4026MAA EEC- Manufacturing Technology and Materials

Course Work 2

Name-: Ravi Chaudhary

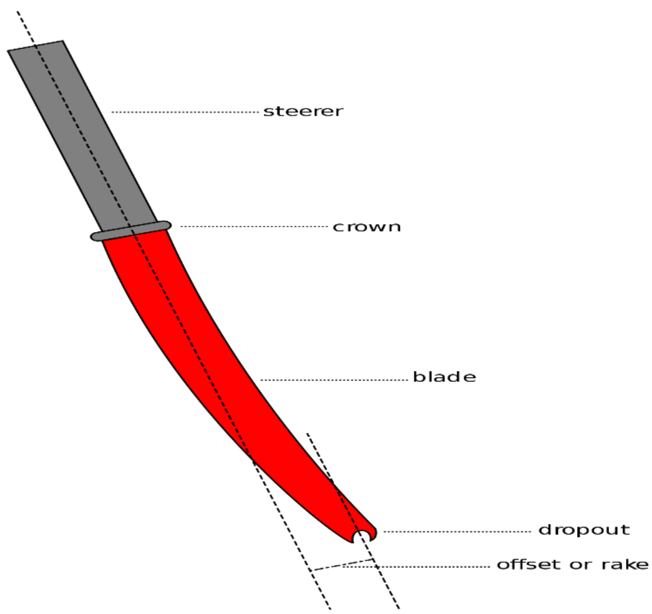
Student ID-: 10947986

Introduction

Manufacturing technology of material is the execution of physical and chemical measures to achieve a certain outcomes which might be its mechanical properties, geometry or appearance either by casting or using advanced machine tools. In this report, the different general, mechanical and thermal properties of the materials as well as stresses and loading conditions are considered to choose an appropriate material for manufacturing fork of the bicycle. Similarly, various manufacturing ways to assemble the manifold jacket with the advantages, disadvantages and applications of the suitable processes are evaluated.

1. Component Function and Operating Environment

1a.



(Fig.1: Racing bicycle fork **(n, 2006)**)

Almost every racing bicycle forks consists of steerer, crown, fork blades, axle, and dropout.

Steerer-: It is attached with the fork blades and allows the cyclist to guide the bicycle.

Crown-: It provides stiffness and strength to stanchions.

Fork Blades-: It provides support and helps to absorb the bumps, hits or energy.

Axle-: It is fixed with the pin or Allen keys in the hub of the fork (dropouts) to add strength. It provides support to put enough force while riding bicycle.

Overall, bicycle fork provides strength, support and soaks up the bumps and hits of overall bicycle providing comfort to the cyclist. Steel (metal), aluminum (metal), Titanium (metal), CFRP (polymer composite) are the most common materials used to make bicycle and bicycle forks. Before choosing the materials, it is most important to have knowledge about its general, mechanical, thermal properties and so on. The table below shows the comparative data between the above mentioned materials.

The fork of a racing bicycle will experience tensile stress, compressive stress stresses as well as lateral stress. The fork will experience the constant compression by the weight of the rider whereas tensile force is experienced by the down tube holding crank area jointly with fork assembly. Due to braking, it will somehow experience lateral stress too.

1b.

Fork of the racing bicycle should be made with strong, tough and stiffer material so that it could absorb high energy, hits and bumps. It should be light weight material (to decrease inertia to accelerate faster) with good thermal properties as it should be able to withstand very high and very low temperature without any failure. It shouldn't react with air or form any kind of oxides, needs to be corrosion resistant. It requires to be cost efficient with easy manufacturing process especially welding, molding and forming. In context of shape and design, the length of fork should be about (1"1/8 – 1.5") inch from top to bottom **(Rogan, 2020)**. Colour of the fork should also be considered and match with frame and structure. It is better to make the fork shape curve which tends to reduce 'trial' and absorbs hits and shocks. Fork of the bicycle will be at continuous static loading condition it is because it has to hold the weight of the cyclist. Moreover, it will experience bending as well as fatigue stress. Therefore, it needs to have high compression strength about (100 – 840) MPa to prevent the fork being compressed and fail. Similarly, high fracture toughness (approx. more than 200 MPa mm^0.5), young's modulus and tensile strength should be considered due to which bicycle can be made stronger, tough, stiffer and shock absorbent.

2. <u>Material Properties and Selection</u>

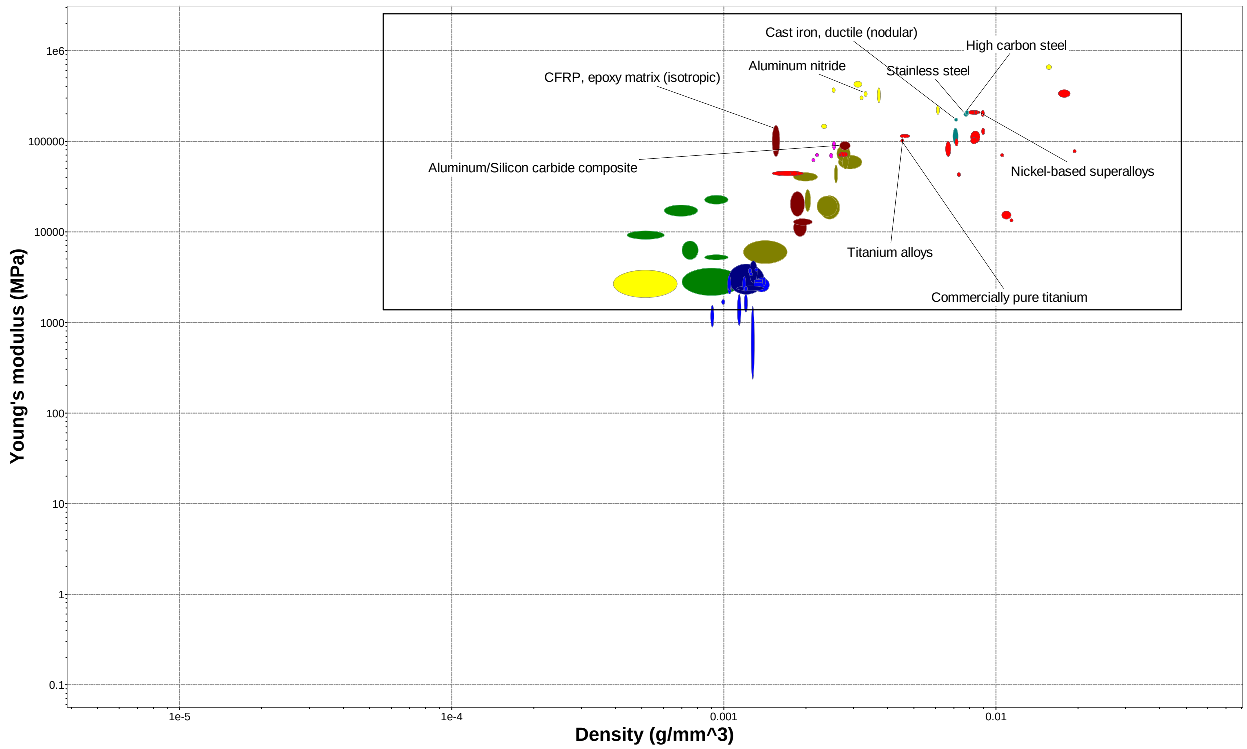
2a.

Table 1: Different properties of CFRP. (ANSYS GRANTA Edupack, 2020)

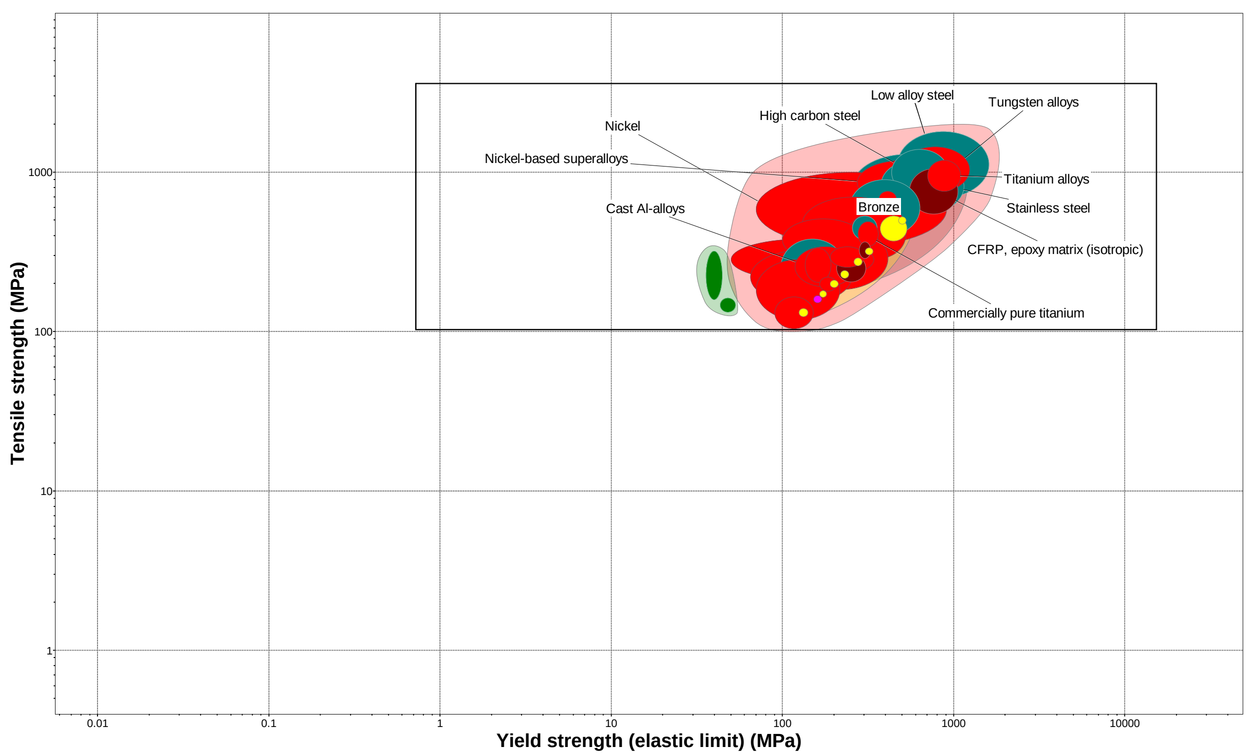
<u>CFRP</u>
General properties
Density: (0.0015 – 0.0016 g/mm^3)
Price: (0.0346 – 0.0364 USD/g)
Mechanical properties
Young's modulus: (6.9*10^4 – 1.5*10^5 MPa)
Yield strength: (550 – 1.05*10^3 MPa)
Tensile strength: (550 – 1.05*10^3 MPa)
Fatigue strength at 10^7 cycle: (150 – 300 MPa)
Fracture toughness: (194 – 632 MPa mm^0.5)
Compressive strength: (440 – 840 MPa)
<u>Thermal Properties</u>
Minimum service temperature: (-123) – (-73.2) degree C.
Maximum Service Temperature: 140 – 220 degree C.

Overall, CFRP would be the relevant material to manufacture the fork of the racing bicycle. It has light weight which is about 5 times lighter than steel, 3 times than titanium and 2 times lighter than the aluminum in comparison. Comparatively, it has high young's modulus (makes it stronger), stiffness to weight ratio (E/ρ) and strength to weight ratio (σy /ρ) is great i.e. 75 and 750 respectively which shows it is extremely strong and stiffer. It has good fatigue strength and fracture toughness to withstand the hits and bumps without failure though it has low fatigue strength and fracture toughness in comparison to steel, aluminum and titanium, it is catastrophic but it is laid up to 90 degree or 45 degree angle to any possible crack which leads to step-by-step failure whereas aluminum is all over if once damaged as it is an isotropic material **(Liu & Huang-Chieh Wu, 2010).** It has high tensile strength as mentioned in table 1 due to which it has better capability to counter the force that tends to pull the fork away. Due to good range of compressive strength i.e. 109 – 251 MPa, it can hold out against the force trying to reduce fork size. In case of thermal properties, carbon could resist more than 200 degree Celsius and below -123 degree Celsius, there will be no risk at extreme high and low temperature it will perform without failure. It is corrosion resistant and chemically stable material due to which there will be no risk of rain, it will not form oxides. Carbon fiber costs approximately 0.0346 – 0.0384 USD/g which is expensive than other materials. Though it is worth to manufacture the fork according to its benefits over the materials as only manufacturing the fork with carbon fiber wouldn't add much cost. (**Data with reference to table 1.**)

Graph 1: Young's modulus of a material against density.



Graph 2: Tensile strength of a material against yield strength



2b.

Table 2: different properties of stainless steel. (ANSYS GRANTA Edupack, 2020)

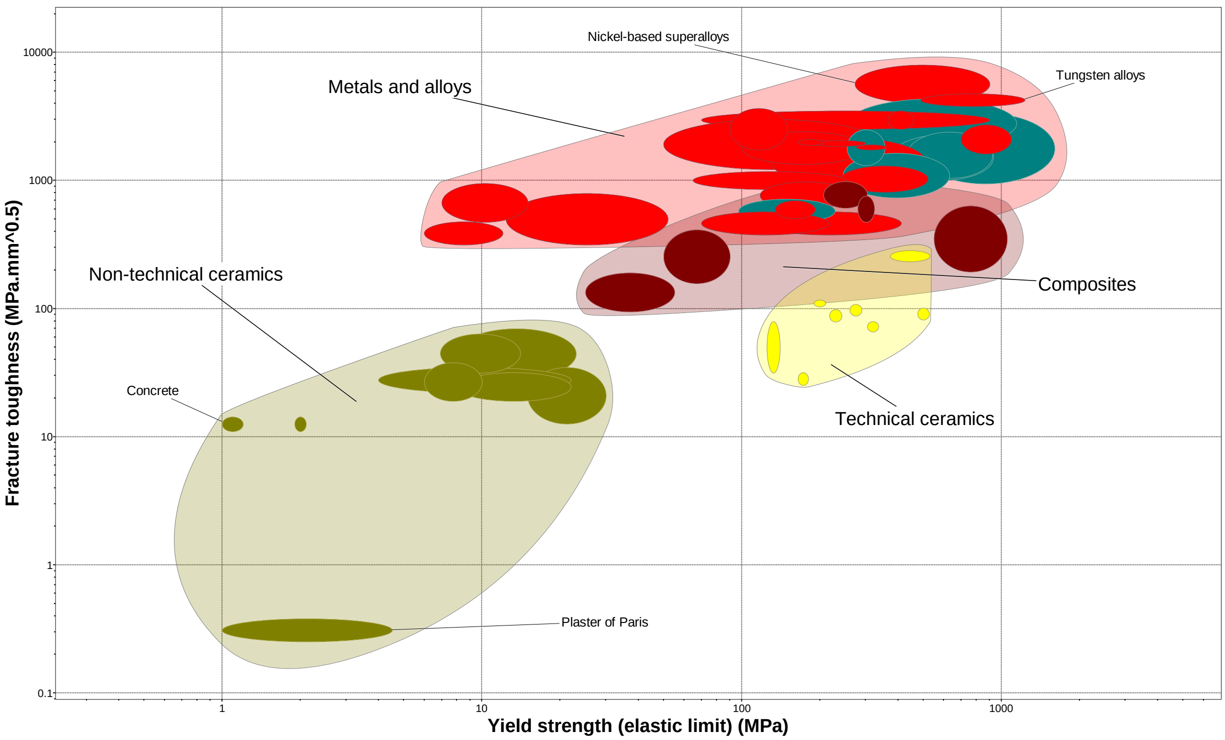
<u>Steel</u> <u>(Stainless Steel)</u>
General Properties
Density: (0.00761 – 0.00787 g/mm^3)
Price: (0.00303 – 0.00325 USD/g)
Mechanical properties
Young's modulus: (1.9 *10^5 – 2.1 *10^5 MPa)
Yield strength: (257 – 1.14*10^3 MPa)
Tensile strength: (515 – 1.3*10^3 MPa)
Fatigue strength at 10^7 cycle: (256 - 542 MPa)
Fracture toughness: (1.8*10^3 – 4.33*10^3 MPa mm^0.5)
Compressive strength: (252 – 1.2*10^3 MPa)
Hardness – Vickers: 170 – 438 HV
<u>Thermal Properties</u>
Minimum service temperature: (-273) degree C.
Maximum Service Temperature: (300 – 330) degree C.

Steel would be the better material to manufacture the mountain bicycle fork. To ride bicycle in mountains, suspension fork is important which will absorb the hits and bumps by letting the wheels move up and down. Therefore the fork needs to be tough and strong. Steel is the strong material with the yield strength of (257 – 1.14*10^3 MPa) and has strength to weight ratio 26 – 62. The density of the mountain bicycle fork needs to be slightly higher than any other kind of forks so that the bicycle should be more directed towards the gravity and the bicycle and the cyclist would be more stable in off roads. Consequently, stainless steel has the density of 0.00451 g/mm^3 and even it costs lower than carbon fiber (0.00237 – 0.00256 USD/g) and titanium (0.0131 – 0.0158 USD/g). It has high tensile strength (515 – 1.3*10^3 MPa) and is stiffer due to which it can oppose the force which tends the fork to fall apart. Due to high compressive strength (252 – 1.2*10^3 MPa) of stainless steel, it won't easily let the fork to be compressed with hits and energies in the wheel. Stainless steel is corrosion resistant, long-lasting, stiffer, ductile, has very high fracture toughness value (1.8*10^3 – 4.33*10^3 MPa mm^0.5) and good range of fatigue strength (256 - 542 MPa). Therefore, it will not easily disintegrate below the critical limit and can be flexed about infinite times. Welding of stainless steel is very common and easy. Stainless steel can be welded using Metal Inert Gas (MIG welding), Tungsten Inert Gas (TIG welding), Flux-cored arc welding, Metal Cored Arc welding, Laser Beam Welding and so on (**Metal Supermarkets, 2019**). So, there is still possibility to use the steel fork after its failure by welding it. Stainless steel can be commonly mold using Metal Injection Molding (MIM) which is cost effective as well as quick. It can withstand maximum temperature of (300 – 330) degree Celsius and minimum temperature of (-273) degree Celsius due to which it can hold out against high sunlight, snow, wind without failure and is suitable to ride in any kind of climate. **(Data with reference to table 2.)**

3. <u>Material Properties- Fracture Toughness in General</u>

3a.

Graph 3: Fracture toughness of a material against yield strength



3b.

Taking graph 3a. as a reference, non-technical ceramics (plaster of Paris) has the lowest fracture toughness and the metal and alloys (nickel-based super alloys) has the highest fracture toughness. The fracture toughness of plaster of Paris is about 0.0256 – 0.739 MPa whereas the nickel based alloy has extremely high fracture toughness i.e. 4.02*10^3 – 7.94*10*10^3 MPa in comparison. The young's modulus, yield strength, tensile strength, bulk modulus, compressive strength, hardness-Vickers of plaster of Paris is 4.5*10^3 – 8*10^3 MPa, 1 – 4.5 MPa, 1 – 4.5 MPa, 2*10^3 – 5*10^3 MPa, 14 – 20 MPa, 1 – 3 HV respectively whereas the nickel-based super alloys has 2*10^5 – 2.2*10^5 MPa, 273 – 900 MPa, 630 – 1.18*10^3 MPa, 1.5*10^5 to 2*10^5 MPa, 280 – 910 MPa, 160 – 400 HV sequentially. This shows nickel-based super alloys are mechanically extremely strong material than the plaster of Paris. In context of thermal properties, Nickel-based super alloys has melting point 1.26*10^3 – 1.4*10^3 degree Celsius however melting point of plaster of Paris is 300 – 500 degree Celsius which concludes nickel-based super alloys are meant to work in extremely high temperature as plaster of Paris couldn't be used in very high temperature. Nickel-based super alloys can withstand the maximum temperature of 777 – 1.04*10^3 degree Celsius and minimum temperature -273 degree Celsius while plaster of Paris resist the maximum temperature of 110 – 180 degree Celsius and minimum temperature (-73.2) – (-23.2) degree Celsius. According to different mechanical and thermal properties of plaster of Paris and Nickle-based super alloys, their engineering application will be contrasting. Nickel super alloy is the composition of Ni+10 to 25% Cr, Ti, Al, Mo, Zr, B and Fe in diverging amount due to which it is extremely strong with outstanding corrosion resistant and is used in to manufacture jet engines as it can withstand very high temperature up to 1040 degree Celsius. It is also used to assemble different parts of automobile, power generation, used in power plants and gas industries because of its excellent mechanical strength, creep resistance at high temperature, good surface stability and corrosion resistance. Plaster of Paris is composed of 2CaSO4.H2O, Gypsum which is used in hospitals to plaster the fractured parts of bones. It is used to manufacture casts and molds because it can be mixed and meld simply, also used as ornamental casting, make mold of teeth. **(ANSYS GRANTA Edupack, 2020)**

4. <u>Component Manufacturing Route/Manifold Jacket Manufacturing technique analysis</u>

4a.

Manifold jacket is used in jets or aerospace's which has 3D hollow space with about 6.7 kg mass. The section thickness of the manifold jacket is about 2-4.5 mm (**From MS word question file**). It can be manufactured by casting, additive manufacturing or machining process. Casting is one of the common and best process to manufacture manifold jacket. There are several types of casting i.e. 1) sand casting 2) Permanent mold casting 3) Shell casting 4) Investment casting 5) Centrifugal casting 6) Die casting

In sand casting process, sand is molded to cast the metal. It is the most common and used method for majority of metals. It has the minimum wall thickness of 3-5 mm **(MRT Casting, n.d.)**. Almost all the metals and alloys with low as well as high melting point like Carbon (3550 degree Celsius), Cast Iron (1204 degree Celsius), Magnesium (650 degree Celsius), Nickel (1455 degree Celsius), and Aluminum (660 degree Celsius), steel and so on can be sand casted. It can be done in relatively low costs as the tools are easily available and cheap. It is especially used to manufacture engine blocks, machine tool basis, cylindrical heads and valves. The drawback of sand casting is, the cast produced through this method has low strength because of the presence of high porosity. It has poor surface finish and inaccurate dimensional accuracy due to contraction, loose grain structure and poor surface texture of the internal sand mold. (**Metal Tek, 2020**)

In the investment casting, wax patterns are produced by injection, molding with metal die. The minimum wall thickness of this casting is in between 0.75-1.5 mm (**Open learn, 2017**). It uses the metals like Aluminum, Stainless Steel, Nickel based alloys, Copper-based alloys, Carbon steel, brass and bronze. This process of casting produces excellent smoothness of surfaces, dimensional accuracy with detailed attainable. The magnificent complex internal detailing is formed either by making simple pores in cooling the tools or by using wax or ceramics. It is economical casting method that offers wide range of benefits over completing processes. It has low tooling cost and complex structures can be manufactured such as true holes, internal as well as external slots and blind holes with high tolerance control. The downside of this casting is, it is comparatively costly than other castings methods like sand casting and permanent mold casting. It has slow production rate and is very difficult to produce in large number. (**Kopeliovich, n.d.**)

In die-casting process, injection of molten metal is done inside the mold at the pressure of about 200 MPa. Most die cast materials are made up of non-ferrous metals like magnesium, aluminum, zinc, copper and tin-based alloys. It has the maximum wall thickness section of 8-10 mm (**High Pressure Die Castings , n.d.**). Complex shape with low dimension tolerance and surface smoothness can be obtained with die-casting. It doesn't need machining after casting and large number of similar castings can be manufactured. It produces stronger, lighter cast without any disparate welded parts. The drawbacks of die-casting is, it cannot be used for the metals with high melting point like steel (2600 – 2800 degree Celsius). It is time consuming and cannot cast larger parts. Some gases can be entangled inside the casting in the form of porosity. It is used in the automotive industries in producing automotive wheels, front steering knuckles, brackets, pistons and gears. (**Kopeliovich, SubsTech, n.d.**)

Additive manufacturing is a 3D-printing instead of molding of parts or machining. Instead of molding of parts or machining, additive manufacturing involves the technology that fuses the materials using laser in case of metal in order to build up as part, one minute layer at a time. Usually, the minimum and maximum layer of 3D-printer is 16 micro meter to 150 micro meter in height respectively (**Sculpto, n.d.**). Due to additive manufacturing, there is possibility to produce complex internal channels, parts with lattice or honeycomb structure inside, customize the parts. Even it is easy to change the details at the last minutes as there is no dedicated mold to link. It can eliminate a lot of assembly work because a part that might be assembled from a lot of smaller components could be grown as a single piece instead. Though additive manufacturing as a production option is an inefficiency, the number of users and applications are growing but still small. The metal thus produced still needs to be machined for finishing because of its complementary process. It is the expensive process and can cost up to 10 to 50 times the cost of the traditional powder metal part. The surface that it produces isn't that smooth as investment method of casting. **(Powder Metal Resources, n.d.**)

Powder metallurgy is the manufacturing process that is used to make very intricate shape with the use of metal powders. It provides good surface finish and large number of products can be manufactured in short period of time. It is usually used to manufacture the materials which can be heat treated in order to increase the strength and wear resistance. It produces complex shape which might be difficult with other processes to assemble. Varieties of alloys like stainless steel, copper alloys, aluminum alloys, titanium alloys, magnetic and electrical materials can be used as a powder in powder metallurgy. To perform power metallurgy, the wall shouldn't be thinner than 1.52 mm **(Design Considerations, n.d.**). The downside of this method is, the density of the product after their production may be different due to uneven compression. The maximum weight of the product that can be assembled is 20kg. The mechanical strength is lower than the product manufactured by casting or other process. Powders like aluminum, magnesium, titanium may cause fire hazards and increase explosion risk. (**Powder Metallurgy, 2019**)

The process of shaping the materials by eliminating the materials using different technologies and power-driven machines. The materials like aluminum, steel, stainless steel, titanium, brass, wood and even wood can be machined. For machining to be done, the machine walls are expected to have the minimum diameter of 4mm, length 1.27 mm and wall thickness of 0.5mm (**Protolabs, n.d.**). In some cases, thinner walls less than 1/32" inch may be possible but needs extra cost. It also varies according to factors like wall height: thickness and length ratio, geometries etc. It produces extremely smooth surface finish, high production in short period as it has ability to do milling, drilling and spinning at a time. Straight edges, screw threads, accurate circle holes can easily be created through this process. In the drawback, it is one of the expensive processes to carry out. Complex shapes like parabolic curvature components, cubicle curvature components are difficult to manufacture. (**Plethora Logo, 2020**)

Overall, investment casting would be the better choice to manufacture manifold jacket. Most manifold jackets are made of nickel which has very high melting point (1455 degree Celsius (**Royal Society of chemistry, n.d.**)) as the investment casting process is excellent to perform with metals having high melting point metals. Powder metallurgy can be carried out but it's expensive as well as the mechanical strength of the material produced by this method is comparatively less than investment casting. Investment casting is the one through which hollow surface, blind holes, fret profiles, gears can be made with extremely smooth surface finish and proper dimension. Manifold jacket is only used in 10 units such as in aerospace vehicles and shuttles because of its limited application (**ukessays, 2017**). Therefore, it can be manufactured through investment casting with worthy economy. In the other hand, additive manufacturing is not that much in use and is very expensive to go through. It needs machining for good surface finish. This is why, investment casting is better over powder metallurgy, machining and additive manufacturing.

4b.

In Investment casting process, patterns made of wax are dipped in to a slurry for preparing the mold. Once the mold is prepared these wax patterns are melted out of the box, so this process is also called lost-wax process. The investment casting process begins with the process of wax mold which is produced by filling a special mold created to manufacture wax patterns. The special mold has the shape of the required wax pattern. As the wax pattern is manufactured, it is placed into a pattern tree which consists of several other wax patterns. The pattern tree employed gated systems which are essential for filling all the mold cavities with molten metal simultaneously. Several wax patterns can be combined to manufacture a single complex pattern. Pattern is then dipped in to a slurry which contains of refectory materials like silica. The slurry also includes water, ethyl silicate and acids due to which it forms a coating around the pattern which is allowed to dry. After the initial coating has dried up, the pattern is coated repeatedly to increase the thickness which is then allowed to dry up for some time and after that it is heated at a temperature of 90-175 degree Celsius to melt the wax pattern inside the mold. The mold is then kept in an inverted position to facilitate the molten wax to flow out of the mold, which is collected in a container and is reused for subsequent processes. The mold is further heated to 650-1050 degree Celsius for around 4 hours to strengthen the mold and remove the left wax. The molten metal is poured into the cavity and allows to cool down. Once it cools down and solidifies, the mold is broken and final casting is obtained. **(Maher, 2020**)

Manifold jacket has the mass of 6.7 kg and has 3D-hollow shape. The section thickness of the manifold jacket is about 2-4.5 mm. Only 10 units are manufactured due to its limited application in aerospace vehicles and shuttles. The precision requirement is 0.1 mm (**From MS Word question file**). Therefore, investment casting is carried out as it can facilities cast part up to 9.07 kg (https://www.avalon-castings.com). As manifold jacket doesn't have more applications, investment casting provides worth to economy though it is not applicable to produce in large number. Investment casting usually provides higher accuracy (+/- 0.005 inch) smooth surface finish (normally 125 micron RMS) and normal tolerance ((+/-0.010") – (+/-0.004")) (**Olsen, 2020**) & (**Prototyping Solutions, n.d.**). The tooling cost to perform investment casting ranges from $5000 to $25000 (**Prototyping Solutions, n.d.**). Investment casting methods has many advantages because of which they are widely applied in industries. This method provides reliable process control. Wide range of complex parts like true holes, internal as well as external slots and blind holes, gears with high tolerance control can be manufactured with this process. It provides excellent dimensional accuracy and smooth surface finish. The tooling cost to perform this process is comparatively lower than other processes like additive manufacturing (which is about 5-50 times higher). This method is environmental friendly as the wax can be reclaimed and reused again. The limitations of investment casting are- It involves high labor cost than performing sand casting and permanent mold casting. The process faces difficulties while using cores. The production cycle time for investment casting is higher when compared with other casting processes. It is infeasible for high-volume production of cast. Despite having many downside, it is one of the best casting processes when it comes to dimensional accuracy, tolerance control and design complexity. Due to this it is used in manufacturing turbine airfoils, aircraft engines, surgical implants, construction tools, manifold jacket etc. (**Mechanical base, 2020**)

4C.

Selective Laser Sintering (SLS) which is a part of additive manufacturing technology is a powder-based printing technology which generally uses production-grade plastic materials for durable, functional parts fabricated. There are many advantages of using SLS to manufacture manifold jacket which are as follows:

- Intricate geometry of can be obtained easily which makes easy to manufacture manifold jacket with excellent surface finish and good dimensional accuracy.
- It provides high level of accuracy so there will be very less chance of failure.
- It saves time, printings (multiple printing at a time) and doesn't need extra support.
- It doesn't require the entire process to be done from the beginning if something goes wrong as it allows last minute design change.
- It provides strong material property as it has good range of chemical and heat resistance. It can be used in mechanical joints.
- Mass production of manifold jacket and other materials are possible with this laser sintering process. **(3D Printing Technologies| Guide, n.d.**)

<u>Conclusion</u>

In conclusion, it can be considered that the CPRF is one of the best materials to manufacture fork of a bicycle because of its high mechanical properties and stainless steel is good choice for mountain bicycle due to its high strength, density and stiffness. For manifold jacket, investment casting is considered as the most effective and efficient way to carry out the manufacturing process with a lot of advantages over other processes.

References

3D Printing Technologies| Guide. (n.d.). Retrieved from Selective Laser Sintering: https://www.3dsourced.com/guides/selective-laser-sintering-sls/

ANSYS GRANTA Edupack. (2020).

Design Considerations. (n.d.). Retrieved from Design considerations with powder metallurgy: https://www.pickpm.com/design-resource-center/design-considerations/

High Pressure Die Castings . (n.d.). Retrieved from Castings: https://elcee.com/castings/high-pressure-die-casting/#:~:text=Technical%20specifications&text=Minimum%20casting%20wall%20thickness%20for,kept%20as%20uniform%20as%20possible

Kopeliovich, D. D. (n.d.). *SubsTech*. Retrieved from Investment Casting: https://www.substech.com/dokuwiki/doku.php?id=investment_casting

Kopeliovich, D. D. (n.d.). *SubsTech*. Retrieved from Die casting: https://www.substech.com/dokuwiki/doku.php?id=die_casting

Liu, T. J.-C., & Huang-Chieh Wu. (2010, April). *ResearchGate*. Retrieved from Fiber direction abd stacking sequence: https://www.researchgate.net/publication/248465368_Fiber_direction_and_stacking_sequence_design_for_bicycle_frame_made_of_carbonepoxy_composite_laminate

Maher, S. (2020, January 17). *General Kinametics*. Retrieved from What is Investment Casting?: https://www.generalkinematics.com/blog/investment-casting/

Mechanical base. (2020, December). Retrieved from Investment Casting: https://mechanicalbase.com/investment-casting-and-its-advantages-and-disadvantages/

Metal Supermarkets. (2019, July 31). Retrieved from Welding Processes for Stainless Steel.

Metal Tek. (2020, November 23). Retrieved from Sand Casting Process: Advantages and Limitations: https://www.metaltek.com/blog/sand-casting-process-advantages-and-limitations/

MRT Casting. (n.d.). Retrieved from Sand Casting Process: https://www.mrt-castings.co.uk/sand_casting_process.html#:~:text=The%20designer%20should%20take%20into,and%20coarse%20grain%20size.

n, X. (2006, July 26). *File:Bicycle fork labeled.svg.* Retrieved from https://en.wikipedia.org/wiki/File:Bicycle_fork_labeled.svg

Olsen, D. (2020, November 23). *MetalTech*. Retrieved from What Is Investment Casting And How Does It Work?: https://www.metaltek.com/blog/what-is-investment-casting-and-how-does-it-work/

Open learn. (2017, November 1). Retrieved from Investment Casting: https://www.open.edu/openlearn/science-maths-technology/engineering-technology/manupedia/investment-casting#:~:text=Minimum%20wall%20thickness%20depends%20on,the%20range%200.75%E2%80%931.5%20mm

Plethora Logo. (2020, December 1). Retrieved from The Advantages and Disadvantages of CNC Machining for Quick-Turn Prototyping: https://www.plethora.com/insights/cnc-machining-advantages-and-disadvantages-for-quick-turn-prototyping-pt

Powder Metal Resources. (n.d.). Retrieved from Advantages & Disadvantages of Additive Manufacturing Process: https://www-horizontechnology-biz.cdn.ampproject.org/v/s/www.horizontechnology.biz/blog/advantages-and-disadvantages-of-additive-manufacturing-process-vs-powder-metallurgy?amp_js_v=a6&amp_gsa=1&hs_amp=true&usqp=mq331AQHKAFQArABIA%3D%3D#aoh=16235086417928&

Powder Metallurgy. (2019, March 24). Retrieved from ClubTechnical: https://clubtechnical.com/powder-metallurgy

Protolabs. (n.d.). Retrieved from Design Guidelines: CNC Turning: https://www.protolabs.co.uk/services/cnc-machining/cnc-turning/design-guidelines/

Prototyping Solutions. (n.d.). Retrieved from Investment Casting: https://prototypingsolutions.com/investment-casting/

Rogan, J. (2020, April 24). *Best Forks | Buying Guide | Reaction Cycles*. Retrieved from Chain Reaction Cycles: https://hub.chainreactioncycles.com/buying-guides/frames-and-forks/forks-buying-guide/

Royal Society of chemistry. (n.d.). Retrieved from Nickel: https://www.rsc.org/periodic-table/element/28/nickel

Sculpto. (n.d.). Retrieved from Layer thickness in 3D printing: An additive manufacturing basic: https://www.sculpteo.com/en/glossary/layer-thickness-definition/

ukessays. (2017, 08 30). Retrieved from Shaping, Joining and Surface Treatement Analysis: https://www.ukessays.com/essays/engineering/shaping-joining-surface-treatment-8590.php?hcb=1