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Manufacturing Processes – Research Report

Materials & Manufacturing

ACMA4005

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1 Introduction

Sprockets are an integral part of the assembly of a bicycle. Allowing the transmission of power from pedals to the wheels, oftentimes at varying gear ratios with cassettes, incorporating multiple sprockets into one assembly.

Mountain Bike Solutions Cymru currently outsources the production of these components. They feel the best way forward is to consolidate the manufacturing of these sprockets in-house.

Our task, and ultimately our goal, with this essay is to evaluate the eligible materials, delve into the manufacturing processes available, and further assess several variables which will impact the financial burden of individual manufacturing processes.

2 Research

2.1 Materials

We begin our research with the selection of materials that are fit for purpose. Sprockets are responsible for transferring force from the rider's legs to the wheels. In essence, all force applied to the pedals by the rider must either be transferred through or dissipate in the sprocket.

Due to the nature of bicycles, sprockets go through a wide range of different intensities of pressure. A bike can often be utilized for long stretches of time, varying speeds to match the environment around it. Our sprocket must be able to withstand continuous use, sudden changes in force and poor weather conditions.

In short, the material we choose must have acceptable wear resistance as well as tensile, impact and fatigue strength. Ideally, we want a strong, hard material to ensure the longevity of the part.

The obvious contenders are metals, due to their strength and rigidity, and some select plastics.

Table 1 (right) depicts a list of the 3 most common metals used in bike sprockets, as well as the 3 highest strength & hardness plastics. We could not find any bike sprockets manufactured from plastics, perhaps with good reason.

Type	Name	Strength (MPa)
Metal	Steel (4130)	670-1000
Metal	Aluminium (7075)	570-700
Metal	Titanium	900-1050
Plastic	Polycarbonate	55-75
Plastic	PPS	75-110
Plastic	PEEK	90-120

Having narrowed down our materials, we must briefly assess them before we move on to manufacturing. Unfortunately, it proved quite difficult to get accurate quotes on their prices, so we will follow a general assumption that steel is cheapest on average, and titanium most expensive.

4130 Steel, also known as Chromoly Steel, is an alloy containing chromium and molybdenum, hence the name. 4130 Steel is commonly used extensively in many industries, as such, it is available in many forms, making it very flexible when it comes to manufacturing techniques (CSWC, 2006).

7075 Aluminium, although not as strong as 4130 Steel on average (WM, 2021), makes up for it by being much lighter, resulting in less unnecessary weight added to the bike. Like the steel, it comes in various forms making it flexible for manufacturing.

Grade 5 Titanium, also known as Ti-6Al-4V, boasts an incredible strength to weight ratio (ARCAM, 2021). Sprockets manufactured from this metal are extremely durable yet lightweight. It does, of course, come at a premium cost. Like our other materials, it is easy to work with and corrosion resistant.

2.2 Manufacturing

With our materials in consideration, there are 4 standard manufacturing techniques we could utilize. CNC Machining, Stamping, Powder Metallurgy & Broaching. We must keep in mind that our goal is to manufacture 1000+ of these cassettes weekly, and that cassettes are composed of multiple sprockets of varying dimensions.

2.2.1 CNC Machining

CNC machining, a reductive manufacturing process, involves cutting out a shape from a sheet of metal. It can be very precise and is suitable for any of our metal materials. CNC machining requires a skilled workman to program the cutting paths, as well as to operate it (Smid, 2008).

We benefit from potentially needing less equipment, as we can have the designs for all the sprockets and manufacture them at will. However, CNC can be a lot slower than other fabrication counterparts, and generally does not scale up well due to this.

There is also a fair amount of material waste, especially so for a circular part as there will be dead space between parts on one sheet. Potentially, this material could be sold back to recoup some of its cost.

2.2.2 Stamping

Stamping, or pressing, involves pressing a sheet of metal between a tool and a die, to achieve the desired shape. For our application, we would also require the stamp to punch or shear material off the sheet (Plunkett).

As with CNC machining, there is some waste material, but it could also be sold back for a small recoup of costs.

Stamping requires bespoke dies for each object, cassettes can have as many as 13 sprockets, so theoretically this could require up to 13 custom instruments to manufacture a full cassette. An extremely high startup cost.

Stamping is much faster than CNC machining, due to this, at high volumes of manufacture, stamping scales extremely well. Stamping also does not require a skilled worker to operate, since the designs are permanently cast onto the dies.

2.2.3 Powder Metallurgy

Powder metallurgy, our first additive manufacturing process in this list, works by pressing the metal in powder form into a die. Like with stamping, this would require bespoke dies for every sprocket size.

Powder metallurgy benefits from having practically no waste product, as all the material is used to fill a Mold. It also scales somewhat well with increased volume, although not as well as some others, due to the time needed for the material to cool, it is certainly faster than CNC.

However, powder metallurgy requires that the material be heated to just below its melting point. Compared to the other manufacturing processes, this is a huge added cost in the equipment to heat up the metal, potentially having to keep it at temperature for hours, added utilities costs and added maintenance costs for this equipment.

Due to the complexity of powder metallurgy, a skilled worker is essential, and with multiple of these necessary to produce one cassette, the labour costs could be severe.

2.2.4 Broaching

Broaching involves having the material ablated by a toothed stick-like instrument called a broach.

It is primarily used for delicate and accurate work, it quite fast so does scale well, but the nature of the instrument means it's susceptible to wear over time, as the area being used to ablate material is smaller than the stamping tool for example. The startup cost is quite high, as the broach must be made bespoke for each design.

Due to the high wear on the machine, it does require a skilled workman to keep it operational.

3 Conclusions

3.1 Material

Having analysed all our potential materials and manufacturing techniques, we must come to a conclusion.

All our materials can ultimately be used regardless of manufacturing technique, so we will begin there.

Our choices were steel, aluminium & titanium. They are all excellent choices, but titanium would be too expensive to conceivably use. Both in material costs and the added wear and tear of tooling a harder metal. Perhaps for a luxury model it could be considered, however, for a mass-produced part aimed at the regular consumer, it is not a feasible choice.

Both steel and aluminium boast high tensile strengths, good corrosion resistance, and relatively low material costs. They are easy to work with and come in ample forms. However, steel is still cheaper than aluminium and stronger. It weighs more than aluminium, but for such a small part, the added weight is practically negligible. Production of 1000+ parts a week needs a steady influx of material, and steel is more readily available.

As such, I would go with the steel alloy.

3.2 Manufactory

Our main focus when it comes to manufacturing is scalability. CNC would not be practical for the intended volume of manufacture.

Powder metallurgy is too costly and unnecessarily complex. Powder form material is also harder to procure and likely more expensive than sheet metal, not practical for a high-volume production.

Broaching could be a strong contender, but considering the object we need to manufacture, almost just an extrusion of a 2D sketch. It is also unnecessarily complex, and the added wear and tear, expensive machinery and requirement for professional staff would be uneconomical.

This leaves stamping. Our object could be manufactured from a sheet of metal, provided it is thick enough. Like any machinery, stamping requires maintenance, but general operation could be done by a non-skilled worker, reducing labour costs. The start up costs may be high, but with the high volume of production, it would not take too long to break even and it should be relatively cheap to maintain. As such, this would be the most appropriate choice for manufacturing our sprockets.

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