AE224:MACHINING AND PRECISION MANUFACTURING - TASK 1

A STUDY ON MANUFACTURING OF COMPONENTS OF SWASH PLATE MECHANISM

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Introduction

The flight of helicopters is heavily dependant on the swash plate mechanism. In helicopters the rotors generate lift but to turn the helicopter uneven distribution of lift is required i.e on one fixed location there must be a fixed lift force which depends upon the angle of attack. So to make the angle location specific the swash plate mechanism is used so that any of the three or four rotors when it passes through a location its angle of attack (AoA) is changed.
Due to its significant role importance the swash plate mechanism is also known as the heart of the helicopter.

Parts

1. Bottom Swash Plate (BSP)
2. Upper Swash Plate (USP)
3. Bearings
4. Upper Swash Connector (USC)
5. Ball Holder
6. Ball Locker
7. Ball
8. Fastners

Basic Structure

Figure: SWASH PLATE ARRANGEMENT [1]

The BSP is fixed (in bronze color) which can be tilted using pistons and the USP (in black color) rotates via bearings between BSP and USP. The central shaft is provided power via the engine and through a connector (in white color) it rotates the USP. The USP is connected to the rotors via connecting rods which chnge the AoA by pulling or pushing the rotors according to how BSP is tilted.

High strength, lightweight, critical metals or alloys are used for the manufacturing of swashplates. Aluminum and Titanium are prominent choices due to their light weight and strength.
Aluminum 2xxx series-

- uses copper as the principle alloying element
- strengthened through solution heat-treating
- good combination of high strength and toughness
- their low resistance to atmospheric corrosion is improved by cladding them with 6xxx alloys series or by painting their surface

Grade 3 and Ti 6Al-4V (Grade 5) Titanium alloys are prominent alloys used for Aircraft structural components.

- Grade 3 is stronger than Grades 1 and 2
- Grade 3 is used in applications requiring moderate strength and major corrosion resistance
- Ti 6Al-4V may be heat treated to increase its strength and also is weldable at service temperatures of up to 600°F
- Ti 6Al-4V (Grade 5) offers its high strength at a light weight, useful formability and high corrosion resistance.

Three important areas where metals possess less than optimum features are weight, availability and damage tolerance.

- Weight has always been a consideration in helicopter construction and with increasing fuel costs it has become a primary objective to reduce the weight of the overall helicopter by using lighter materials.
- Even though metals and alloys provide a lightweight and strong component, aluminum is corrosive which could lead to the development of cracks and reduce the useful life of the component. Titanium, while more corrosion resistant than aluminum, is extremely expensive and weighs considerably more than aluminum.
- In addition, many of these lightweight metals are classified as "critical" materials with their primary availability being through importation and reliance on foreign sources for these materials is not desirable. Furthermore, these metals do not impart a damage tolerance to their components.

- Damage tolerance is a property of a structure relating to its ability to sustain defects safely until repair can be effected.

Reserches are being done to replace metal components by composites. However, it is not always practical to replace a metal component with a composite material due to particular design considerations and shortcomings in the composite physical properties. Braided tubular composite is one such example where the composite consists of graphite fiber reinforcement and epoxy resin matrix which is selected so that it is compatible with the fibre reinforcement.

Manufacturing of Components

The following points are to be taken into consideration when the castabilty, formability, weldablity and machinability are concerned.

- Aluminum and Titanium can be easily forged and cast.
- Aluminum and Titanium both can be welded but require special processes and methods.
- Machining of Aluminum is easy whereas machining of Titanium is comparitively difficult.

- Titanium alloys have a low Young's modulus, which causes spring back and chatter during machining which results in poor surface quality in the finished product.
- Because of titanium's high work hardening tendency and the stickiness of the alloy, long continuous chips are formed during turning and drilling, which can entangle the tool and impede function. This almost eliminates the possibility of automating titanium machining.
- Machining titanium requires coated carbide tools that will resist the stickiness of the alloy and break up the long chips. The tool coating also helps to manage the heat produced with machining.
- Application of high pressure coolant helps to reduce heat and damage to the tool. Currently, ultrasonic assisted machining is in R&D. The goal is to reduce the contact time of the tool, and prolong tool life.

Bottom Swash Plate

- The BSP can be manufactured by forging aluminum alloys as they are most readily forged into precise, intricate shapes. This is because they are very ductile at normal forging temperature and can be forged in steel dies that are heated to the same temperature as the workpiece.
- The BSP if it has to be made by forging titanium alloys would require dies made of heat resistant alloys and also precision is also not expected out of this process due to the intricacy of the shape.
- Titanium casting is difficult and at present, consumable vacuum arc melting offers the only suitable commercial method of producing titanium castings.
- Thus for commercial manufacturing forged aluminum stock, machined to appropriate dimensions is a suitable option.

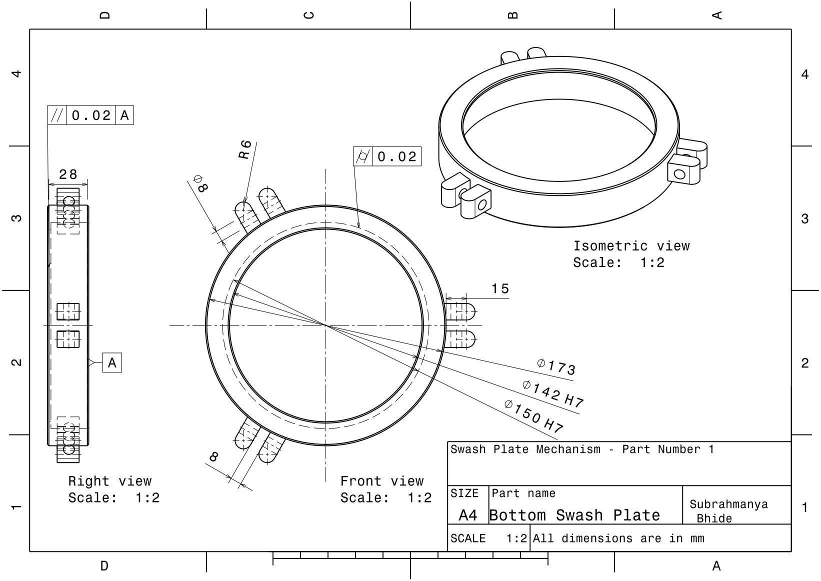

Figure: PRODUCTION DRAWING OF BSP

Upper Swash Plate Upper Swash Connector

- Both Upper Swash plate and Upper Swash Connector can be manufactured in processes similar to that of the BSP.
- The Swash plates have to withstand great amount of forces in the radial directions and hence structural integrity for the structure is of utmost importance.
- Thus even though casting of aluminum alloys is relatively easy it is not prefferd as cast products have porosity.
- Hence for commercial manufacturing forged aluminum stock, machined to appropriate dimensions is a suitable option just as the BSP.

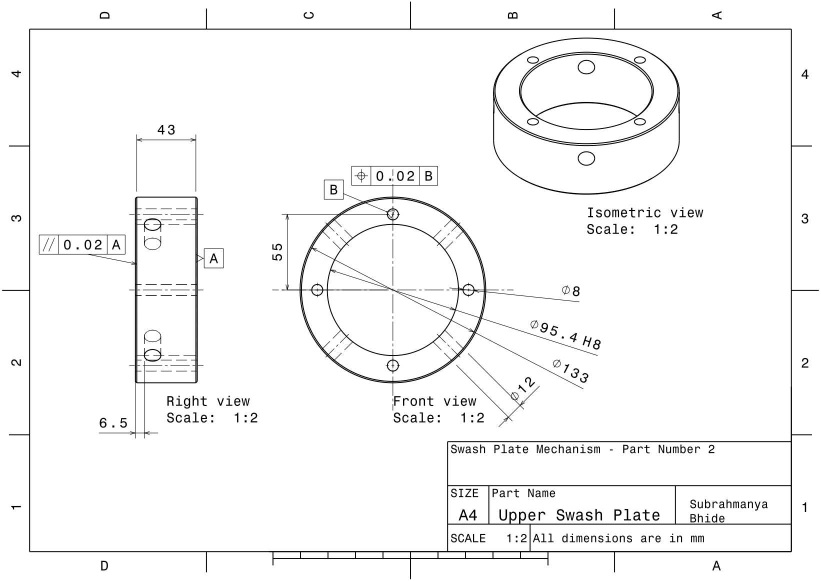

Figure: PRODUCTION DRAWING OF USP

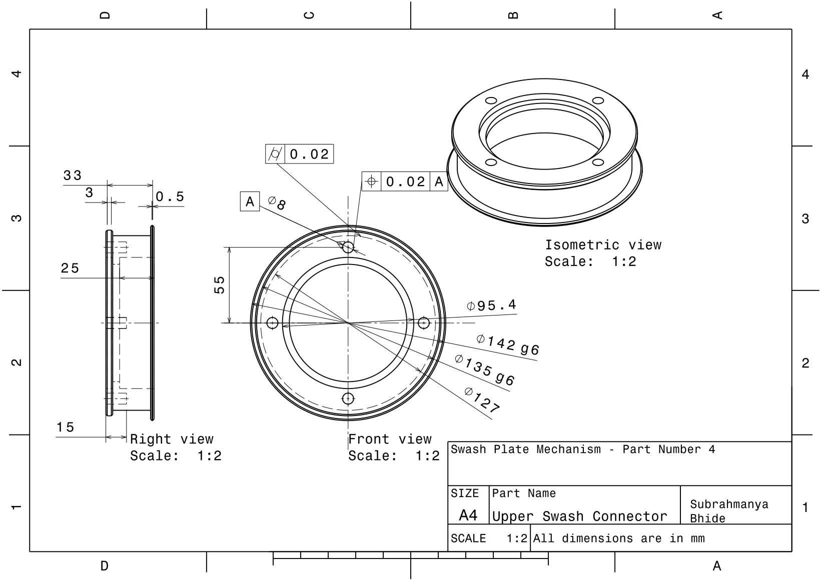

Figure: PRODUCTION DRAWING OF USC

Forging for BSP, USP and Upper Swash Connector

- A single step forging process is not an option for the three components as BSP has lug kind of formations on its periphery for connecting the pistons.
- When products with high strength, circular cross section are required rolled-ring forging is the best method. The process typically begins with an open-die forging to create a ring preform, shaped like a doughnut. Next, several rollers apply pressure on the preform until the desired wall thickness and height are achieved. After this the last forging takes place which creates the lug like protursions.
- This is followed by drilling for holes and finishing.

Fastners

- Titanium alloys or steel can be used to manufacture fastners.
- Raw material in form of wire is uncoiled and straightened and cut to appropriate length.
- Next cold forging followed by heading process is performed to shape the head of the bolt. This is done in progressively in steps.
- Next threading is done by rolling or cutting.
- Heat treatment is done to harden steel. Followed by surface treatement where Zinc-plating is done to increase corrosion resistance.

Thrust Bearing

- Firstly the outer and inner ring are manufactured by CNC machining of billets or forging of billets. These are then subject to heat treatment followed by grinding.
- The cylinders or Balls, outer ring and inner rings are arranged in position. After this the cage is fit in and seals are used to cover both the sides.
- Thrust bearings are required to withstand the radial force due to the rotation of the USC.

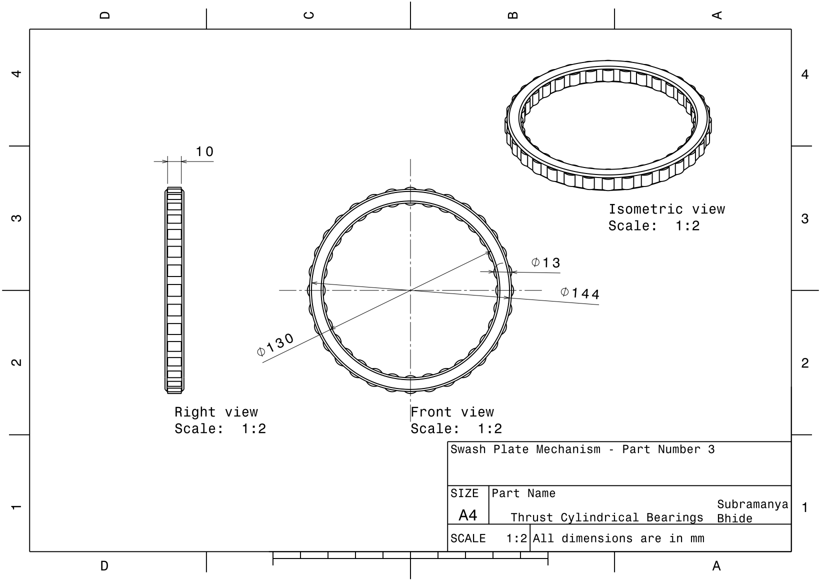

Figure: PRODUCTION DRAWING OF Bearing

Ball, Ball Holder and Ball Locker

The manufactring of the ball happens in the following steps:

- Heading: In the first step, heading machines cut wire into short lengths and forms it into spherical shapes between dies.
- Deflashing: The flash line, a ridge left by the forming dies, is removed as balls roll between heavy, cast iron plates.
- Soft Grinding: Similar to deflashing, except that a grinding stone is used to improve precision.
- Heat-treating: Carbon steel balls are next carburized and hardened. Heat treatment imparts the desired hardness and case depth.

- Descaling: This step removes the residues and by-products from the heat-treating process.
- Hard Grinding: Slow, meticulous grinding assures proper sizing and sphericity, with tolerances as close as
- Lapping: Several proprietary lapping processes can bring balls to the requirements of ISO 3290 Grade 3 2- 48.
- Finishing: Proprietary chemical and mechanical processes give the balls their final micro-smoothed finish, for increased wear resistance and product longevity.

Both Aluminum and Titanium alloys can be used as material to manufacture the ball. Taking into consideration that Titanium grade 5 has tensile strength of 950MPa whereas Aluminum 2xxx has tensile strength of about 310MPa it is in our advantage to use Titanium alloy Balls.

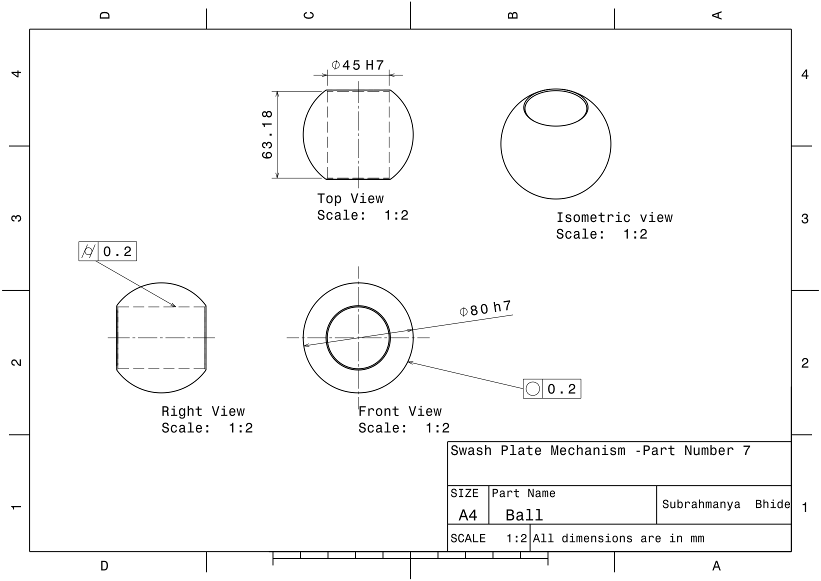

Figure: PRODUCTION DRAWING OF BALL

- Since the ball has to be fit into the ball holder the ball holder has to be made in two halves and then joined together.
- The two halves can be manufactured by Internal profiling using a CNC Lathe.
- Then once the ball is placed in it the two halves can be joined using TIG Welding process.
- Both the alloys could be used but Aluminum is easier to machine and it can also be welded even though it would require additional care during welding due to its higher thermal conductivity due to which full penetration might not occur and also proper filler materials have to be chosen and proper feeding mechanism has to chosen.
- The Ball Locker can be manufactured by forging of Billets followed by drilling and machining and grinding to obtain good finish on the surface.

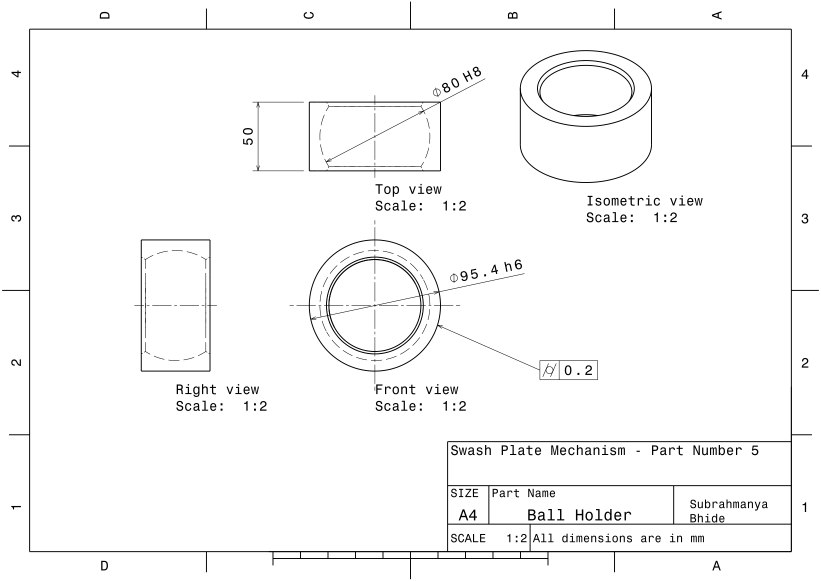

Figure: PRODUCTION DRAWING OF BALL HOLDER

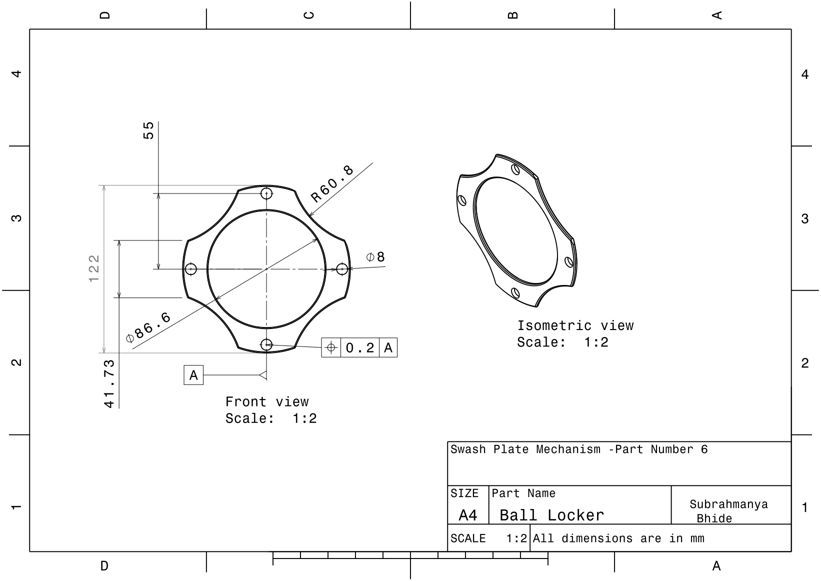

Figure: PRODUCTION DRAWING OF BALL LOCKER

Assembly and Working

The Ball is placed around the hub which is held by Ball Holder and locked by Ball Locker. Pistons hold the BSP and bearings are placed in its inner periphery and the USC is placed such that bearings lie between the BSP and USC, which permits rotation of USC while holding BSP stationary. The USP is placed over USC and held in place with fastners. The Ball holder is placed inside the USP.

During normal working the BSP is flat thus providing equal AoA to all the rotors so that lift is generated in the vertical upwards direction. When more lift is required all the pistons are moved up to increase AoA of all the rotors and thus generate greater lift. When change in direction is required the BSP is tilted at such a position that the position of control rods changes as they rotate which in turn gives rise to different AoA hence leading to different lift at different positions. By Newtons Law of Conservation of Angular Momentum the helicopter turns.

- For Aluminum alloys High Speed Steel (HSS) tools are preffered with different coatings like titanium carbo-nitride (TiCN) or Titanium aluminum nitride (AlTiN or TiAlN) which are slippery enough to help keep chips moving.
- Titanium and its alloys have low thermal conductivity and so the heat generated is not dissipiated through chip. Hence for Titanium alloys cutting tools must have good hot hardness, low cobalt content and must not react with titanium. One of the best solution is a very sharp cutting tool, one with a multilayer titanium aluminum nitride (TiAlN) PVD coating and micro-grain carbide substrate.

Table: SUMMARY OF THE MANUFACTURING METHODS

Component	Material	Method
BSP USC USP	Aluminum 2xxx series preferably alloyed with 6xxx series	1.Rolled Ring Forging 2.Drilling 3.Finishing
Ball	Titanium Grade 5	Standard Ball Manufacturing Method
Ball Holder	Aluminum 2xxx series preferably alloyed with 6xxx series	1.Internal Profiling 2.Welding 3.Finishing
Ball locker	Aluminum 2xxx series preferably alloyed with 6xxx series	1.Forging 2.Machining 3.Finishing

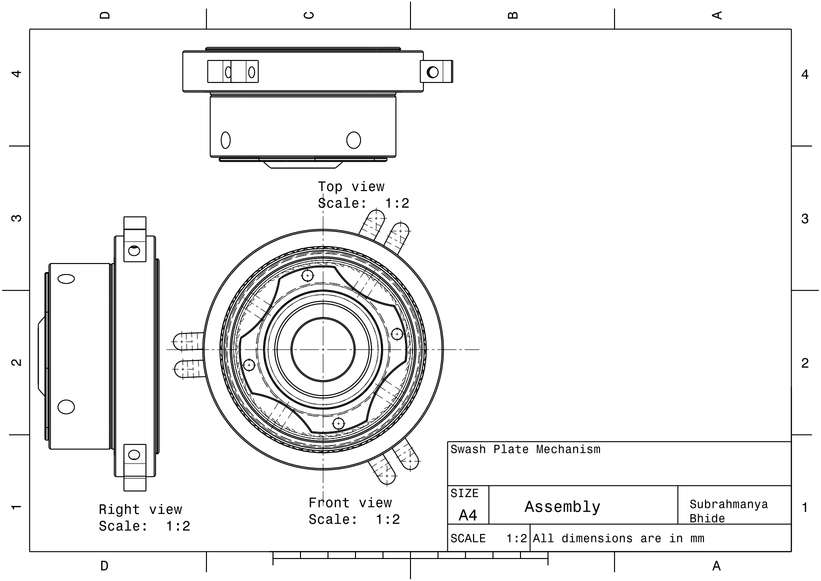

Figure: PRODUCTION DRAWING OF THE ASSEMBLY

- The basic structure consists of an outer tubular ring and an inner tubular ring. The outer ring is made from braids of tri-axial graphite fibers interwoven with unidirectional plies. The inner tubular ring is made from braided 45 degree graphite fibers.
- The outer layer is preferably formed from a tri-axial (quasi-isotropic) braid (fibers extending in approximately the 0 and 45 degree directions) of graphite fibers embedded in a resin matrix binder.
- Additionally, a 90 degree ply of graphite fibers is wrapped around the braid to produce a quasi-isotropic laminate (0, 45 and 90 degrees).
- In order to accommodate rotor loads, the outer layer preferably has a nominal thickness of about 3 mm. The resin is preferably a toughened epoxy resin that is typically utilized in a resin transfer molding process.

- The inner ring is formed from four braided plies of graphite fiber. Between each ply in the inner ring at the control rod attachment points is an interwoven ply pack of quasi-isotropic composite material.
- A support ring is located within the outer ring which is preferably made from chopped graphite fibers in an epoxy resin matrix and has a plurality of projections extending radially outwardly from the periphery of the support ring.
- The support ring is preferably made as a precure from sheet molding compound, such as a mixture of chopped graphite fibers in an epoxy resin matrix (e.g., PR500 resin) and is machined into a scalloped configuration when weight is of concern else it can be made as a uniform cross section.
- A plurality of apertures are formed through the outer and inner rings which are are adapted to receive the terminal ends of the control rods.

- There also exists a braid of fiberglass material overwrapping the outer ring to form a durable outer surface.
- A mounting block is also located at the control rod attachment points within the secondary tubular member.
- At each attachment point, a slotted aperture for receiving a lug end of the control rod is preferably machined out of the mounting block. Alternately, the mounting block can be formed (e.g., molded) with the slotted aperture already in it.
- the secondary tubular ring is formed from a continuous braid of graphite fibers in a resin matrix binder. There are preferably four layers of approximately 45 degree fibers. The resin is preferably a toughened epoxy resin.

- it also may be desirable to form an external layer over the outer layer on the swashplate. Preferably the external layer includes one ply of braided 45 degree fiberglass with a thickness of 0.015 inches. The fiberglass braid provides the surface of the structure with added durability.
- Foam material is cut and machined to the desired shapes to form the spacers and the core members to provide support before curing.
- The swashplate is then placed into a resin transfer mold. Resin is injected under pressure into the mold to mix with the graphite fibers. The assembly is cured and then removed from the mold.
- Additionally, the foam materials (spacer and core members) may be designed to decompose (melt) at the end of the curing process. This would lessen the final weight of the swashplate.

Conclusion

Hence through this study we can see that while Conventional metallic materials are an excellent option for manufacturing Swash Plate Assembly components of a helicopter it is also not possible to completely discard the possiblity of use of composite components as replacements for metallic components. Composite Swash plate components are still in the research phase and we are not yet ready to have a complete shift from metals to composites. The technique mentioned at the end is one of the proposed methods for composite parts.

References

- https://patents.google.com/patent/US5810562A/en
- https://patents.google.com/patent/US4804315A/en
- https://www.harveyperformance.com/in-the-loupe/titanium-machining/
- https://www.aluminum.org/industries/processing/forgings
- https://www.forging.org/forging/design/46-titanium-alloys.html
- https://www.youtube.com/watch?v=2tdnqZgKa0E&t=241s (Working of Swash Plate Mechanism) [1]

- https://www.abbottball.com/about-abbott/today/manufacturing.html
- http://asm.matweb.com/search/SpecificMaterial.asp\?bassnum=MTP641
- http://asm.matweb.com/search/SpecificMaterial.asp\?bassnum=MA6061T6
- https://www.youtube.com/watch?v=rH9UnzYki1Q (Ring Rolling Process)
- https://www.compass-anvil.com/forging-vs-casting
- https://www.nord-lock.com/insights/knowledge/2018/the-making-of-bolts/