# Mini Project 4: Machining

**Ashank Behara, Yutian Gao, Anisha Rao**
ME 270: *Design for Manufacturability*
Team: **AB5_3**

# MACHINING

## Machined Part

The machined part that we have selected from Mack's is a hub for either a bicycle or large cutting power tool. The holes that were machined along the outer edge of the disc were machined most likely using a drill press with a step drill bit and the chamfers along the sides of the hole were formed using a deburring tool. The part would not be able to function as a hub if the holes were not created which shows that drilling was an integral process and is of primary importance. In order to provide a nice surface finish to eliminate the burrs that would have formed from drilling, the manufacturer most likely used a deburrer and for further smoothness along the surface, used a sander which indicates that secondary processes were used.



## Machining Feasibility

Machining feasibility is dependent on a number of factors such as microstructure, grain size, heat treatment, chemical composition, and tensile strength, but the two most important factors that we focused on are hardness and specifically yield strength[1]. Yield strength is the point just before plastic, or permanent, deformation occurs. A piece with a higher hardness has a higher yield strength meaning that more force is required to permanently damage or alter the part. This is also directly correlated to tensile strength and inversely related to heat treatment. By this logic, the material that has the lowest yield strength and is therefore the easiest to machine, is polyethylene (HD - PE) which has a maximum yield strength of *31 MPa*. The material that has the highest yield strength and is the hardest to machine would be tool steel (AISI D2) which has a maximum yield strength of *2,290 MPa*.

[1] https://www.americanmachinist.com/cutting-tools/chapter-3-machinability-metals

## Effects of Strain-to-Failure

The Strain-to-Failure affects the machining process because the plastic mechanism of yielding in the shear zone is the same as during a tensile strength test, except faster and hotter. During permanent deformation, above the yield stress, dislocations begin to occur. Dislocations are line imperfections in the crystal lattice. Room temperature creates more of these dislocations. This increases the stress level to maintain plastic deformation. However, heating up the metal decreases these dislocations which returns the higher Strain-to-Failure.[2] Therefore, the machining process that unintentionally heats the metal, creates a higher Strain-To-Failure,the more power and force is takes for the machining process. Strain-to-Failure also affects the ductility of a metal. The higher the strain-to-failure, the higher the deformability and the lower the tensile strength[3]. However these are not always directly related as tensile strength can also be affected by the stiffness and hardness of the part. Tensile strength and strain to failure are more often than not directly related so as strain-to-failure increases, the total energy required to plastically deform a material increases. Therefore, a higher strain to failure affects the cutting force required to permanently deform a part.

## Machining Force

$$U^{*} = \frac{P}{M_{RR}} \;||\; P = F_C v \;||\; M_{RR} = vfd$$

*: constant.

$$U = \frac{F_C}{fd}$$

Based on the cutting force equation stated above the cutting force ( $F_C$ ) and cutting depth ($d$) are directly related. If the cutting depth is increased, in the case of the problem, doubled, then the cutting force will also increase by a factor of two.

[2] https://docs.google.com/document/d/178aXryAP_JjGguHcVGEmSHyUqcTDGpJJPmRgVZekUdY/edit
[3] https://www.researchgate.net/post/What_do_you_mean_by_strain_to_failure

# Deflection of Cantilever[4]

$$L = 300\ mm \parallel B = 30\ mm \parallel W = 30\ mm \parallel d = 0.1\ mm$$

*The formula for maximum deflection at the end of the cantilever beam is[5]:*

$$\delta = (F \times L^3) \div (3 \times E^* \times I^!)$$

*: Young's Modulus || !: Moment of Inertia

$$E = 72\ GPa^* = 72{,}000\ MPa = 72000\ N/mm^2$$

**: Average of Young's Modulus from table in guidelines*

$$I = B \times h^3/12 = 30\ mm \times (30\ mm)^3/12 = 67{,}500\ mm^4$$

$$0.1 = \frac{F \times 300^3}{3 \times 72000 \times 67500}$$

$$F_v = \mathbf{54\ N}$$

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$$F_h \times 30\ mm - F_v \times 300\ mm = 0$$

*Sum of Moments adds up to 0*

$$F_h \times 30\ mm = F_v \times 300\ mm$$

$$F_h = F_v \times 10$$

$$F_h = \mathbf{540\ N}$$

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$$d = \frac{F_c}{f \times U}$$

$$d = \frac{M_{RR}}{f \times v}$$

$$v^* = 6{,}244.5 \parallel f^* = 0.0035$$

*Average values of end mills with diameter 3/16" or 5 mm as stated in the problem [6]*

$$d = M_{rr} \div 21.8588$$

*$U$ = 0.4-1.1 W-s/mm$^3$ for aluminum alloy || select 0.75*

Material removal rate is found by taking the power of the CNC-milling machine and dividing it by the experimentally found *U* constant. Given this constant and the power of the milling machine, the calculation of the depth is as simple as plugging in the material removal rate into the derived equation formed above.

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[4] https://www.sciencedirect.com/science/article/pii/B9780080999227000044#s0010

[5] https://www.engineeringtoolbox.com/cantilever-beams-d_1848.html

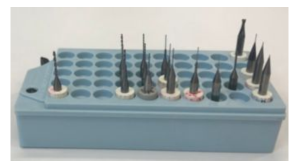
[6] http://www.endmill.com/pages/training/Speed%20and%20Feed%20-%20HSS%20End%20Mills.pdf

# MechSE Workshop

**Solid Carbide Drill Bit**: This drill bit is made of solid carbide and is used to machine hard materials like stainless steel. They are extremely heavy relative to the other types of drill-bits and are also very expensive.

**High Speed Steel Drill Bit:** These drill bits are made of high speed steel and after machining are coated with titanium nitride. These drill bits are  used to machine soft materials, like wood. They shorter screw displayed in the picture is a screw machine length drill bit while the longer one is called a jobber drill-bit.

**Micro Drill:** These drill bits are used to make holes on a micrometer level. Micro drill bits range from a starting point of 0.002 inches to 0.1 inches and are extremely precise and miniscule. There are very few practical uses for these drill bits, but in many research labs, many professors use these tiny drill bits to allow heat flow to occur and allow for small amounts of liquids to flow from one chamber to another.



**Masonry Drill Bit:** Masonry drill bits are often combined with impact drills to make a hole and create an impact force at the same time. Drill bits that have durium or carbide tips are made specifically for hammer drills rather than others. Masonry drill bits and impact drills are excellent for drilling through extremely hard surfaces such as concrete and brick.

**Hole Saw:** The primary purpose of a hole saw is to create a large circular hole in a part. The tool is a round cylindrical drum with the edge that makes contact with the surface of the part being toothed. In order for the tool to stay on its path and not slip, there is a small pilot hole drill bit in the center to hold it steady. This drill bit operates on a decimeter level.

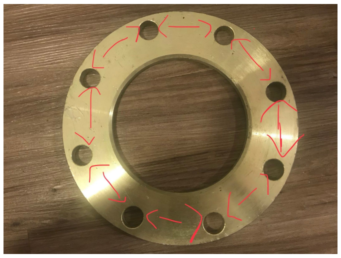
**Insert-Spade Drill Bit:** Insert spade drill bits are two-dimensional shapes drill bits. These drill bits are traditionally used for soft metals such as aluminum, but can be used for wood as well. These drill-bits serve a similar purpose to hole saws as they are both used to create holes, and are especially known for being able to make stepped holes. After the spade wears out, only the top spade needs to be replaced.

## Machining and Material

Milling, turning, and drilling are all involved in this product. Milling and turning are used to turn a stock metal into a perfectly circular disc. Drilling is used to create create the eight holes along the outside edge. Finishing is done using a deburring tool which chamfers holes and with a sander which creates a smooth surface.  This part is made of standard aluminum alloy.

1. It is a part that machining is fully involved. In this case a material with high machinability should be chosen. The machinability of  this product should be around 360% to 450%, obtained from machinability of 6061 Aluminum and Cast Aluminum.

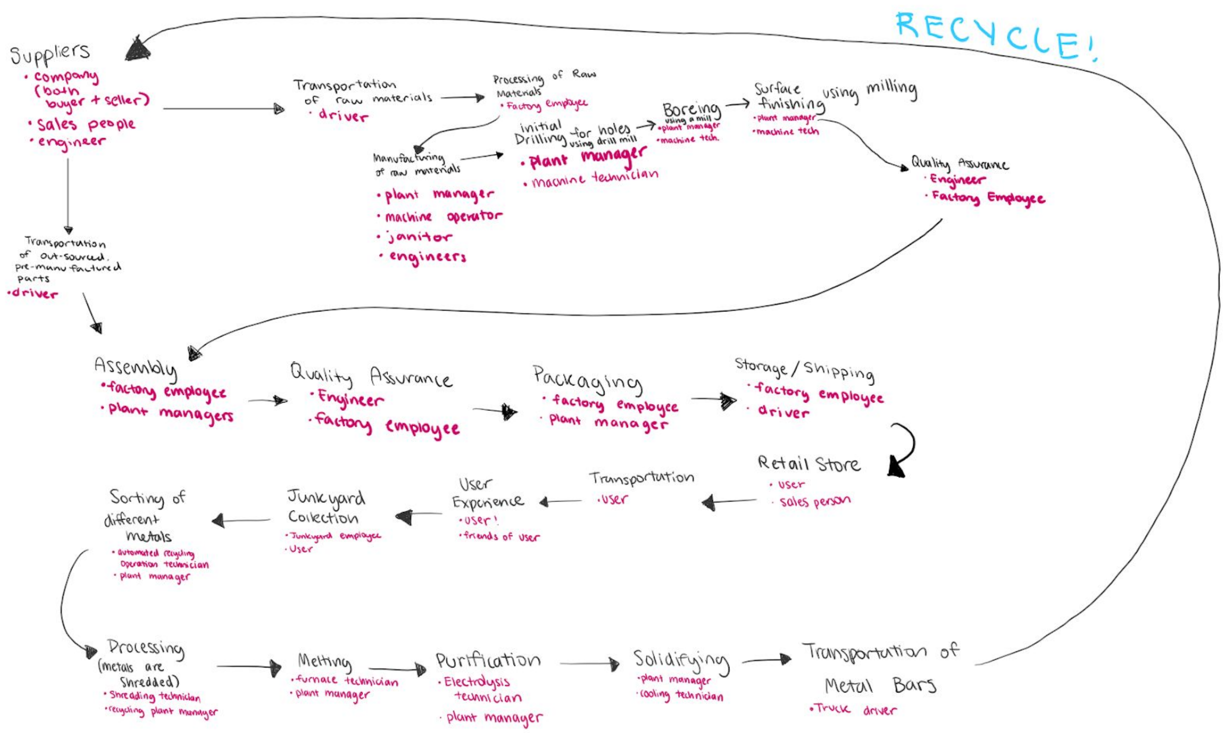
2. Overly thin or narrow feature should be avoid to withstand the high force of machining. Small holes are spreaded equally on the outside to keep minimum distance as large as possible while not close to the center big hole.



3. Chamfer structures are prefered for the outside corners so cost of machining will be minimized while round feature should be applied for inside corners. All features are through and no blind feature is used so on our part  we can only find chamfering outside corners is used.

# CHALLENGE

## Process Framework




## Product Damages and Failures

The shape and structure of the product that we have is very basic and has no necessarily unique qualities that suggest its use, but given the size and through reverse image searching the part is most likely a hub of some sort possibly for a very old bicycle or a large circular saw. The part looked mainly untouched and had no major damage except for a few scratches and chips along the edge which could have formed while the part was in use or when it was discarded in the junkyard. Plants, scratches from other metals and rocks, or scrapes from off-road biking could have all been possibilities for why this part had markings on it. This part was most likely discarded due to old age. Bicycle wheel circular hubs have been optimized over the years and there is only a basic resemblance to the part we have just picked up. Bicycle and other automobile hubs now have the spokes attached to the hubs, and hubs on circular saws are now as small has the screw head itself with an external guard to keep the blade rotating on the same plane. We do not believe that any of these problems were caused by the manufacturer, but rather the user and nature when the product was disposed. The only major stakeholders would be the former user and the manufacturer. The manufacturer would be hard to find as the part has no branding on it or any information that suggests it was machined by a major manufacturing company and seems like a simple enough part to have been machined in one's garage. The easier stakeholder who might be easier to track down would be whoever had previously used this part.

## Potential Design Opportunities

Assuming that this piece is indeed a hub, the main issue would be the amount of metal used up in making this part. The part has a lot of unnecessary material between holes and there are not too many industrial screws with heads that are used in a consumer product that require that much distance between each hole. Material optimization would be the change that needed to be made that is easy to see from far away. The other design issue that this part has is the weight. Hubs must be sturdy enough to keep whatever is rotating, to rotate in only two-dimensions, but the part is extremely heavy. A way to remove material in a methodical and precise manner is called skeletonizing. This means removing material evenly and symmetrically throughout the part in order to reduce weight. It is important to not remove too much material from the part or else the functionality of the part will decrease. A person who would be extremely useful to speak to would be one of lead members of one of the car teams on campus or Mr. Cheek. Both, especially members of the car teams, have extensive knowledge regarding wheel hubs and which ones provide optimal performance so they would be a good place to start and see if these design opportunities are valid.