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Manufacturing of Gears

18F02 Kinetic A

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1 BACKGROUND

1.1 Introduction

As the team selects the final design, an important question arises: which material will the team use? Through different analyses of various aspects of the proposed design, the material will be selected. This report will showcase the analysis of different materials for the casting of the gears. The gears being analyzed are a ring gear, a sun gear, and planetary gear.

1.2 Contemporary Issue

The issue with casting is the time it takes to cast and the amount of heat to perform the casting operation. As stated in the ME467 Manufacturing Processes book, “time is money” [1]. In order to keep within our budget, a cheap, yet durable, material will be selected. This material must also have a melting and pouring temperature less than that of the mold or else the mold will melt.

1.3 Materials Examined

Due to a corrosion analysis of different materials, the team deducted our list of materials to the following seven metals: stainless steel 316, aluminum bronze, naval brass, yellow brass, red brass, muntz metal, and pure aluminum. Stainless steel 316 is a steel. Aluminum bronze, naval brass, yellow brass, red brass, and muntz metal are all copper alloys.

2 Calculations

2.1 Equations

This analysis requires the following equations:

$$H = \rho V[C_s(T_m - T_0) + H_f + C_l(T_p - T_m)] \quad [1]$$

Where, H = heat required to raise temp of metal to pouring temp (kJ), ρ = density of metal (kg/m^3), V = volume of heated metal (m^3), C_s = weight specific heat for solid metal (kJ/kg*K), T_m = melting temperature for metal (K), T_0 = initial temperature of metal (K), H_f = heat of fusion (kJ/kg), C_l = weight specific heat for liquid metal (kJ/kg*K), and T_p = pouring temperature of molten metal (K). This equation requires assumptions due to the lack of data for some materials. Equation 1 also shows the team how much energy is required to melt the selected material. The next equation used is as follows:

$$T_{ts} = C_m \left(\frac{V}{A}\right)^n \quad [2]$$

Where T_{ts} = time for metal to solidify (min), C_m = the mold constant (min/m^2), V = volume of casted part (m^3), A = area of casted part (m^2), and n = 2. This equation is known as Chvorinov's rule [2]. Equation 2 will determine how long the metal will solidify, given the volume and area of the cast.

2.2 Assumptions

The equations used in the calculations are dependent on a few assumptions. For equation 1, the following assumptions were used:

- T_0 is ambient temperature of 23°C ~ 296K
- T_p is 50K higher than T_m
- If C_l could not be found for an alloy, C_l of the main metal within the alloy is used
- For red brass and muntz metal, H_f of copper was used

The third assumption doesn't skew the calculations as the specific weights of the alloys were similar. The last assumption may cause discrepancies. The heat of fusion for the other copper alloys highly vary than that of pure copper. For equation 2, a single assumption was needed. The mold constant, C_m, differs depending on the molten metal, the shape of the mold, and the size of the mold. No consistent mold constant data could be found. The values used in the calculations, 2 min/cm^2 – 4 min/cm^2, were taken from a manufacturing processes lecture from MIT [3].

3 Solidworks Model

This section will showcase the Solidworks models of the three gears being examined. The volume and area of each gear will be calculated by Solidworks. The Solidworks model is in the imperial system, so values of area and volume must be converted to metric.

3.1 Ring Gear

The ring gear is the biggest gear in the assembly. This gear will house the planetary gears and the sun gear. This gear will be the centerpiece of our final design. The 16 inch ring gear can be seen in Figure 1 below.

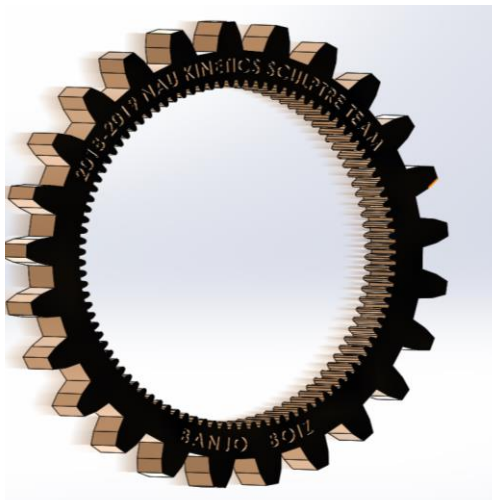

Figure 3.1: Ring Gear Solidworks Model

With Solidworks feature, “Mass Properties”, the volume and surface area of the gear can be found. The volume of this gear is 128.43 in^3 and the surface area is 461.25 in^2. Since all calculations were done using the metric system, these values had to be converted to m^3. So, the volume and area in metric are 0.002104099 m^3 and 0.297612308 m^2, respectively.

3.2 Planet Gears

The planet gears are much smaller than the ring gear because there will be two planet gears between the ring gear and the sun gear. The planet gears will contain the names of the team members. Figure 3.2 below shows a single planet gear.

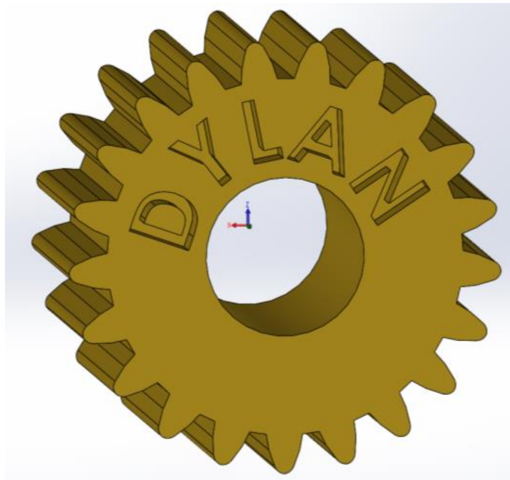

Figure 3.2: Single Planet Gear Solidworks Model

The diameters of these planet gears are approximately 2.73 in (0.069m). Again, analyzing the mass properties on Solidworks, the volume and area of these gears are 0.000131097 m^3 and 0.029612844 m^2, respectively. There are a total of six planet gears.

3.3 Sun Gear

The sun gear is placed in the center of the ring gear. The sun gear is the only stationary gear. This gear will be connected to the supporting rod that holds the sculpture in place. Figure 3.3 below shows the Solidworks model of the sun gear.

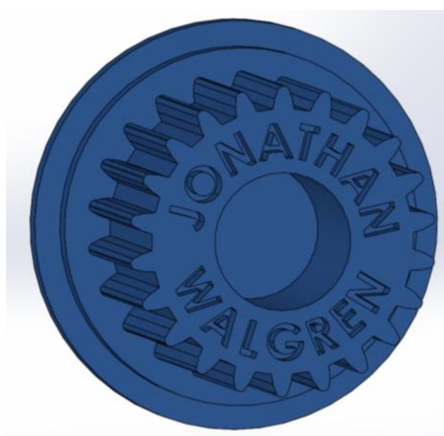

Figure 3.3: Sun Gear Solidworks Model

This gear is about 3.04 inches (0.077216 m) in diameter. The area and volume of this gear is 0.053032152 m^2 and 0.000252361 m^3, respectively. With these areas and volumes, the heat required to melt metal for these gears can be calculated. Also, the time to solidify can be approximated given the areas and volumes.

4 Results and Discussion

4.1 Heat Required

The heat required to raise the temperature of the metal to its pouring temperature is essential to find. The metal with the lowest energy required will be the safest for the team to use and the easiest to cast. Plugging researched values into equation 1, we get the following heat energy values.

Table 4.1: Heat Energy Values for Various Gears and Metals

Material	Ring H (kJ)	Planet H (kJ)	Sun H (kJ)
Stainless Steel 316	17096.70847	1065.215481	2050.5398
Aluminum Bronze	11242.8358	700.4882119	1348.439808
Naval Brass	9263.64989	577.174448	1111.060812
Yellow Brass	9255.101294	576.6418252	1110.035513
Red Brass	11248.90984	700.8666566	1349.168314
Muntz Metal	9902.198015	616.9593779	1187.646802
Aluminum	5749.032806	358.1951904	689.5257415

Table 1 above shows the energy required to heat each different material given the volumes of the various gears. Stainless steel 316 is by far the most difficult to melt to its pouring temperature. The more energy that is required, the longer it will take to cast and the more it will cost. The copper alloys are within 200 kJ of each other given any gear. Aluminum has the lowest heat energy values. These significantly lower values demonstrate the ease of use of aluminum. Since aluminums melting temperature is much lower than that of the copper alloys and steel, the heat required to raise it to its pouring temperature is significantly less. Thus, aluminum is the dominant metal for casting.

4.2 Time to Solidify

The solidification time results are generalized since mold constants for specific alloys couldn't be found. So, the maximum and minimum times are calculated for each gear. Table 4.2 below shows the various calculations, using equation 2.

Table 4.2: Chvorinov's Rule Calculations

Gear	Volume (in^3)	Volume (m^3)	Area (in^2)	Area (m^2)	V/A (m)	(V/A)^2 (m^2)	Tts Min (min)	Tts Max (min)
Ring	128.4	0.002104099	461.3	0.297612308	0.007069933	4.99839E-05	0.999678999	1.999357997
Planet	8	0.000131097	45.9	0.029612844	0.004427015	1.95985E-05	0.391969282	0.783938564
Sun	15.4	0.000252361	82.2	0.053032152	0.004758637	2.26446E-05	0.452892613	0.905785225

The minimum and maximum mold constants, 20,000 min/m^2 and 40,000 min/m^2, from the MIT lecture were used for the calculations. With these mold constants, the biggest gear, the ring gear, will take 1-2 minutes to solidify. The smaller gears won't take a full minute to solidify. These mold constants were found experimentally for steel and iron. So, these results will be skewed for our alloys as mold constants vary depending on the molten metal. After the team selects a material for our final product, casting experiments will be done to verify a mold constant.

5 Conclusions

Given the areas and volumes of the gears and researching material properties for the seven materials, an analysis of manufacturing these gears was completed. After inputting these values into equations 1 and 2, aluminum appears to be the best for sand casting the team's gears. Due to its low melting temperature and low density, the heat required to melt aluminum is 38% less than that of the closest alloy, yellow brass. If the team were to select aluminum as their final material, aluminum cans can be collected. Not only will this be cost efficient, but it will be great for the environment.

6 References

[1] M. P. Groover, *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*. Wiley, 2013. pg 22

[2] M. P. Groover, *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*. Wiley, 2013. Pg 242

[3] T. Gutowski, “Lecture 10 - Casting.” MIT.