy)* and thus compare their resistance against deformation. After finding values for Young's Modulus [3][4][5], I calculated the strain of each metal using $\frac{\sigma}{E} = \varepsilon$.

The table below shows the following results:

STRAIN COMPARISON BETWEEN MATERIALS			
Material	**Young's Modulus (MPa)**	**Strain**	**Strain (μ)**
Tungsten Carbide	600000	2.12167E-06	2.12
Steel	200000	6.36500E-06	6.37
Brass	117000	1.08803E-05	10.88
		Stress (MPa)	**1.273**

Figure 4: Comparison of Strain in Metals

Here, we can see that the Tungsten Carbide has the lowest strain out of the steel and brass. Thus, it has the most resistance against deformation and is the best choice for the ballpoint pen.

This comparison is important when considering longevity. Using WC helps keep the pen functional even in after extreme cases *e.g. pressing the pen forcefully into a hard surface.* Additionally, having a strong ball allows the manufacturer to focus on other aspects of the pen, such as ink storage, knowing that the ballpoint will function perfectly for each revision.

Bad Material: Chairs with Plastic Legs

Figure 5: Plastic Chair with Broken Leg

Fig. 5 illustrates the material I have chosen as a poor material choice [6], which fits perfectly with my theme of common household items. This chair has one of its legs snapped off, possibly due to excessive force.

Plastic chairs, as the name implies, are made mostly from thermoplastics. The most common thermoplastic used is *Polyethylene terephthalate (PET)* [7], which has good toughness and is very cheap to manufacture with. Although it appears to be a good material, it is not the best material for prolonged sustainability.

It is safe to assume that plastic chairs are not used in perfect conditions throughout their lifespans. Notably, the legs of the chair undergo deflection when a force is applied. After many uses, this deflection can cause the material to become weaker at its fulcrum. Additionally, excessive deflection could cause the leg to deform permanently, compromising the structural integrity of the chair. All in all, these weak points eventually lead to failure and thus quickly reduce the lifespan of the chair.

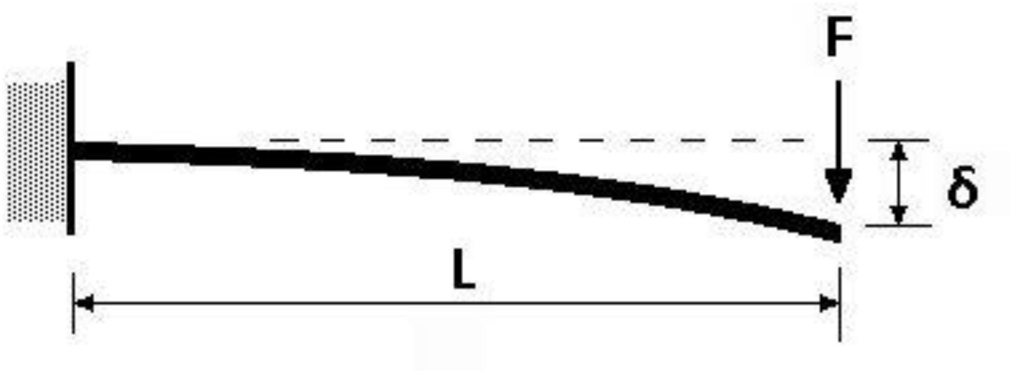

Figure 6: Example of Beam Deflection

Analysis: Comparing Plastic vs. Steel Deflection

For this analysis, we will compare the max deflection caused by plastic beam vs. a steel beam with the same dimensions & force. The formula to calculate maximum beam deflection (mm) is as follows:

$$\delta = \frac{PL^3}{3EI}$$

P = Applied Force (N), L = Length of Beam (mm), E = Young's Modulus (MPa), I = Moment of Inertia (mm^4)

Given an arbitrary beam of length 500mm and width 50mm, we can also calculate the moment of inertia of the beam.

$$\frac{50 * 500^3}{12} = 5.2x10^8\ mm^4$$

Applying a load of 1kN to both bars and, using Young's Modulus for PET plastic [8] and steel, we produce the following deflection table below. *Note for our deflection formula, we are assuming a simple bar, fixed at one end.*

MAX DEFLECTION COMPARISON BETWEEN MATERIALS				
Material	**Young's Modulus (MPa)**	**Max Deflection (mm)**	**Constants**	**Values**
PET Plastic	2950	0.027119	Applied Load (N)	1000
Steel	200000	0.000400	Length (mm)	500
			Moment of Inertia (mm^4)	5.21E+08

Figure 7: Max Deflection Comparison Table

From our table, we can see that a PET bar has a higher max deflection than a steel bar with the same dimensions and applied load.

While PET bar could be cheaper to manufacture, high loads will wear the material constantly since it must deflect due to force constantly. While the steel bar is not prone to deformation due to deflection, it would be able to sustain its shape for much longer. Furthermore, the steel requires a larger amount of force to deflect to the same degree as the PET bar.

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