Mini Project 3: Sheet Metal Forming

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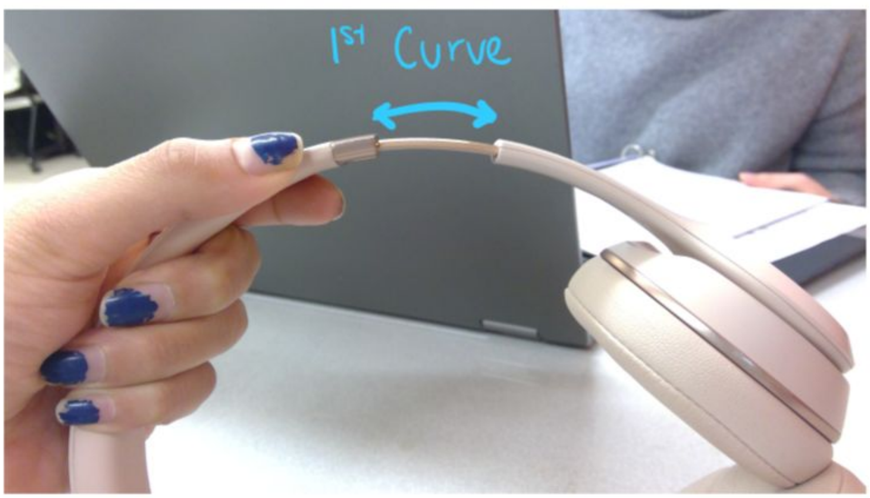
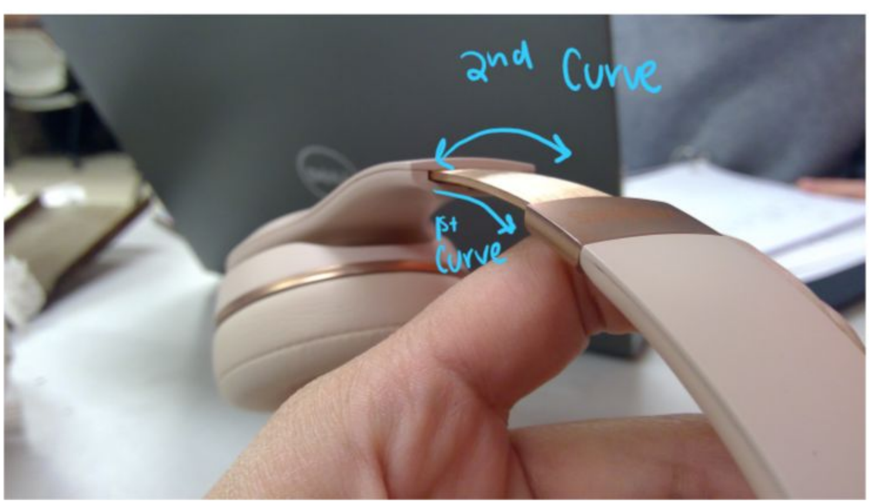
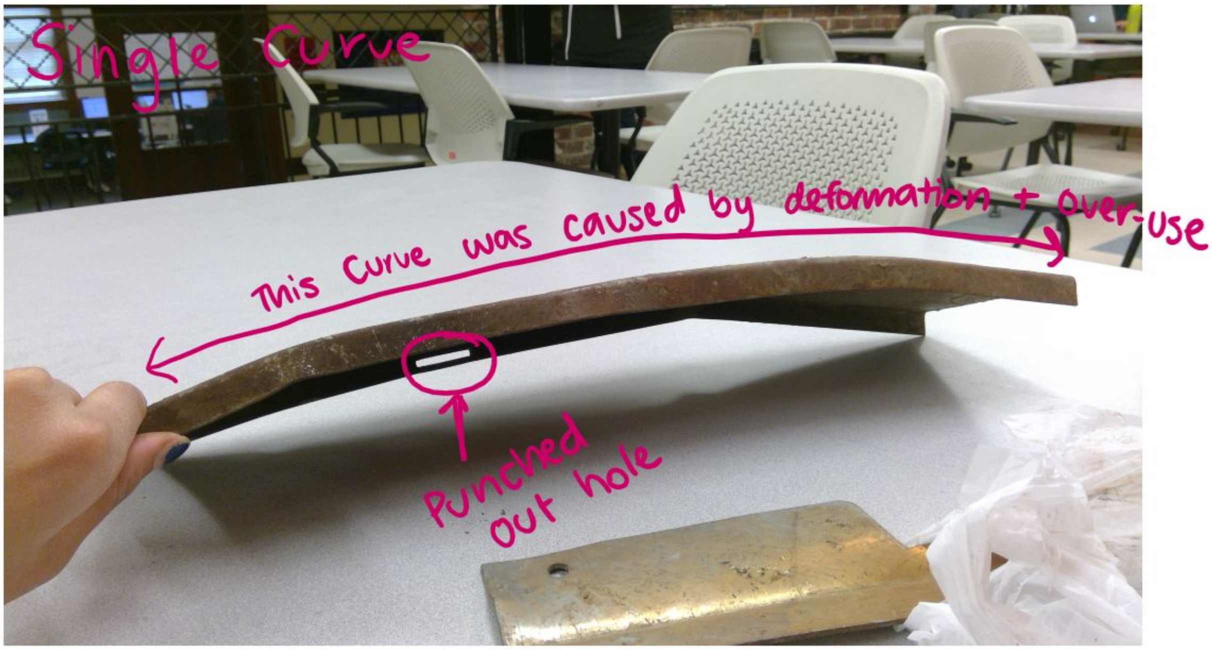
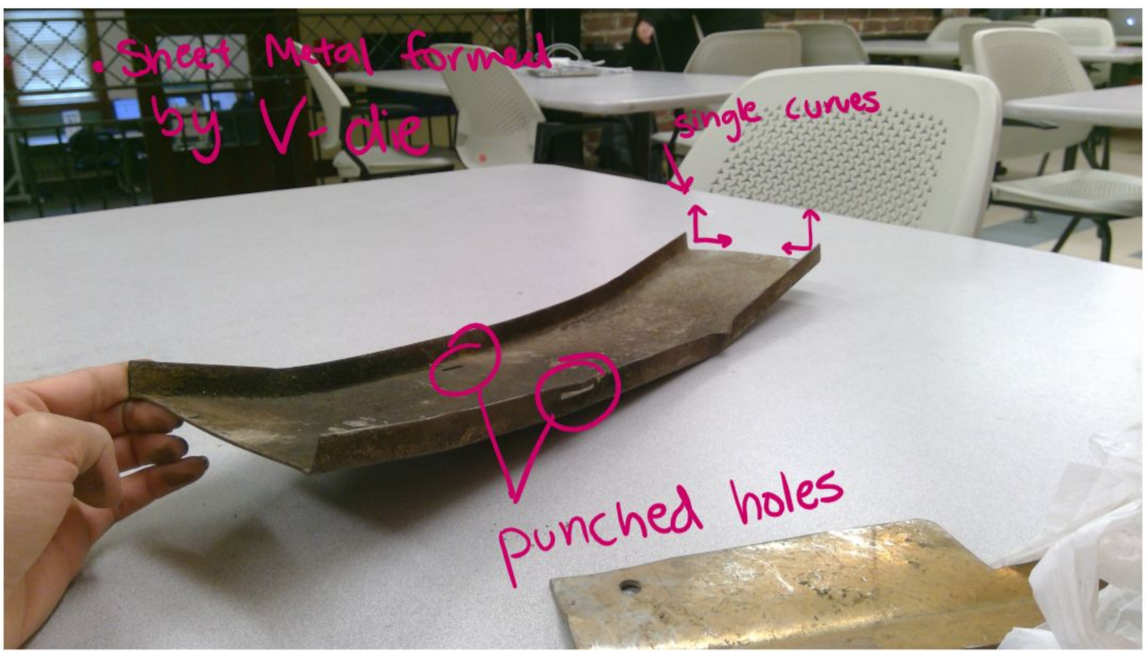
ME 270: Design for Manufacturability
Team: **AB5_3**

1. **Sheet Metal Forming: Description**
   The double curved sheet metal came from the inner headband strip of a Beats Headphone. The clean finish, lightweight feel, and shiny surface suggest the metal used is either aluminum or zinc. The headband strip has two distinct curves in the x and y plane.







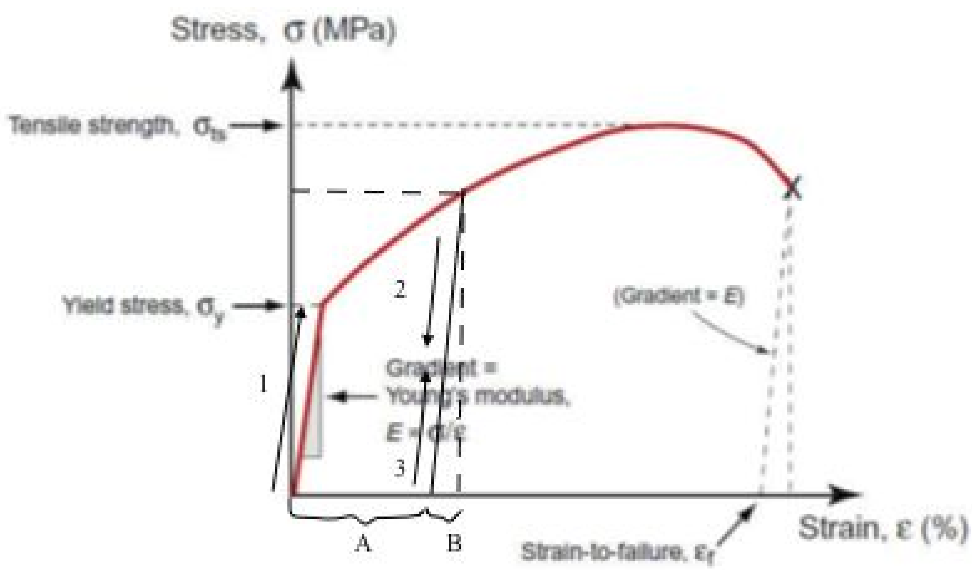


This single curved sheet metal has two distinct v-die bends. The two long edges have 90 degree bends. The metal used seem to be aluminum. There are also 2 rectangular holes that seem to have been punched out.

2. Formability

Strain to failure is the main principle constraint. Strain to failure is how much we can form the metal. Other factors are just practical limits. The higher strain to failure and the lower young's modulus, the better formability. Low carbon steel has the highest strain-to-failure, so it has the best formability. Aluminum alloy has the lowest strain-to-failure, so it has the worst formability.

3. Stress-Strain Diagram[1]



The first step to finding the plastic strain is to identify the stress which, as indicated in the problem, is the halfway point between its yield stress and its tensile strength. Then one has to draw a line at a 0.2 percent offset towards the strain axis. This action is the unloading and indicated by arrow #2. The distance from the origin to the intersection of this line and the strain axis as indicated by "A" on the graph is the plastic, or permanent strain, up to this point. After it is reloaded, indicated by arrow #3, you would go back to where the stress was measured and go straight down towards the strain axis. The distance from the first test's intersection to the strain axis to the new intersection point is the elastic strain. The elastic strain plus the previous permanent strain, or the region of "A" + "B", is the new permanent strain after being reloaded. The nominal value of the new permanent strain is greater than the previous value of the permanent strain because the sheet metal component's dimensions are elongated which means it has a higher strain value as indicated by the strain equation where the initial length remains unchanged:

$$(L - L_0) \div L_0$$

[1] http://www.uobabylon.edu.iq/eprints/publication_12_24290_1049.pdf

4. Maximum Elastic and Plastic Energy [2] *for Low Carbon Steel*

The maximum energy formula:

- **Y:** Young's modulus ()
- **Epsilon:** $\Delta\delta \div Y$
- **Stress (σ): (**TS_{avg} + Yield Strength_{avg}) $\div$ 2

$$U = \frac{1}{2}Y\varepsilon^2$$
$$U = \frac{1}{2} \times 215000 \times \left(\frac{392.5}{215000}\right)^2$$
$$U = .35827\,\text{MPa}$$

The maximum plastic energy:

- $\Theta = \tan^{-1}(Y)$
- $\boldsymbol{\Delta}\varepsilon = \cos(\Theta)$

$$U = \frac{1}{2}Y\varepsilon^2$$
$$U = \frac{1}{2} \times 215 \times (0.004651)^2$$
$$U = 0.002325\,\text{GPa} = 2.2325\,\text{MPa}$$

The equations above are derived from Hooke's Law equation. The epsilon value in the equations are equivalent to the change of length in Hooke's Law and the k value of the spring force equation is the same as Young's Modulus when applied to elastic and plastic energy. The epsilon in the elastic energy equation is found from the gradient when the part is being loaded and unloaded.

[2] https://en.wikipedia.org/wiki/Elastic_energy

5. Springback [3]

The amount of spring back is determined by the ratio of elastic energy to total energy. The springback will increase if we double the bending radius because the springback increases dramatically as the inner radius of the bend increases in relationship to the material thickness. Therefore, if the inner radius is 8 times larger than the thickness of the material, the springback will increase dramatically. However, if the material thickness and the inside radius have a 1:1 ratio, the springback is two degrees or less. Also, the higher tensile a material is, the greater the springback will be. Therefore, the steel will have a higher bending radius than if the material was made out of aluminum.

6. Deformation and energy

100 km/h = 27.78 m/s

$\Delta KE = 0 - \frac{1}{2}mv^2 =- 0.5 \times 1500\ kg \times (27.78\ m/s)^2 = 578796\ J$

$V = |\Delta KE| \div (200 \times 10^6\ J/m^3) = 0.002894\ m^3$

$m = \rho V = 7900\ kg/x^3 \times V = 22.8625\ kg$

We need to deform 22.8625kg HSS to provide the energy we need.

7. Deformation and Springback

The rectangular tray started off as a flat piece of sheet metal until the sides were folded and the walls of the tray stood ideally perpendicular to the base of the tray. Due to springback, the sheet metal would want to go back to its original shape due to its internal elastic energy. Based off this information the sides would curve outwards. The springback would not be significant as the tray still has to hold a general geometric form and the metal is already far past its Yield Stress. It will hold close to its original shape because the adjacent walls will be providing support alongside stiffening techniques, but springback outwards will be present.

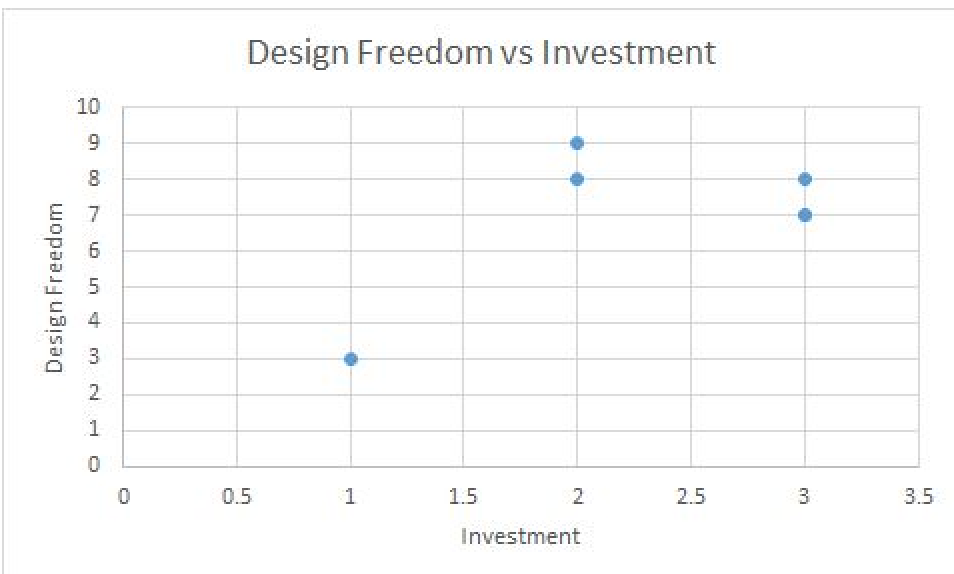
[3] https://www.thefabricator.com/article/bending/bending-basics-the-hows-and-whys-of-springback-and-springforward

8. Forming of double-curved parts and design freedom

Name	Part size	Range of metals	Complexity	
Hammering	1	1	1	3
Deep drawing	2	3	2	7
Rubber forming	3	2	2	7
Matched die forming	2	3	3	8
Sequential die forming	2	3	3	8
Hydroforming	3	3	3	9
	1 for low part size	1 for soft material	1 for simple structure	

9. Forming of double-curved parts and financial investment

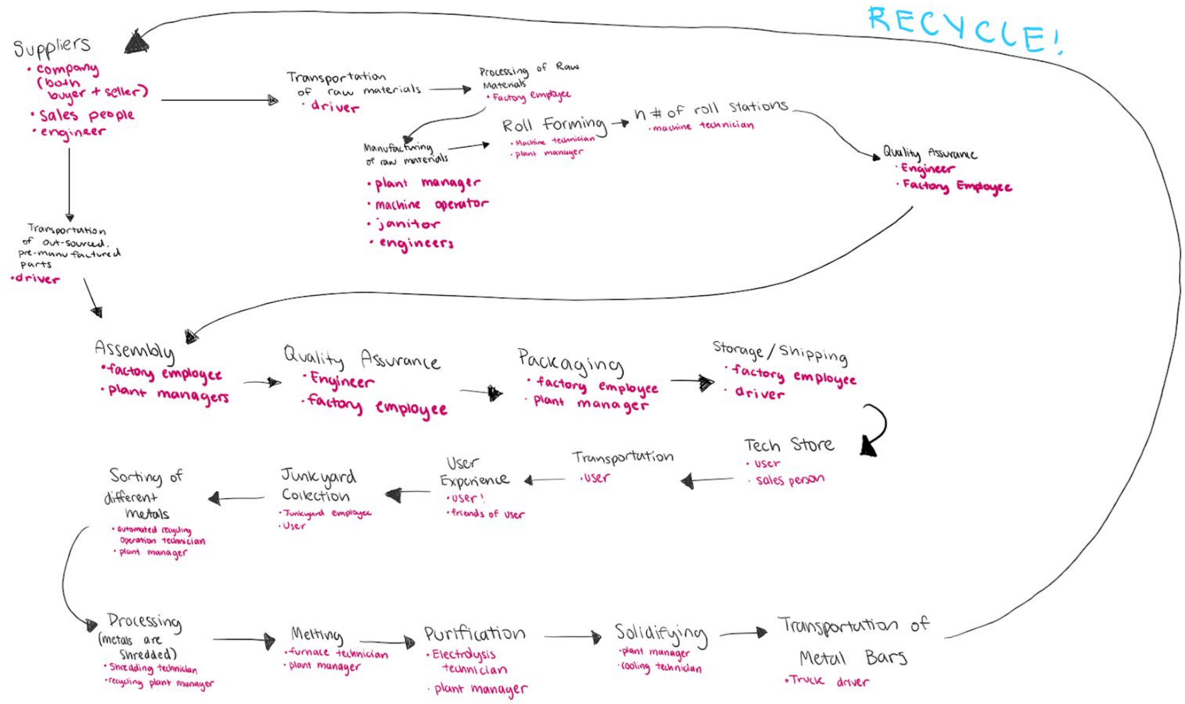
Name	Financial investment
Hammering	1
Rubber forming	2
Hydroforming	2
Deep drawing	3
Matched die forming	3
Sequential die forming	3



The chart above shows that higher design freedom means higher investment.

Challenge

1. **Process framework [4]**



2. **Product Design and Failures**

   For the double curved part, we used the adjusting part on a pair of Beats headphones. The part has visible curves in both the z and y planes. The part could have done without a double bend, but the double bend allows for comfort of the headphone when placed on the user's head. The part has no deformations or indications of misuse or damage and we know that it is not broken because it is still in use by the owner. From this information, we know that there are no manufacturing flaws, repairs made, or any user-related issues with the product. Two stakeholders we can speak two are the owner, Anisha, or the manufacturers of these headphones, Monster Cable in Brisbane, California.[5]

   EC: After speaking to one of the stakeholders in this product, Anisha, we came to understand that these headphones are made in a very robust manner and that she has not had any problems regarding her headphones since they were purchased. She also gave us

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[4] https://www.thebalancesmb.com/an-introduction-to-metal-recycling-4057469

[5] https://en.wikipedia.org/wiki/Monster_Cable

information that she has never had to make any repairs regarding the part, or damaged it in any way. It was, “As good as new!”.

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For the single curved part, I am very unsure of what the previous usage was. The part is made of aluminum and looks like it could have been rolled to provide a hard casing for some electronics or motors. The very simple shape does not really shed any light on what it was used for, but it makes it easy to identify damages on the part. There is extremely visible rusting on the part as well as paint chips. There is also a dent in the walls on the part which could come from when the part was in use, or when it was thrown into the scrapyard. The same idea applies to the rusting and the paint chipping. There are also several other deformities on the part that indicate it has been damaged either before or after being thrown out. We think that this part was thrown out with a larger assembly and that this happened to be a small part of it. The assembly was most likely of old age as we found the part in the very back of the scrapyard. A stakeholder in this assembly would be the person who threw it out or the manufacturer both of which are extremely hard to identify.

3. Product Design Opportunities

For the double curved part, it is very hard to identify places for this product to grow design-wise as Beats has a lot of success in their work and are recognized for making products with a long life-span. A potential design opportunity for this may be to use a sturdier material than the supposed aluminum, because the part looks a little flimsy. Carbon fiber may be a good alternative as it is lighter, stronger, and more durable, but that also brings up cost issues. For a design idea, I might talk to a design engineer at Apple Inc. as they could give me valuable insight into the ideation of the product and reasons why they used their respective materials.

For the single curved part, because the use of the product is unknown and hard to determine, it is hard to identify potential design opportunities. Some very general but visible issues with the part are that the bends did not hold that well. It is not a smooth bend anymore, indicating that the part is probably too long and flexed extremely easily. It might be a good idea to make the one part into two separate pieces which would allow the bends to hold for longer. I would love to talk to a stakeholder to see what the part is actually used for and why it was designed this way, but because we are unsure of the use, it is extremely hard to find any stakeholders in general.