EGR 110
Engineering Graphics
File: N110IL8

Inventor Lecture #8

Mass Properties of Solids

A powerful analysis feature available in Inventor is the ability to determine the mass properties of complex objects. Many engineering students will later calculate many of these properties in courses like ***Statics*** and ***Mechanics of Materials***. The calculations can become quite involved, even for fairly simple objects, so the ability of Inventor to find mass properties for complex object made of various types of materials is quite impressive.
In particular, Inventor can be used to specify the material type for each part, including the density, and then it can calculate:

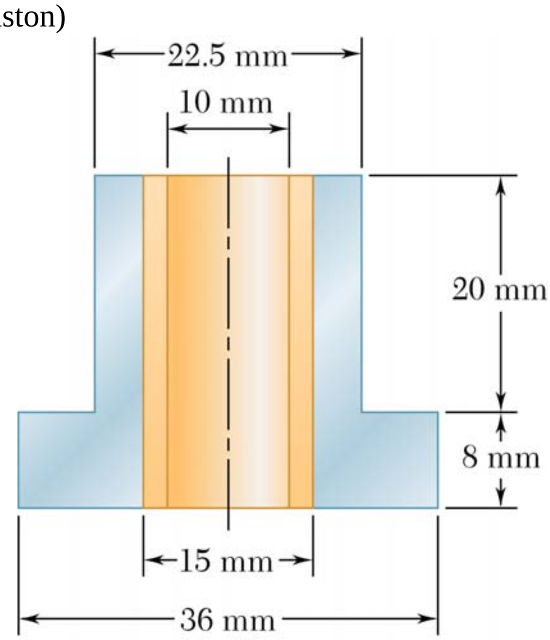
- Volume
- Mass
- Surface Area
- Center of Gravity
- Mass Moments of Inertia
- Principle Moments of Inertia

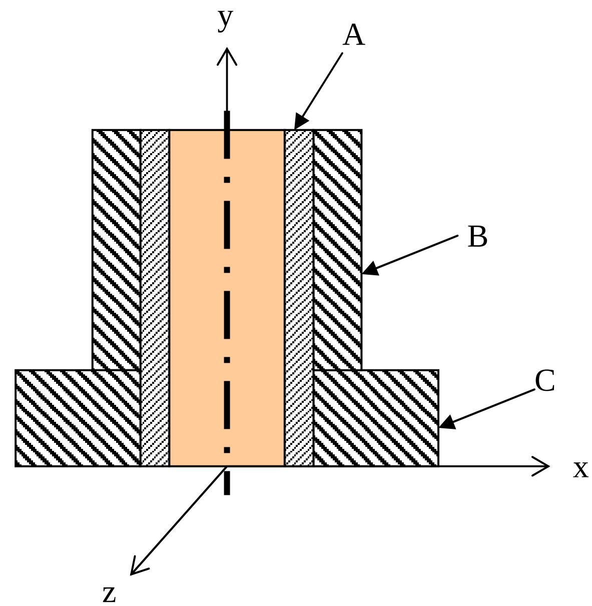
Center of Gravity

It is often important to know the center of gravity of a part in order to use it properly. The center of gravity of the boom of a crane is important in determining the max load that the crane can lift and weights are added to wheels on automobiles in order to "balance" the wheels such that their center of gravity will be in line with the axle of the wheel.

Example: Students taking EGR 140 - Statics will learn to calculate the center of gravity for various types of objects. Shown below is a problem from a Statics text used recently in EGR 140. The solution is also shown. You do not need to understand the solution at this point, but it will be nice to see that we can build the part in Inventor and achieve the same result.

Problem 5-113 (Statics, 7th Edition, by Beer & Johnston)
A bronze bushing is mounted inside a steel sleeve. Knowing that the density of bronze is 8800 kg/m^3 and steel is 7860 kg/m^3, determine the center of gravity of the assembly.





Solution:
The centroid or center of gravity of the referred to as $(\bar{x}, \bar{y}, \bar{z})$

Note that symmetry implies that $\bar{x} = \bar{z} = 0$
so we only need to find $\bar{y}$.

Divide the object into three parts as shown:
A – Bronze bushing
B – Upper part of steel sleeve
C - Lower part of steel sleeve

Note that the volume of a cylinder is:

$$V = \pi \cdot R^2 \cdot H = \pi \cdot \left(\frac{D}{2}\right)^2 \cdot H = \frac{\pi}{4} \cdot D^2 \cdot H$$

and the volume of a hollow cylinder is :

$$V = \frac{\pi}{4} \cdot \left[(D_{outer})^2 - (D_{inner})^2\right] \cdot H$$

so (using values in meters)

$$V_A = \frac{\pi}{4} \cdot \left[(0.036)^2 - (0.015)^2\right] \cdot (0.008) = 6.7293 \text{ x } 10^{-6} \text{ m}^3$$

$$V_B = \frac{\pi}{4} \cdot \left[(0.0225)^2 - (0.015)^2\right] \cdot (0.020) = 4.4179 \text{ x } 10^{-6} \text{ m}^3$$

$$V_C = \frac{\pi}{4} \cdot \left[(0.015)^2 - (0.010)^2\right] \cdot (0.028) = 2.7489 \text{ x } 10^{-6} \text{ m}^3$$

Also note that :

$m = \rho V$ or mass = (mass density)(volume)

and

$W = mg$ or Weight = (mass)(acceleration due to gravity)

and $g = 9.81 \text{ m/s}^2$

Part	Material	Volume (m^3)	Mass Density (kg/m^3)	Mass (kg)	Weight (N)	$\bar{y}$ (mm)
A	Bronze	2.749E-06	8874	0.0244	0.2393	14
B	Steel	4.418E-06	7860	0.0347	0.3406	18
C	Steel	6.729E-06	7860	0.0529	0.5189	4
B and C	Steel	1.115E-05	- - -	0.0876	0.8595	9.55
A, B, and C	- - -	1.390E-05	- - -	0.1120	0.8595	10.52

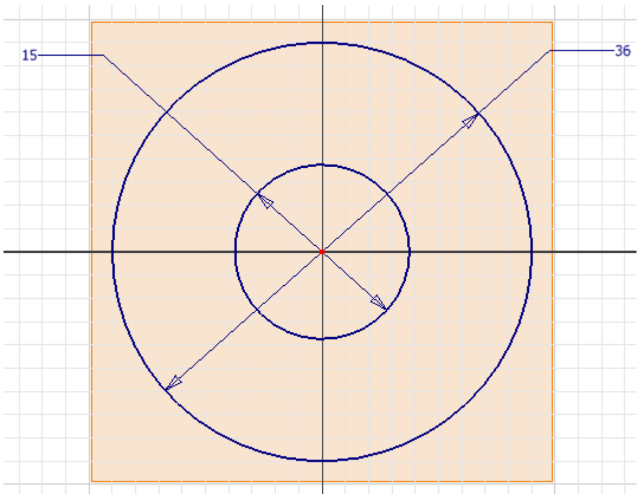
The centroid is calculated using a weighted average of the centroids of each part, so

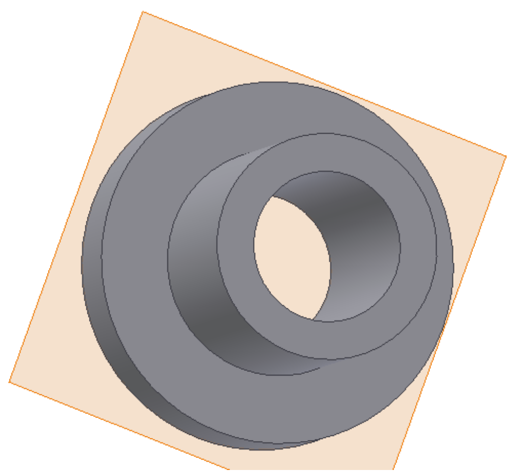
$$\bar{y}_{ABC} = \frac{\sum \bar{y}W}{\sum W} = \frac{y_A W_A + y_B W_B + y_C W_C}{W_A + W_B + W_C} = \frac{14(0.2393) + 18(0.3406) + 4(0.5189)}{1.0988} = 10.52 \text{ mm (entire assembly)}$$

$$\bar{y}_{BC} = \frac{\sum \bar{y}W}{\sum W} = \frac{y_B W_B + y_C W_C}{W_B + W_C} = \frac{18(0.3406) + 4(0.5189)}{0.8595} = 9.55 \text{ mm (entire steel portion)}$$

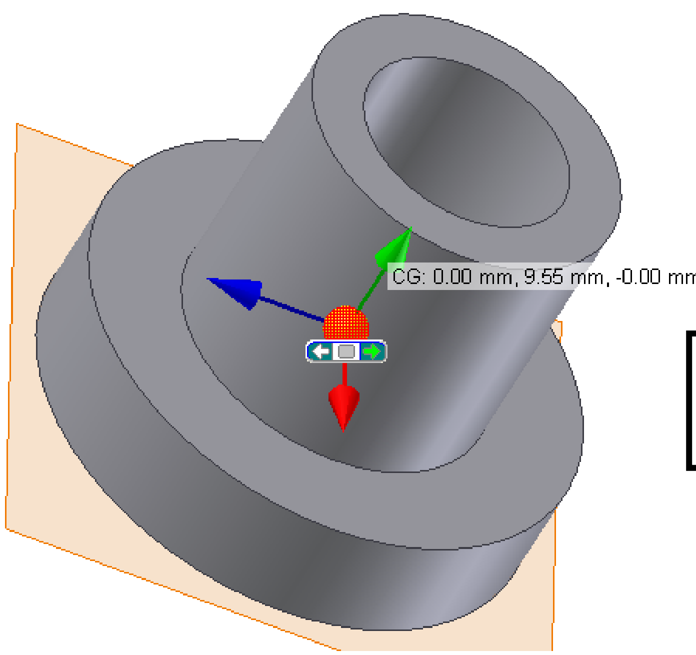
Example: Build of model of Problem 5-113 above and use the mass properties of Inventor to find the center of gravity.

1. Create a metric part for the **steel sleeve**
   - Since the solution above has the axis of the assembly along the y-axis, begin the part by:
     - Selecting on the **xz plane**
     - Making the xz plane **visible**
     - Adding a Sketch Plane to the xz plane
   - It is important that the position of the object is known precisely with respect to the origin, so select **Project Geometry** from the 2D Sketch Panel and then pick **Center Point** under the browser. The Center Point should be clearly seen as a dot on the sketch plane.
   - Note that two extrusions are required for the part. Only the sketch plane for the first extrusion is shown below.



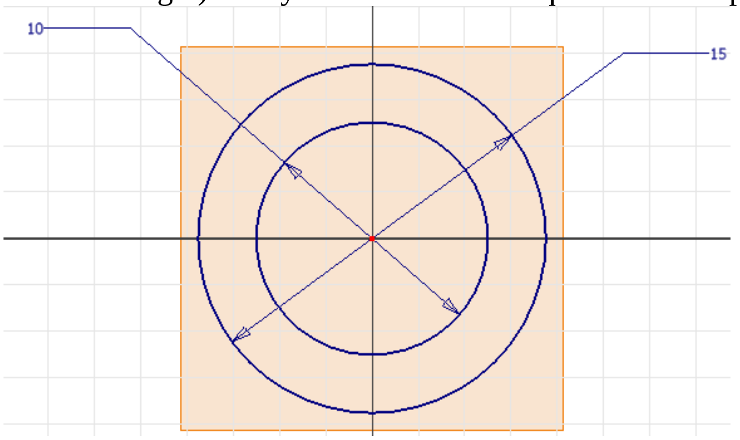


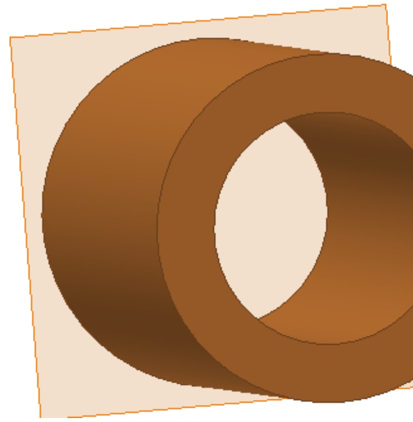
2. Find the center of gravity (CG) for the steel sleeve just created. To do this:
   - Select **View – Center of Gravity** from the main menu. The center of gravity axes icon should appear. Note that the origin of this icon is located at the CG.
   - Pause the mouse over the center of gravity symbol until the select tool appears. Click on one of the arrows until the coordinates for the CG appear. Note that the axes are color coded as follows:



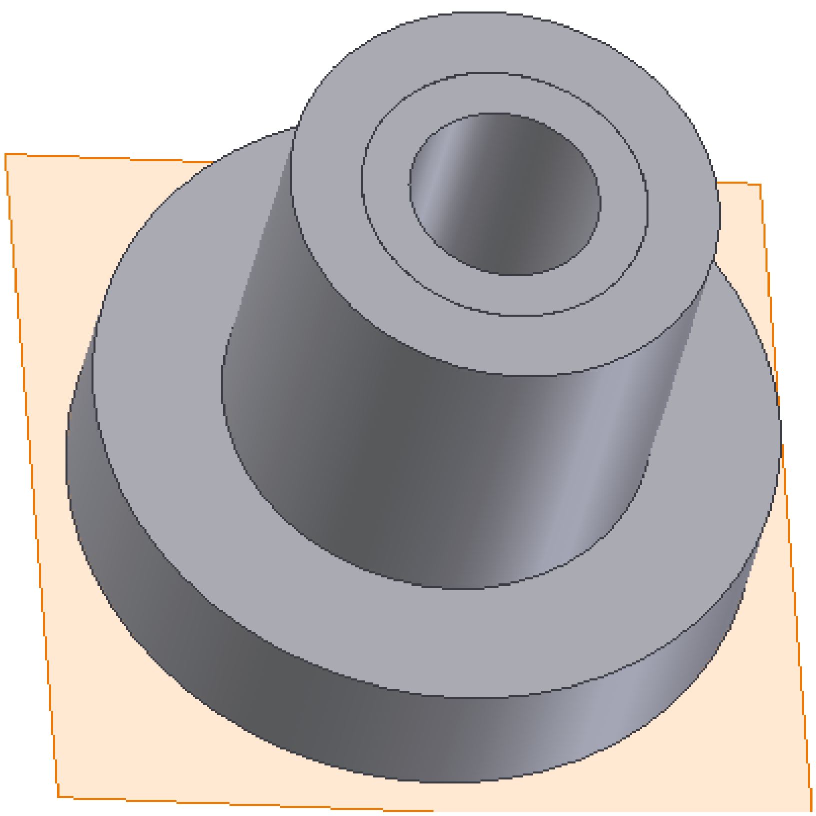
x-axis: Red
y-axis: Green
z-axis: Blue

3. Create a metric part for the **<u>bronze bushing</u>** in a similar manner (again be sure that it is centered at the origin). Only one extrusion is required for this part.

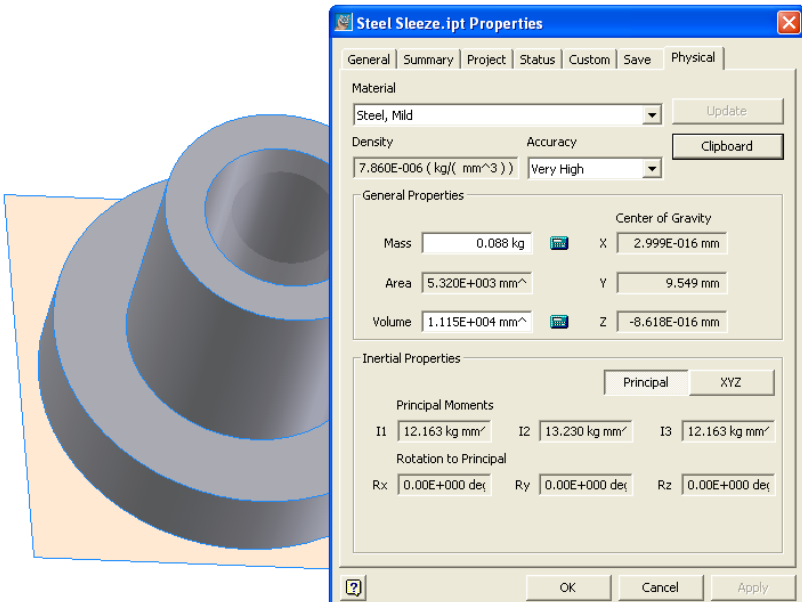




4. Create a **<u>metric assembly drawing</u>**.
   - Use the steel sleeve as the base part. ***<u>Note that the origin for the assembly will be the same as the origin of the base part.</u>***
   - Next add the bronze bushing to the assembly
   - Use an **<u>Insert Constraint</u>** to complete the assembly.



5. Change the properties of each part and copy the mass properties to a Word document.
   - Right-click on the steel sleeve in the Parts Browser and select **Edit**.
   - Right-click on the steel sleeve in the Parts Browser again and select **iProperties**.
   - Select the **Physical** tab and change the **Material** to **Steel, Mild** (see below)



   - Click the **Clipboard** button on the Properties window above and the information in the window will be copied to the clipboard.
   - Open a new Microsoft Word document and select **Paste**. The mass properties information should be pasted into the document as shown below.

Physical Properties for Steel Sleeve
General Properties:
Material: {Steel, Mild}
Density: 7.860E-006 (kg/(mm^3))
Volume: 1.115E+004 mm^3
Mass: 0.088 kg
Area: 5.320E+003 mm^2
Center of Gravity:
X: 2.999E-016 mm
Y: 9.549 mm
Z: -8.618E-016 mm
Mass Moments of Inertia
Ixx 12.163 kg mm^2
Iyx Iyy -2.771E-016 kg mm^2 13.230 kg mm^2
Izx Izy Izz 2.921E-016 kg mm^2 2.671E-016 kg mm^2 12.163 kg mm^2
Principal Moments of Inertia
I1: 12.163 kg mm^2
I2: 13.230 kg mm^2
I3: 12.163 kg mm^2
Rotation from XYZ to Principal
Rx: 0.00E+000 deg
Ry: 0.00E+000 deg
Rz: 0.00E+000 deg

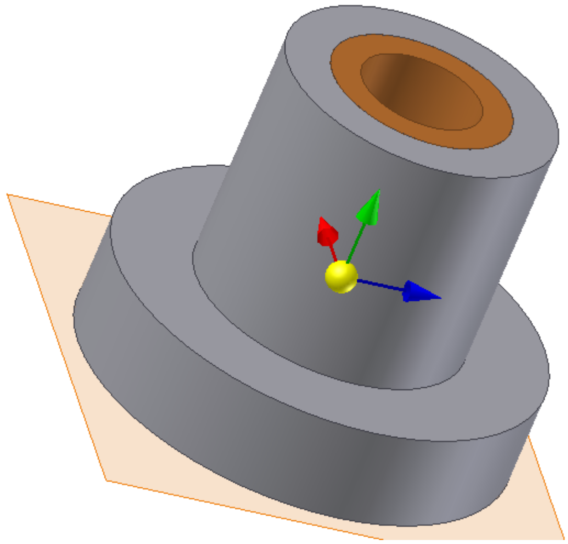
- The mass properties for the bronze bushing are shown below.

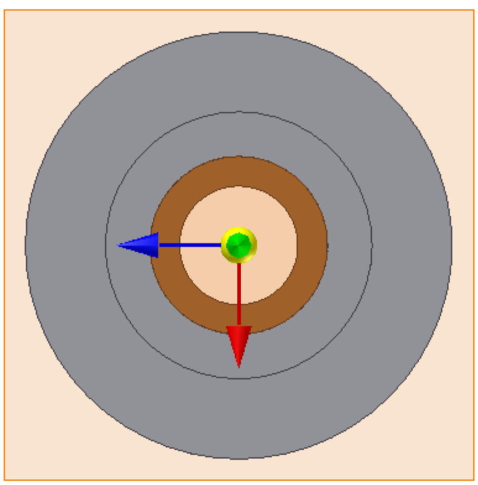
Physical Properties for Bronze Bushing General Properties: Material: {Bronze, Soft Tin} Density: 8.874E-006 (kg/(mm^3)) Volume: 2.749E+003 mm^3 Mass: 0.024 kg Area: 2.395E+003 mm^2 Center of Gravity: X: -4.554E-016 mm Y: 14.000 mm Z: -1.477E-016 mm Mass Moments of Inertia Ixx 2.089 kg mm^2 Iyx Iyy -3.385E-017 kg mm^2 0.991 kg mm^2 Izx Izy Izz 3.463E-017 kg mm^2 -2.821E-018 kg mm^2 2.089 kg mm^2 Principal Moments of Inertia I1: 2.089 kg mm^2 I2: 0.991 kg mm^2 I3: 2.089 kg mm^2 Rotation from XYZ to Principal Rx: 0.00E+000 deg Ry: 0.00E+000 deg Rz: 0.00E+000 deg

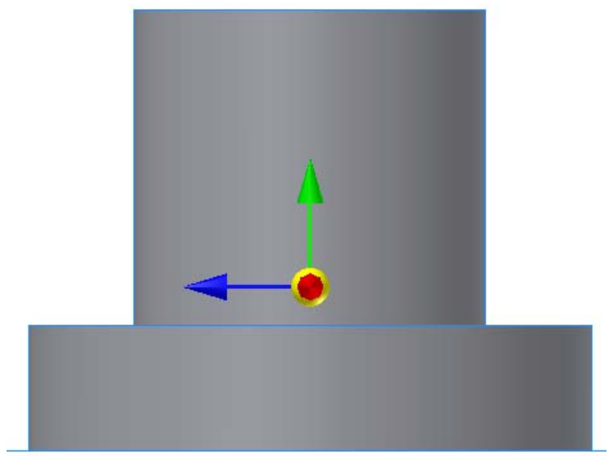
- The mass properties for the entire assembly can also be found as follows:
  - Right-click on the assembly in the Parts Browser and select **iProperties**.
  - Select the **Physical** tab. You might need to select the **Update** button if the properties are currently set to 0 or dimmed.

Physical Properties for Prob 5-113 Assembly General Properties: Material: {} Density: 8.061E-006 (kg/(mm^3)) Volume: 1.390E+004 mm^3 Mass: 0.112 kg Area: 7.716E+003 mm^2 Center of Gravity: X: 1.354E-016 mm Y: 10.518 mm Z: -7.063E-016 mm Mass Moments of Inertia Ixx 14.631 kg mm^2 Iyx Iyy -2.468E-016 kg mm^2 14.221 kg mm^2 Izx Izy Izz 3.267E-016 kg mm^2 2.036E-016 kg mm^2 14.631 kg mm^2 Principal Moments of Inertia I1: 14.631 kg mm^2 I2: 14.221 kg mm^2 I3: 14.631 kg mm^2 Rotation from XYZ to Principal Rx: 0.00E+000 deg Ry: 0.00E+000 deg Rz: 0.00E+000 deg

- Select **<u>View – Center of Gravity</u>** from the main menu to show the CG for the entire assembly. The center of gravity axes icon should appear. Pausing over the CG symbol does not seem to display the coordinates for an assembly. Note that the origin of this icon is located at the CG. Viewing the object from several directions gives a good impression of the location of the CG.







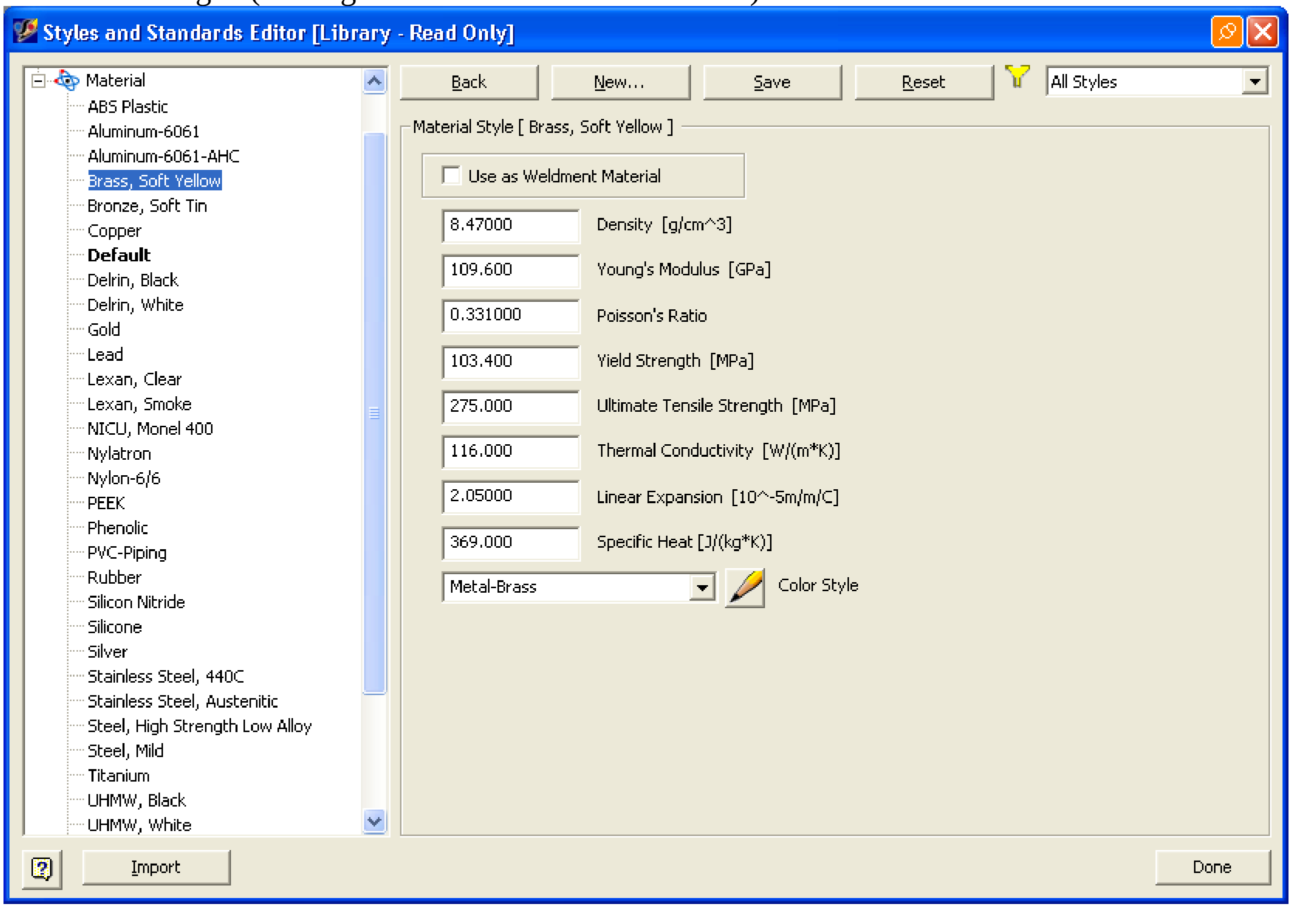
<u>Comparison of results</u>: (they agree!)

Quantity	Hand Analysis	Inventor
Volume – steel sleeve	1.115E-05 mm^3	1.115E+004 mm^3
Volume – bronze bushing	2.749E-06 mm^3	2.749E+003 mm^3
Volume – entire assembly	1.390E-05 mm^3	1.390E+004 mm^3
Mass – steel sleeve	0.0876 kg	0.088 kg
Mass – bronze bushing	0.0244 kg	0.024 kg
Mass – entire assembly	0.1120 kg	0.112 kg
$\bar{y}$ - steel sleeve	9.55 mm	9.549 mm
$\bar{y}$ - bronze bushing	14 mm	14 mm
$\bar{y}$ - entire assembly	10.52 mm	10.518 mm

Viewing Material Properties

Inventor has a number of predefined materials. Each material includes several material properties which may be used by Inventor in calculating center of gravity, moments of inertia, stress calculations, etc. To view the properties for a material, select **Format – Styles Editor – Material** – the **type of material** (such as Brass) – then right-click and pick **Edit Style**.

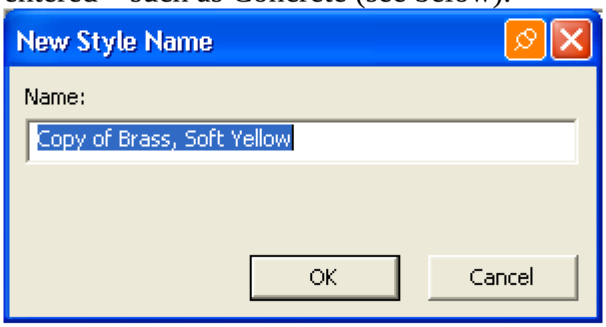
The material properties for Brass are shown below. Note that it is a Read-Only file, so the values cannot be changed (although new materials can be created).

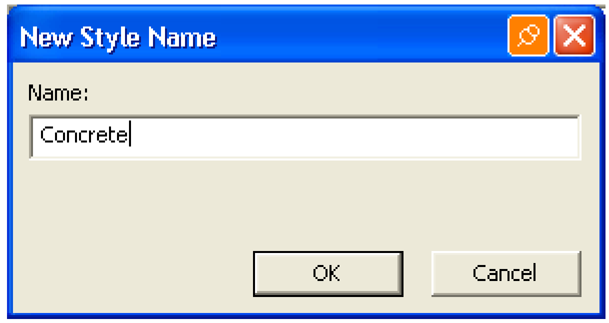


Specifying New Types of Materials

Suppose that we wanted to create a new material such as concrete, which has a density of perhaps 2320 kg/m^3 (though it can vary considerably).

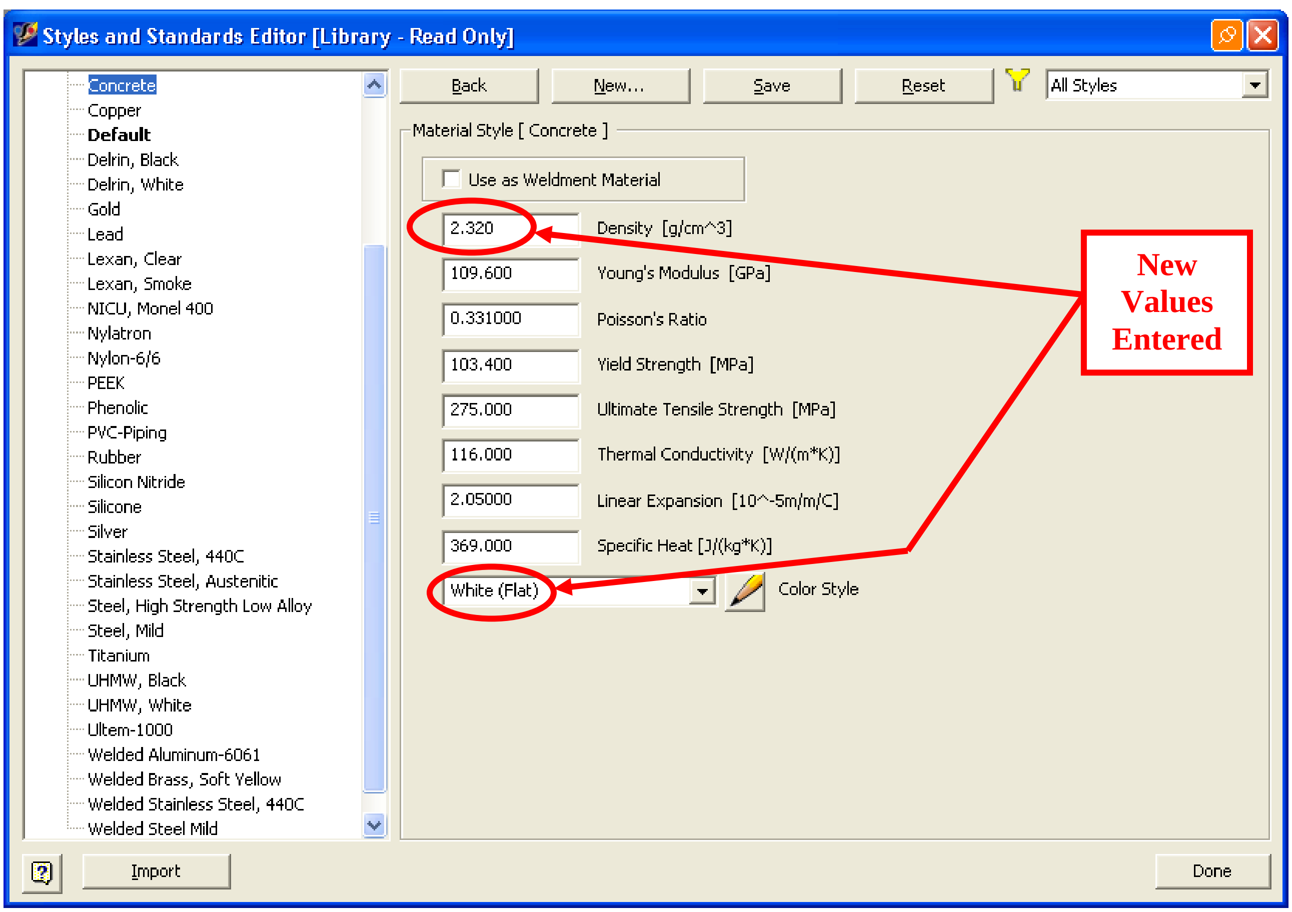
To create a new type of material in Inventor, select **Format – Styles Editor – Material - New** – pick any material (such as Brass) and a box will appear in which the new material name can be entered – such as Concrete (see below).





Enter the new **Density** for concrete and pick a **Color Style**. If other properties are available, enter them as well (if not, leave the values from the material being modified). See below.

Pick **Save** and then **Done** to save the new material.



<u>Using the New Materials</u>

New materials can be used like any other materials in Inventor. In the example below, change the material to concrete as follows:

- Right-click on the name of the part in the browser
- Select **<u>iProperties</u>**
- Select **<u>Physical</u>** tab and select **<u>Concrete</u>** as the material. Note that since this part is a standard (in) part, Inventor converted the density to US units (from 2.32 g/cm^3 to 0.084 lbmass/in^3).