Emulsion Technique in Fabrication of Space Telescope Mirror

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Emulsion Technique in Fabrication of Space Telescope Mirror

Major Project Part-I

Submitted in partial fulfillment of the requirements
for the degree of
Master of Technology in Mechanical Engineering(CAD/CAM)

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May, 2017

Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master in Technology in Mechanical Engineering(CAD/CAM) at Nirma University and has not been submitted elsewhere for a degree.
2. Due acknowledgement has been made in the text to all other material used.

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ABSTRACT

The optical primary mirror is the most critical and important component of an space optical telescope. The primary mirror is main heaviest component used for manufacturing the astronomical optical telescope. The optimization of the optical telescope design can be addressed by reducing mirror weight, cost, and mirror materials. For improvement of the mirror active surface figuring, polishing, and surface coating is required. Traditional way of fabricating techniques like milling is expensive and consume lots of time. Existing joining process like Hydroxide bonding technique can be used for fabricating primary mirror. Establish the bonding between materials becomes a challenging task, when high stability is required at temperature variation. Stable, simple room temperature bonding process with less thickness and better strength makes hydroxide bonding process better option for making primary mirror. For making light weight and stable large primary mirror CFRP is the best candidate. By optical surface transfer method CFRP mirror can be manufacured. Due to use of coating and other suggestion like to add an extra resin layer, CFRP mirror active surface can improve.

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Chapter 1

Introduction and Literature Review

1.1 Preamble

Recently, the sensitivity performance required for satellite telescopes is expanding, ever-advance because of the developing requirements for earth perception to comprehend the instruments that cause abnormal climate wonders, an unnatural weather change or worldwide environmental change and astronomical observation for research into the Earth's origin or mechanisms of the universe. As needs be, a scope of measures to enhance perception execution have been actualized, of which the most suitable strategy is to expand the opening distance across of the primary reflecter of telescopes. However, the maximum weight of the satellite is limited by the launch capacity of the rocket, meaning the main mirror and satellite structures must be lightweight and highly rigid.

1.2 Introduction to Organization

The primary body for space research under the control of the government of India is Indian Space Research Organization (ISRO) and it is the one of the leading space research organizations in the world. In early 1960's the space activities in the country started with the scientific investigation of the ionosphere and upper atmosphere over the magnetic equator that passes over Thumba which is near Thiruvananthapuram using rockets realizing the massive potential of space technology for national development.

Playing a significant role in national development and solving the problems of the common person, Dr. Vikram Sarabhai, the idealistic leader imagined that this powerful technology could help them. The Indian Space program was born for the space activities in the public affairs which was mainly for the achieving of independently developing the capability to build the launch communications satellites for telecommunications, for T.V broadcasting, for meteorology, for remote sensing satellites and for natural resources management. The development of space technology and its application to various national tasks is the main objective of ISRO.

Indian Space Research Organization (ISRO) has successfully operationalized two major satellite systems Indian National Satellites (INSAT, for communication services) and Indian Remote Sensing (IRS, satellites for management of natural resources). Polar Satellite Launch Vehicle (PSLV) for launching the IRS type of satellites Geostationary Satellite Launch Vehicle (GSLV) for launching INSAT type of satellites.

1.2.1 Space Applications Center (SAC)

Space Applications Center is one of the most important research centers of the Indian Space Research Organization (ISRO). The major area of research in SAC Ahmedabad is focused on the design of space-borne instruments for ISRO mission & development and operationalization of application of space technology for national development. SAC is the only one center where they deal with a wide variety of projects for design and development of payload, capacity building, societal application and space sciences in this manner creating a synergy of technology, science and applications.

The research center is liable for the ground system, development, data processing, realization and qualification of earth and planetary observation, meteorological payloads and related data processing, communication and navigation. Several national level application programs in the area like, disaster monitoring/ mitigation, natural resources, and environmental studies, weather, etc. This center develops and connecting space technology application for social benefit in a wide range. This center maintain and operate Delhi and Ahmedabad work station Affected by United Nations (UN) under the center for Space Science & Technology education in Asia training programs related to Metrology and Satellite Communication is hosted by SAC, Ahmedabad.

1.2.2 Major Activities at SAC

- For communications and remote sensing satellite payload design.

- Design and develop a sensor system for communication satellite.
- Develop Communication satellite like INSAT/GSAT series.

Research and development on utilization of space infrastructure for remote sensing/meteorological application like survey and information on agricultural applications like crop, coastal zone regulation, mobile communications, telecommunications, medicine, forestry, studies in ocean and atmosphere science for weather forecasts, SATCOM applications like broadcasting, telecommunications, navigation, disaster monitoring and mitigation, natural resources, acreage and production estimation, etc.

1.2.3 Optical Payload Mechanical Group (OPMG)

Many groups are there in SAC, Ahmedabad from that most important, target oriental and efficient group is OPMG. OPMG is involved in many activities like the design and analysis of payload, development and assembly of payload, experimentation and management of mechanical systems of optical remote sensing payloads. At the present time OPMG is involved in project viz. GISAT, INSAT-3D, CARTO-2C/2D, OCEANSAT-3, HUMAN SPACE PROGRAM, GSAT-6 PMT etc. OPMG is divided in two groups: GLMD and LPMD. This dissertation has been carried out at the Geo Payload Mechanical Division (GLMD) and the Leo Payload Mechanical Division (LPMD), OPMG, MESA, SAC-ISRO, Ahmedabad.

1.2.4 Geo Payload Mechanical Division(GLMD)

This division is responsible for mechanical design and development of optical systems for GEO based satellites and development of mechanical hardware for human space programmer. This division is also responsible for the design and development of mechanical hardware of all the base band electronic packages.

1.2.5 Leo Payload Mechanical Division(LPMD)

This division is responsible for mechanical design and development of optical systems for LEO payloads, lunar and interplanetary systems.

1.3 Introduction of Telescope

The galaxies and stars are far away from us in the unit of the number of light years. So the distance is so large and our technology is not that much level high that we go there and take the information and data about them. But the stars and galaxies are omitting the electromagnetic radiation and this electromagnetic radiation can travel from all over the universe. This electromagnetic radiation, including visible light travel large distance to the earth. With the use of technology which can study this electromagnetic radiation and new things can be gained about the universe, galaxies and stars.

Telescopes are instruments used to view, observe and study the object which are far away from us, out of the earth. The Telescope is the combination of two Greek words, they are "tele"(from a far distance) and "scope"(viewer). The main principle on which the telescope work is that to collect and concentrate the electromagnetic radiation, which came from different parts of the universe then focus it. Due to focus of that radiation that image of that object can be magnified.

Depending on the wavelength or type of radiation, there are different types of telescopes available for studied

The space telescope collects the visible light from the electromagnetic radiation. There are mainly three types Optical telescopes

1. Refracting telescopes
2. Reflecting telescopes
3. Cassegrain telescopes

1.3.1 Refracting Telescopes

The refracting telescope is a close hollow tube. At the one end of the tube one glass is fitted known as object glass or object lance, and at the other end one other glass is fitted known as eyepiece lens. When the light came from the object enter into the telescope tube via objective lens. The light rays are refracted and image is framed at the point of focus. This framed image acts as an objective for eye lens. The size of this image is so small and eye lens magnified that framed the image into bright and visible image. Through the eye piece lens the image of that object cam be view or camera can be attach to record the image.

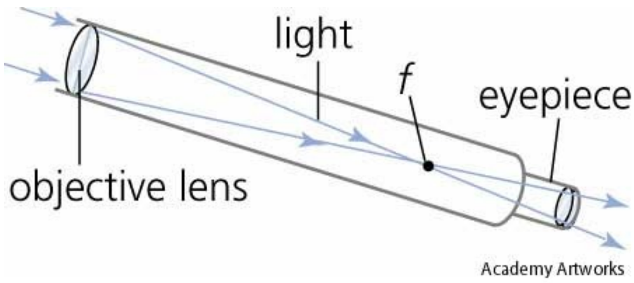


Figure 1.1: Working of Refracting telescopes[1]

1.3.2 Reflecting Telescopes

Reflecting telescope is also known as Newtonian telescope. This name is given after their inventor Sir Isaac Newton. Reflecting telescope contains one large primary concave mirror reflect the light which enter into the telescope tube. This concave mirror is covered with the reflecting coating material. The light reflected from curved primary mirror forwarded to a flat secondary mirror. The secondary mirror stands at 45 degree angle.

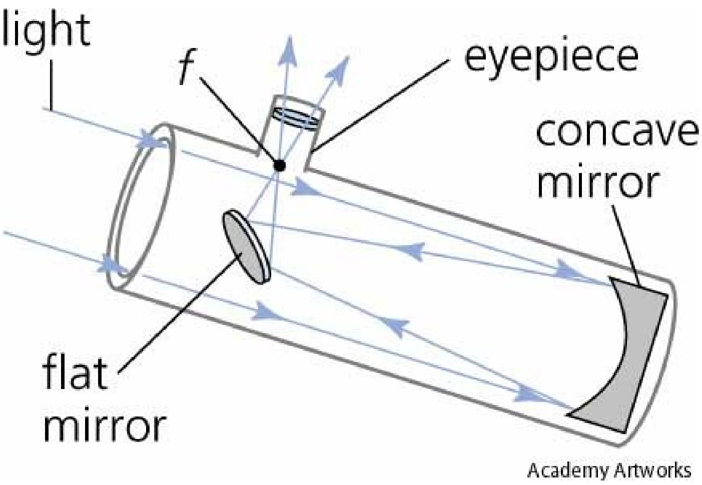


Figure 1.2: Working of Reflecting telescopes[1]

1.3.3 Cassegrain Telescopes

Cassegrain telescopes are one type of reflecting telescope. The name of this telescope Cassegrain telescope is given after their French inventor. Cassegrain telescope contains concave primary mirror which reflects and collect the light. This light forwarded to the secondary mirror. The secondary convex mirror reflects the light, this light rays pass through the center hole of the primery mirror. At that point receiver is fitted which receive the light and formed the final image. Due to combine the action of the two mirror this telescope the actual length of the telescope over the effective focal length is less. Hence the length of a telescope is more compact.

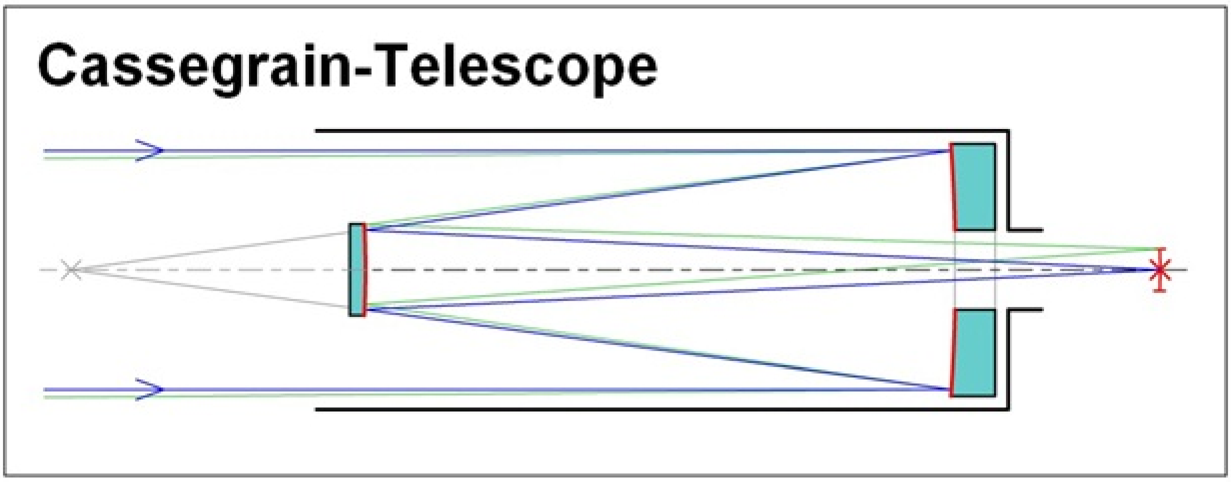


Figure 1.3: Working of Cassegrain telescopes[2]

1.4 Space Base Telescope Component and Parameter

1.4.1 Base Structure

Base structure is the main frame of the telescope on which all other parts of telescope are mounted. The main objective of the base structure is to give proper fixing and inclination of primary mirror, secondary mirror, sensor etc. The material requirement for base structure are have low thermal expansion, proper strength, light in weight, high thermal conductivity etc.

1.4.2 Primary Mirror

The optical telescope primary mirror is the most sensitive and critical component of the telescope. Primary mirror collect and focus the light at its point of focus.

Size, weight and focal length of the primary mirror are the major dimension and telescope performance characteristics is depends upon that dimension. As the diameter of the primary mirror is more it collect more light so the diameter of the primary mirror determine how much light telescope can gather. The small size finished blank mirrors are coming in some well-defined standard diameter $4\frac{1}{4}$, 6, 8, 10, and $12\frac{1}{2}$ inch. When the standard size has increased 56% to 77% more surface area is increased. Hence much more light came be collect but due to increase the diameter, weight, cost, longer thermal cool-down time, telescope size are also increasing.

1.4.3 Secondary Mirror

The light which collects by primary mirror is focused at its point of focus. To make the image from this collected light, light rays must be directed towards the light sensitive sensor. For direct this light ray towards the lighting sensitive sensor the optical secondary mirror is used. The shape and the size of the secondary mirror are different in different type of telescope.

In some telescope like Newtonian Reflectors secondary mirrors, flat and 45 degree incline. In Cassegrain- type telescope the convex shape secondary mirror used. It direct the light rays towards the back side of the telescope through the primary mirror central hole.

1.4.4 Focal Length

The focal length of an optical system is a measure of how strongly the system converges or diverges light. For an optical system in the air, it is the distance over which initially are collimated rays brought to a focus. A system with a shorter focal length has a greater optical power than one with a long focal length that is; it bends the rays more strongly, bringing them to a focus in a shorter distance. The effective focal length is simply the focal length of a lens or a group of lenses.

1.4.5 F/Number

The final imaging cone reaching the image at its center is defined by its f/number where, For example, if a lens's focal length is 15mm and its entrance pupil diameter is 5 mm, the f-number is 3 and the aperture diameter is f/3[18].

F/number $=\frac{FocalLength}{CleareAperatureDiameter}$

1.4.6 Field of View

The field of view(FOV) of an optical system is often expressed as the maximum angular size of the object as seen from the entrance pupil[18].

FOV $= \frac{Diameter of Object}{Image}$

1.5 Objectives

- Select the proper material which gives the required stiff, thermally and mechanical properties to the primary mirror.

- Select the proper shape of the primary which give excellent performance.
- Select the proper coating material which is feasible and optimum for selected material and give a performance as per requirement.

1.6 Working Methodology

- Understanding the working of the telescope.

- Study the different parts of the telescope and its important.
- Detail study of primary mirror.
- Study the different material from which primary mirror can be made.
- Select the proper material which gives better thermal and mechanical properties to the primary mirror.
- Select the shape as per requirement and which give the best performance.
- Study the coating material which is done on the primary mirror to increase the performance.
- Study different bonding techniques and choose the best one for mirror making.
- Study CFRP manufacturing process.

Literature review

1.7 Review of Published Study

Now a days telescope system are reached their limitation in terms of mass and size. So now it is required to develop a new telescope system in which the collecting area of the primary mirror will need to be increased and also meet resolution goals. Hence can say that this increasingly challenging science goal will need to meet by the next generation space telescope system. For satisfied that requirement some new technologies must be taking a consideration like active optical control, light weight mirror, sparse or segmented apertures. Instead of using a single technology by combining the technology the result which produce is better. This design can be done by detail modeling and analysis. For the making light weight mirror best way to design ribs. Making the model of rib stiffened mirror it is easy to analysis many different geometries. For the optimize the design of the rib shape control algorithm will generate. By doing different condition testing on the mirror with the use of strain gauge sensor and temp sensor are used. By doing all this experiment the best design for a monolithic mirror is the light weight rib stiff mirror with many tall, thin ribs and put most of the mass on to the mirror rib structure.[3]

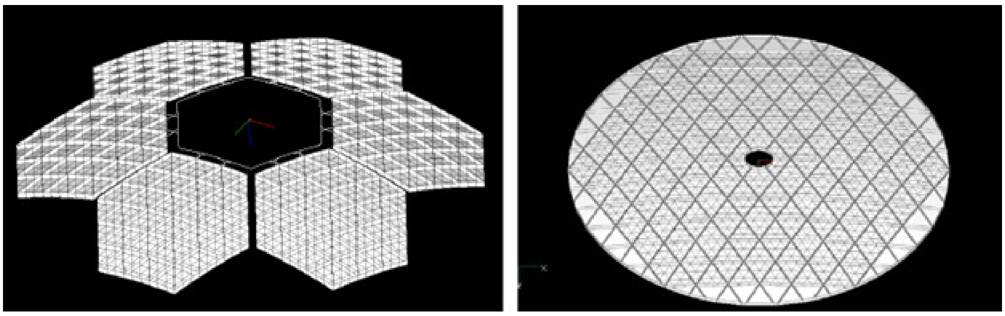


Figure 1.4: Segmented and Monolithic Mirror Models.[3]

HB-Cesic® is the 'hybrid' carbon fiber reinforced silicon carbide composite. To

use this new material in space application first of all highly precise measurements of thermal expansion has been done on the range of 310-10K. In the olden day C/SiC composites material is used for the mirror or the structure of the space base cryogenic telescope, but this material has major disadvantage is anisotropic thermal expansion. Using the combination of different type of chopped, short carbon fiber, newly HB-Cesic® composite is developed. The main aim of the development was reduced anisotropic thermal expansion. Due to hybridization the anisotropy was much reduced down from 20% to 4% as per measurement result. The main concentration of that reduced the residual anisotropy of the thermal expansion, which mainly lie in the horizontal plane.[19][20]
Till that day monolithic light weight mirror system producing from the Beryllium. But due to the advance requirement of science goal that system has reached its limitations like environmental effect, high processing costs, high lead time and lunch load/weight requirement. The AMSD program gives full awareness about this technology from starting with Hubble base technology, including light weight, cost reduction and stability. By advancement of both approaching light weight mirror limitation solution and much more reduce in the areal density. Suggested new material such as SiC, SiC form optics and hybrid/composite optics. In future there will be required of the deployment, large and more powerful launch system and space shuttle, but for manufacturing its processing cost and lead time will be most important. From this new material some small size structure and component of the telescope can be fabricated, but up to 1 meter size scaling become challenging the stability assurance. Final manufacturing method for optical instrument like film spinning, figuring, polishing, finishing, and replication are also required some advancement to maintain accuracy on that much larger object. After fabricating all the things mechanical-thermal qualifications and NDT will be required for the large mirror system.[4]

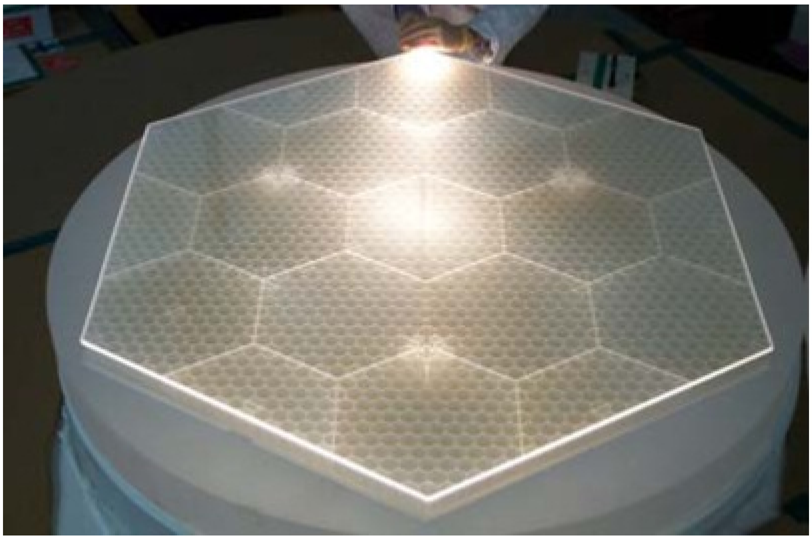


Figure 1.5: Telescope lightweighted mirror with honeycomb(Made by Kodak)[4]

Compared to the other conventional optical material due to its superior thermal and mechanical properties SiC is now becoming recognized as an attractive material for mirror making. Zygo Corporation and POCO Graphite Inc. combine work and find out the rapid fabrication of lightweight silicon carbide optics. Using this approach now capable of producing highly finished component of SiC within a short period of time. Two unique control system Zygo Corporation has large work envelope, MR polishing platform which is used for process CVD-Clad substrates deterministically. On CVD_SiC high precision material removal rate can be obtaind so even the large size mirror is possible to produce.[21]
The NSF ULTRA telescope program is continuous optical mirror development program. In this program the mirror can be developed from the CFRP. In the demonstrate the produce 16-inch mirror of f/4.0 parabolic mirror. After successful testing it is done the scale the up fabrication process for 1m and 1.4m will conduct. Then 1m f/3 parabolic primary mirror makes. The CFRP mirror can be made using optical surface transfer (OST) method or replication. For that 1m parabolic mandrel is used. This mirror is used in Newtonian telescope and yielded the quality optical image.[5]

Figure 1.6: Simpal step of Optical Surfacr Transfer Method.[5]

With the use of replica technique ultra-light weight as well as high accuracy CFRP mirror can fabricate. To get required strength the mirror made from the lay-up of CFRP skins and CFRP cores. The experiment done on the 150 mm demonstrated mirror with diameter accuracy 0.8μm but this accuracy is not more excitable for the space application. By optimizing fabrication technique the shape accuracy get 0.2 μm RMS and surface roughness 6.2 nm RMS and areal density get 0.7 kg/m2. For the space application point of view, this objects are must be tested at cryogenic temperature. In that vacuum chamber with a He-Ne laser interferometer was constructed. For the CFRP not only CTE but CME is also an important factor. CME mean co-efficient of moisture expansion. In the orbit deformation due to moisture desorption whatever the shrinkage would be occurs is several times more than the thermal distortion due to temperature variation.[6]

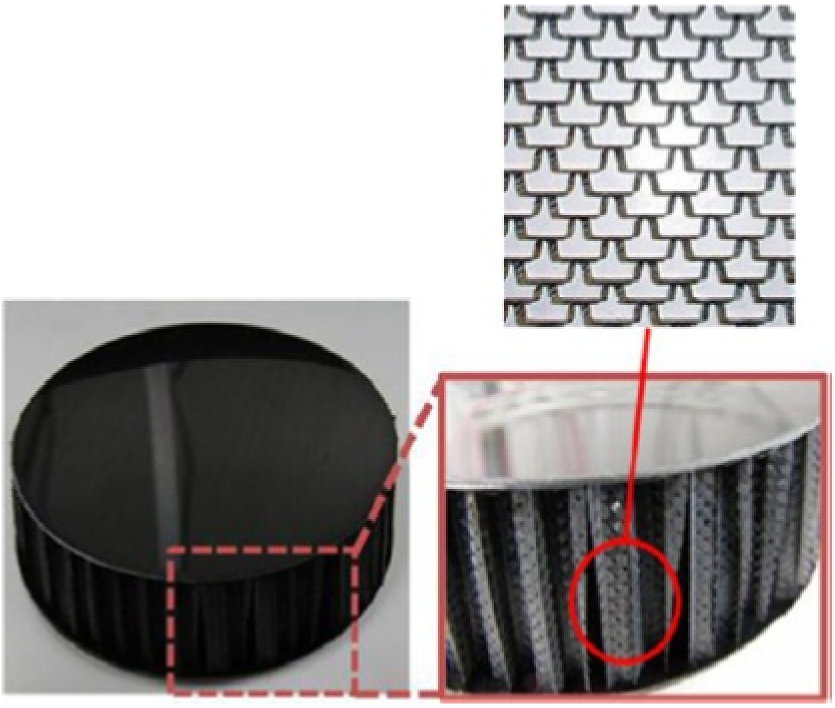


Figure 1.7: CFRP mirrors[6]

The deployable optical/ Infrared telescope requires to be light weight and rigid enough to withstand self load as well as most critical environmental condition. CFRP composites are ideal candidate material for the optical telescope application. CFRP have great thermal and mechanical properties compared to other conventional material in terms of strength, thermal expansion and stiffness. The main thing which has to take the consideration of CFRP is its anisotropic nature. CFRP single fiber have anisotropic behavior, it has unidirectional property distribution. For the space optical telescope point of view, it required isotropic nature of material. By using multi layer unidirectional carbon fiber with different orientation get the quasi-isotropic property. The CFRP OST process is effectively planned and after preparing CFRP it will be tested.[7]

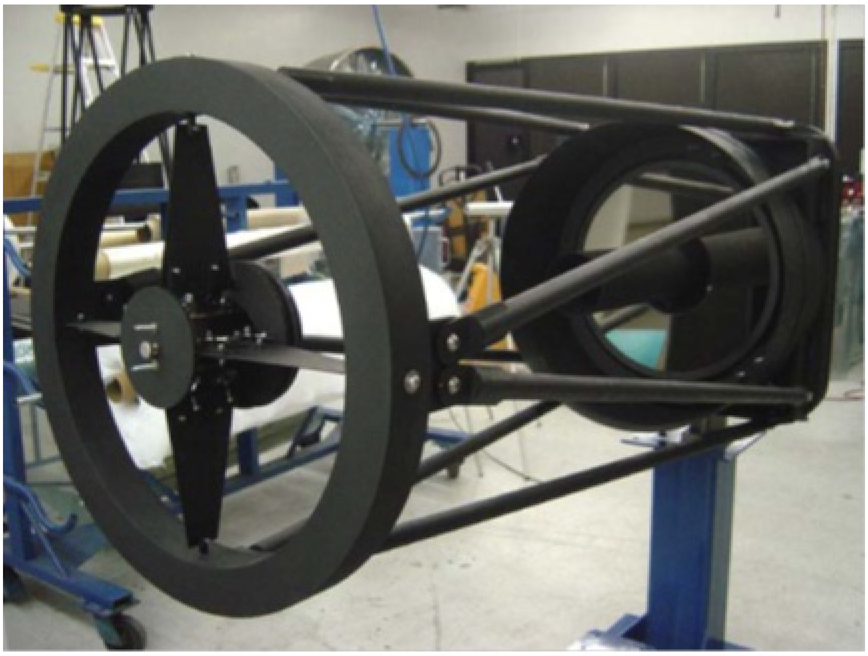


Figure 1.8: CFRP Cassegrain Telescope[7]

The most powerful solar telescope in the world is the Daniel K. Inauge Solar Telescope, known as DKIST, formerly the advance technology solar telescope, ATST. This telescope mount on the mountain Haleakala of Maui, height 3000m of sea level, built by the Association of Universities for Research in Astronomy, Zerodur is the material which has very very low thermal expansion. The primary mirror blank of diameter 4.26m is made from this glass ceramic Zerodur which is made by SCHOTT AG Advance optics. In this telescope mirror thickness is only 78mm to 80 mm which is the smallest thickness ever machined as compared to its diameter 4.26m. The casting of that mirror is also the biggest casing of zerodur which is 4m diameter. For the challenging thickness to diameter ratio of this zerodur mirror making highly precise CNC grinding machine will use. The thickness of the mirror must be 80 mm to maintain its strength and additional acid etch treatment is used to increase the surface roughness and improve the strength of the blank.[8]

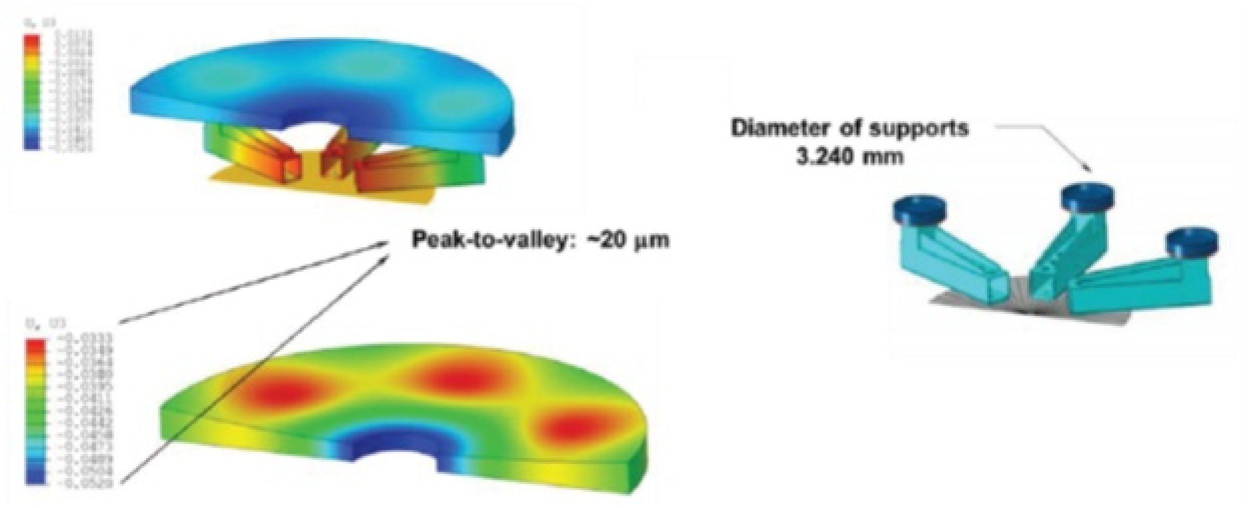


Figure 1.9: 6 support pads with diameter of 3240 mm gravity distortion of the continuous support.[8]

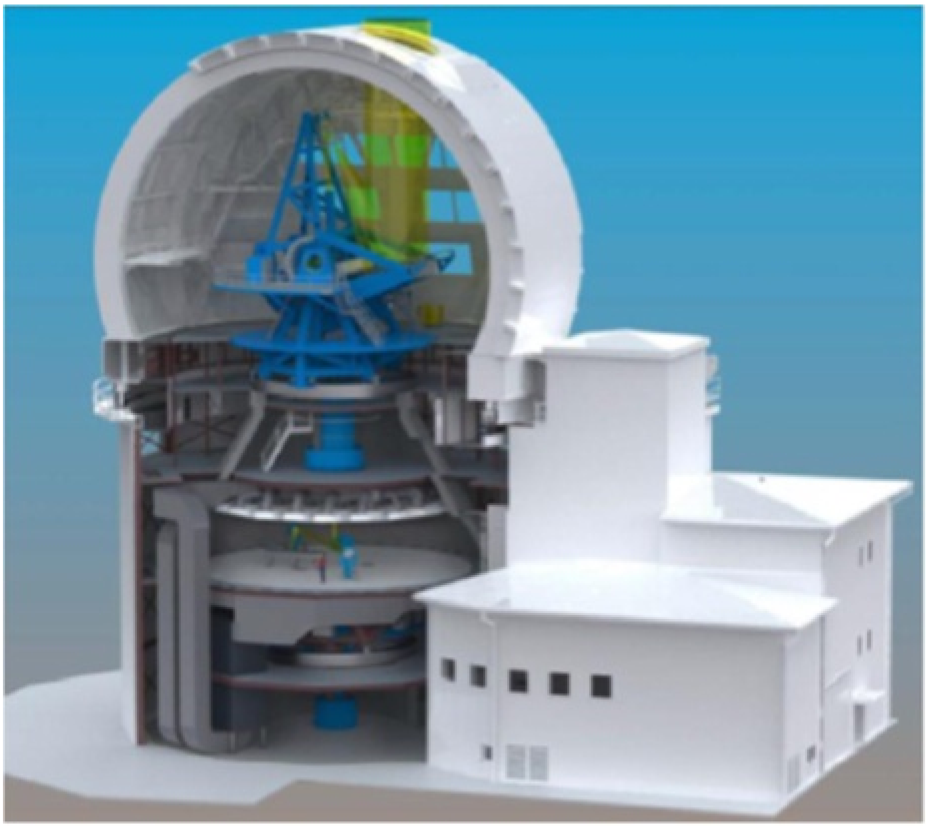


Figure 1.10: Sectional view of the DKIST[8]

Now a day the main space science goal to minimize the weight of the primary mirror. To full fill this requirement a topology optimization technique is used. This optimization technique the new explicit parameterization is introduced for simultaneously designing the distribution and the heights of the stiffeners on the mirror blank. For light weight optimization different back structure is used to produce best light weight optical primary mirror with required strength. More strength is required at the time of figuring and polishing. To reduce the material and make the mirror more lighter tree like stiffer or double directional multiple arch back are proposed. By done all experiments and testing result say that the double directional multiple arch back is the great significance then another back structure.[9]

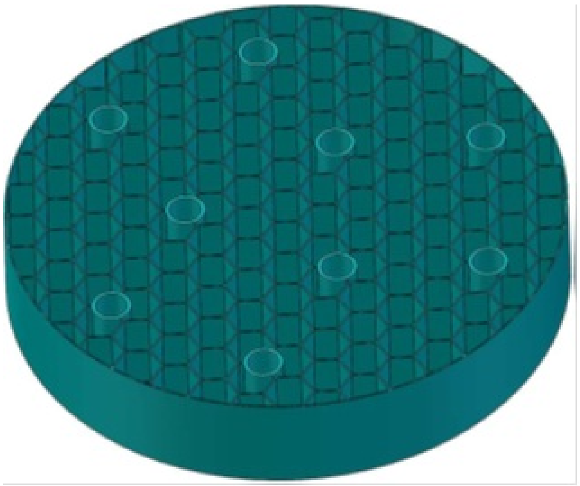


Figure 1.11: Flat-back mirror[9]

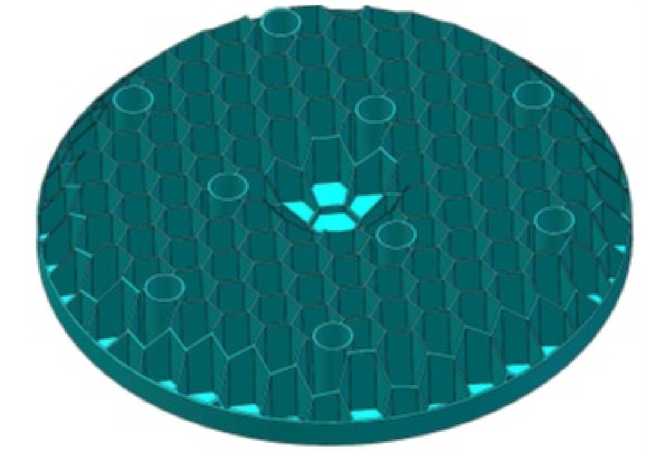


Figure 1.12: Mirror with Double-arch[9]

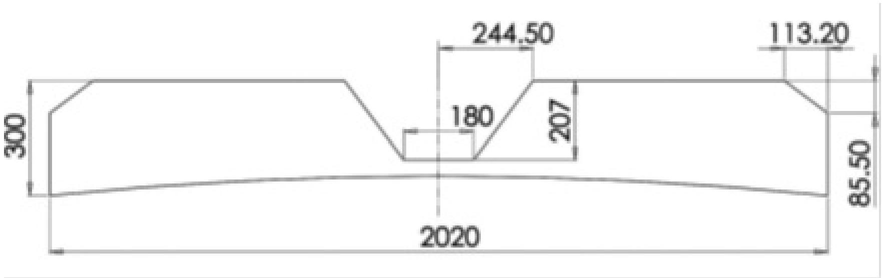


Figure 1.13: Dimension of Mirror with Double-arch[9]

Chapter 2

Selection Material, Shape and Coating for primary mirror

2.1 Selection Material for primary mirror

2.1.1 Introduction

A space telescope is the very sensitive light rays collector. Which contain many important and sensitive components. Among those components the primary mirror is the most important critical and sensitive component. Also, it is the biggest and the heaviest part of the telescope. The efficiency of the telescope directly depends on the primary mirror and primary mirror's efficiency depends upon its surface accuracy, its reflectivity and its area. Selection of the material for the primary optical mirror is the tradeoff process. So many factors to be consider for selecting the material. That factor includes weight, cost, mechanical and thermal properties, material availability, transportation, fabrication and many more. The space telescope must required lightweight material with superior required strength.

2.1.2 Properties Requirement of Primary Mirror

The special properties required for the mirror material are maintained high precision surface, shape and stable other thermal and mechanical factor. Cer-Vit, fused quartz and zerodur are the major optical ceramic material for optical mirror. SiC, composites and hybrid of SiC, CFRP, metal and alloys are new mirror material. What are the fundamental requirements of optical mirror materials?

- The co-efficient of thermal expansion of the material should be very low near to zero.
- The stress produces during fabrication and transportation to withstand that material have enough rigidity and hardness.
- For maintaining the high precision shape over the long period of time the mirror should have excellent shape stability.
- For more increase the reflectivity of the active surface of primary mirror after polishing thin metal film is coated in vacuum condition.
- Some material which is very soft and can't be polished used a layer of hard material on their active surface.

2.1.3 Material and its Properties

Material	Density (ρ)	Elastic modulus (E)	Thermal expansion (α)	Thermal conductivity (K)	Mechanical Figure of Merit (E/ρ)	Thermal Figure of Merit (K/α)
Units	g/cm^3	GPa	x 10^{-6}/K	W/m K	(LARGE)	(LARGE)
RBO SiC	2.89	391	2.4	155	135	65
CVD SiC	3.21	466	2.2	280	145	127
HP SiC	3.2	455	2	130	142	65
POCO SiC	2.93	232	2	170	91	85
Beryllium	1.85	287	11.3	190	155	17
Zerodur ®	2.53	91	-0.09	1.64	36	18
BK7 (glass)	2.53	80.7	7.1	1.12	32	0.2
SXA	2.91	117	13	125	40	10
Aluminum	2.7	68	23.6	170	25	7
Invar	8	145	1.26	10.15	18.125	8.055
CFRP	1.75	104	-0.9	24	59.4285	26.66

Table 2.1: Different material used for making the primary mirror with its properties

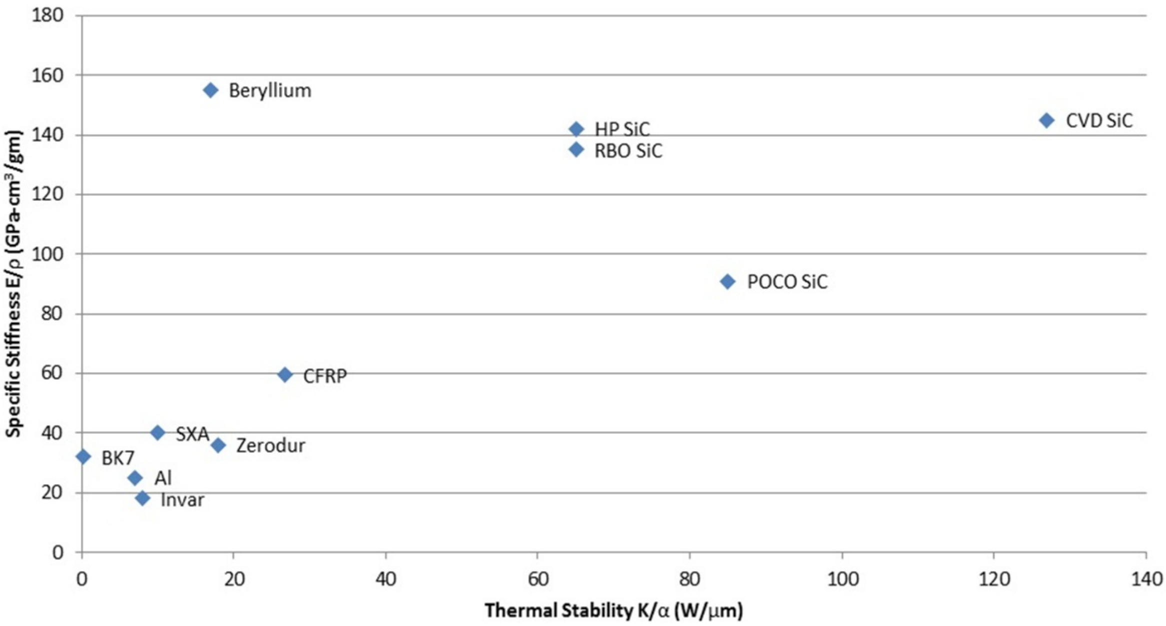


Figure 2.1: Specific Stiffness vs. Thermal Stability for Different Materials

2.1.4 Aluminum

Aluminum is the third most common element which is in the earth's crust. After oxygen and silicon, and second most widely used metal in the world after steel. Low weight, easy machine low density, excellent corrosion resistance, high strength, good electrical and thermal conductivity are the most important properties of Aluminum. The best property of Aluminum is that the light in weight almost one third density than steel, 2700 kg/m3 although its light weight does not affect the strength. Tensile strength of Aluminum alloy is between 70 to 700MPa. Extrusion range of Aluminum is 150-300 MPa. At low temperature the strength of Aluminum does not become brittle as like steel, instead of that its strength is increased. The coefficient of linear thermal expansion of the Aluminum is high, in some design this property will consider. The strength is become weak at continuously above 100 degree Celsius temperature. Milling, bending, cutting, drilling, punching, etc. this type of most common machining method can easily done on Aluminum and also the required energy for machining will be less. Due to its malleability property rolling of strips and foils, forming and other bending operation can be easily done. Electrically and thermally Aluminum is good conductor having same Aluminum has half weight compare to copper. Aluminum reacts with the atmospheric oxygen and make a thin layer of oxide. Aluminum is also used in some joining process like friction strip welding, fusion welding, bonding and tapping. Aluminum is a good reflector of both visible light and radiated heat. Aluminum is a non-magnetic material. So that it is most of the time used in X-ray device to avoid interference of magnetic field.[22]

2.1.5 Invar

In 1896 Charles Edouard Guillaume discovered the Inver in Paris. Inver is well known for its low CTE. Charles Edouard Guillaume found that when 36% of nickel and 64% of iron is mixed and make alloy it shows very less CTE, this alloy is nothing but Inver. Inver is the iron base alloy. So it's become senses that Inver is appearance and feel like steel. But keep in mind that cast iron and steel are iron base alloy. However Inver is an iron-nickel base alloy. In Inver hardly 0.01 to 0.1% of carbon consist. Highly pure Inver contain carbon percentage less than 0.01. The carbon percentage in Inver with other impurities is the major factor in its sequential stability. Inver 36 contain not only iron (Fe) and nickel (Ni) but also titanium (Ti), sulfur (S), cobalt (Co), manganese (Mn), phosphorous (P), chromium (Cr), silicon (Si), magnesium (Mg), zirconium (Zr), aluminum (Al), and carbon ©. [23]

2.1.6 BK7

Unique Properties of BK7 are High optical quality bro-crown glass, Practically free of air pockets and considerations, Very clear and colorless appearance appearance, Made of purest raw materials. N-BK7 glass is the arsenic-and lead free successor material of BK7, which has been discontinued. It is a standout among the most widely recognized specialized optical glass materials, utilized for a large number of high quality optics like optical windows, substrate and lenses in the visible range. N-BK7 is a moderately tough bro-crown glass and shows a good scratch resistance. N-BK7 glass has a low measure of considerations and is free of air pockets. Another motivation behind why NBK7 material is regularly utilized for light transmitting optics, is the high linear optical transmission of the glass in the visible range down to 350nm. In view of stable chemical properties of N-BK7 glass, no exceptional treatment is required to grind and polish the material. NBK7 raw glass is produced in strips and pieces up to around 350mm wide and around 70mm thick. It can be fabricated to any smaller size. [24, 25]

2.1.7 SiC

With strongly bound in the crystal lattice silicone and carbon atoms are composed of tetrahedral in Silicone Carbide so that SiC is very strong and hard material. Some important properties of SiC are excellent thermal shock resistance, high hardness, low density, high elastic modulus. Up to 800°C no chemical like acids or molten salts or alkalies attacked on SiC. In atmospheric air at 1200°C silicon oxide protective layer forms and it is standing on that stage up to 1600°C. SiC has superior quality of thermal shock resistance because of high strength, high thermal conductivity, in addition with low thermal expansion. At high temperature up to 1600°C due to little or no grain boundary SiC maintains its strength. Resistance to chemical up to high temperature, chemical purity and maintains strength at high temperature made this material so much favorite to use in paddle in semiconductor furnaces and wafer tray support. SiC is used as key component in varistors (voltage variable resistors) and thermistors (temperature variable resistors).[26]

2.1.8 Zerodur

SCHOTT develops the zerodur glass ceramic in 1968 due to its special properties this material is used in astronomical application for decades. The most important properties of zerodur glass ceramic is the excellent low coefficient of linear thermal expansion. Over the large temperature range zerodur exhibit very small linear expansion, which is homogeneous throughout the entire piece. With the use of high resolution push rod dilatometry CTE will be measured. After ceramisation process an individual piece of zerodur raw material taken for the measurement the samples. Zerodure has chemically better stability, so as an astronomical point of view, it is a good material. By doing a machining operation extremely smooth surface can be taken which roughness is less than 1nm. In the temperature range 0°C to 50°C the linear thermal expansion in three classes as following.

Expansion class 2: 0 +/ - 0.10 • 10-6/K
Expansion class 1: 0 +/ - 0.05 • 10-6/K
Expansion class 0: 0 +/ - 0.02 • 10-6/K

2.1.9 Beryllium

In alkaline metal family Beryllium is the lightest metal. Beryllium is the member of Group 2 (IIA) in the periodic table. Beryllium is a least dense (1.8 grams per cubic centimeter) and can use for construction and Beryllium has brittle in nature with a grayish-white surface and hard metal. Melting point and boiling point of this light metal are as following 1,287°C (2,349°F) and 2,500°C (4,500°F). Beryllium has the property of being transparent to X rays, so it is sometimes used to make the windows for X-ray machines. Beryllium has higher heat conductivity and high heat capacity. From the isotope of Beryllium Beryllium-9 is the only naturally occur. Isotopes are two or more forms of an element and they differ from each other based on their mass number, they all contain the same number of protons but differ in neutron quantity. The radioactive isotopes Beryllium is Beryllium-6 also known. This isotope had not found in commercial application. A radioactive isotope is one that gives off some form of radiation when it breaks apart and they are produced when small particles are fired at atoms and stick to atom. Beryllium oxide (BeO) exists as a white powder. This BeO power can be molded into many desired shapes. Because of good conductor of heat and a poor conduct of electricity this power is used as an electric insulator like in systems designed to hide from radar signals, lasers, microwave ovens, high-speed computers and auto ignition systems. Especially in powder form Beryllium is a very toxic metal. Inhaling of Beryllium affects the respiratory system (throat and lungs). Came continuous contact of Beryllium cause bronchitis and lung cancer without precaution.[27, 28, 29]

2.1.10 CFRP

The properties of CFRP is mainly depends upon the matrix material used in that plastic. The relationship between plastic material and matrix material have to consider. CFRP material is well known for its rigidity and great strength. Some other important properties of the CFRP are modified thermal expansion with modification in material selection, great damping, low density but high strength. The CFRP has important properties, then the common glass fiber reinforce (GFR) like conductivity of thermal and electricity, more rigidity and low density. The utilization of this material in many advance field like in the car business, parts of advance aerospace engineering, parts of formula one car, robotic arms, the hardware which subjected to a large amount of stress, some critical pump and compressor part, high strength, high rigid and less dense mechanical application part. Depending upon geometry and profile requirement different procedure is used in which semi finished or finished CFRP material with matrix material is used. There is some technique for the produce CFRP are resin transfer molding or manual overlaying, fiber winding, board squeezing, autoclave squeezing for individual and series production.[30, 31, 32]

2.2 Selection of Shape for primary mirror

There are mainly three types of shape can made for primary mirror.

1. Spherical mirror
2. Parabolic mirror
3. Hyperbolic mirror

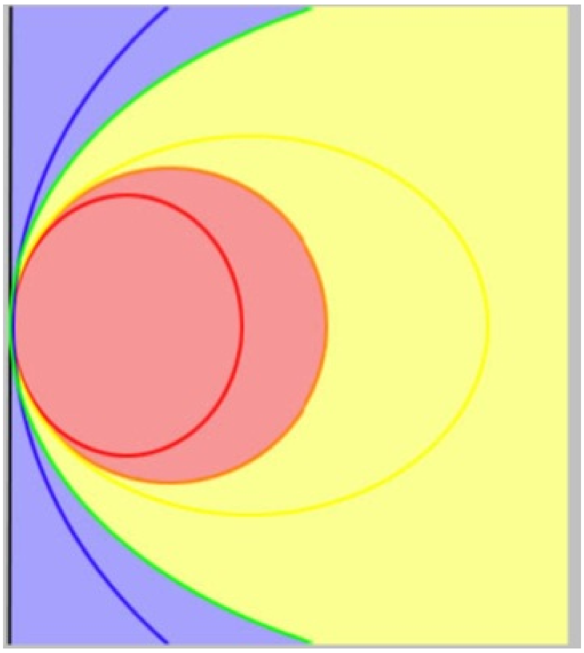


Figure 2.2: Different shapes of curved mirror[10]

A mirror can be fabricated in many different shapes. The simplest and easiest shape is spherical mirror. But the spherical mirror can't be focusing light at one point that called spherical aberration. Due to spherical aberration pure spherical shape mirror is rarely used. In lance same things will accrue. Curved mirror collects the light rays at one point, but in spherical mirror light reflecting from the edge and light reflect close to the center focuses to a slightly different point. Due to that, many possible solutions are there in spherical mirror. One of the solution of this problem is to use long focal length. The advantage of this mirror is due to this mirror the OTA will become smaller.

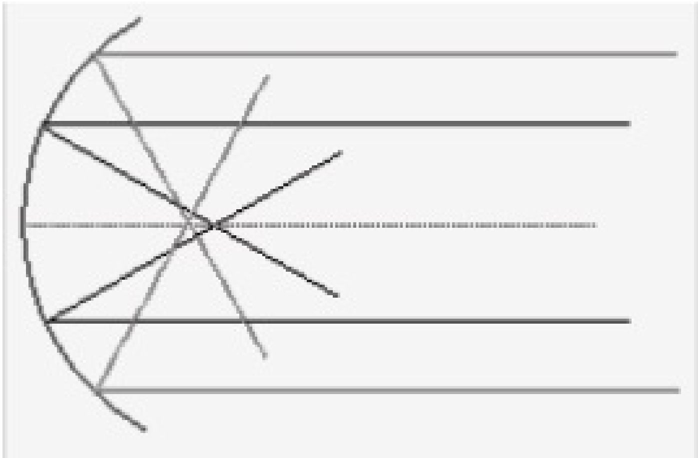


Figure 2.3: Spherical aberration occurs in spherical mirror[11]

The hyperbolic mirror the shape of a hyperbola is a solid of revolution. In that shape curved at the center and the edge diverse forever. In Hubble space telescope as a primary mirror hyperbolic mirror is used. In the Hubble space telescope mirror which is used have small error so corrective optics have to add in the entire instrument. However, Hubble was a better telescope than any other telescope at that time. The fabrication of perfect hyperbolic mirror is hard and very expensive process.
Parabolic mirrors have the ability to correct spherical aberration, but they introduce coma error.

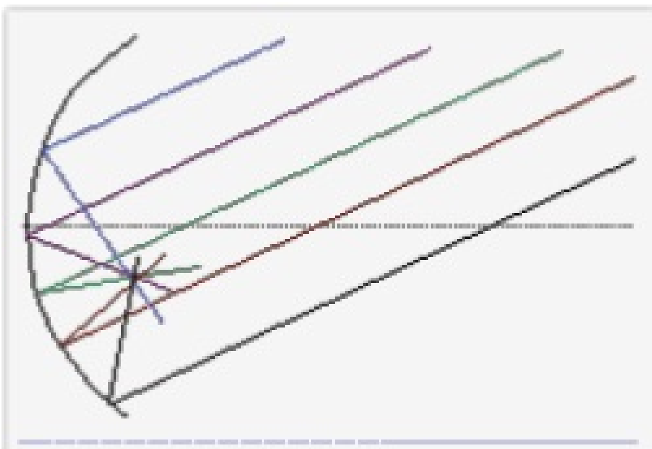


Figure 2.4: Coma occurs in parabolic mirror[11]

Parabolic mirror is the best shape which can used for primary mirror because parabolic mirror does not suffer spherical aberration and this mirror are easier and cheaper to fabricate compare to hyperbolic mirror. If the requirement is to view off the center of this mirror image is scattered. If the requirement is to view as a center it gives the best result. When the light rays are not caming parallel to the axis of parabolic mirror the coma error will occur. That focus is a little off from the center and image is not that much better.

2.3 Selection of Coating for primary mirror

2.3.1 Introduction

The primary mirror is a sensitive and important part of a space telescope system. The main function of the primary mirror is to reflect the light or redirect the light the purpose of making a telescope system more compact. For improving the reflectivity of the active mirror surface thin film coating that can be used. On the mirror active surface many different type material coatings can be done. The choice of coating material depends upon many factors like the optical wave front quality required, application, cost limitation, including the spectral range of interest. The household mirror and optical mirror are not same.

In household mirror coating is done either front or back side, but in optical mirror front surface is used as the active surface. This mean household mirror reflective surface was not come in contact with the environment while optical mirror's active surface always contact with the environment.

Flat and smooth surface are required for optical mirror. Which wavelength of light the surface deviate based on that the flatness of the mirror is specified. For reflecting few wavelengths of visible light glass should be flat enough as wave length. For some special application reflecting surface must be smooth to a quarter of the wavelength or less. In terms of scratches and dig the surface quality of the mirror can be measured. Generally scratch/dig specification is 80/50 but for some special case that specification is 20/10 in which very smooth surface can be taken but more expensive.

In some specific application mirror must have the ability to conduct heat. For that metal mirror must be used instead of glass mirror. With the use of polishing and single point diamond turning operation optical quality mirror surface can be create. Aluminum and Copper are the most commonly use metal material for this application. For more light weight and stiff mirror, although it is toxic Beryllium is used. To improve the active surface reflectivity and increase the resistance to scratch and make it more durable coating can be done.

2.3.2 Metal Material used for Coating on Primary Mirror

The easiest and generally used mirror coating is a thin layer of metal. A thin layer of aluminum and silver can be a great reflector for the visible spectrum. Silver 95%, while aluminum 90%of the light reflect for the visible spectrum. With the use of terms index of reflection n and the extinction coefficient k reflectance of metal mirror can be calculated.

$$\mathrm{R}(\%)=\frac{(n-1)*(n-1)+k*k}{(n+1)*(n+1)+k*k}$$

In visible spectrum silver is the best reflective coating. But like optical telescope mirror application for UV, silver is not a good candidate. For that aluminum is the better choice. But aluminum is weak to reflect light in the region from 0.8 to 1.0 μm. In this region, its reflectivity below 90%. This is not good for optical application because in optical system application several mirrors can be used and this type of less reflectivity harmful for optical system performance. Suppose an optical system has five mirrors and reflectance is 85% so at the end, 44% of light get which is not acceptable for space application point of view. The reflectance of several shiny metals vs. wavelength from 0.2 to 1.2 μm.

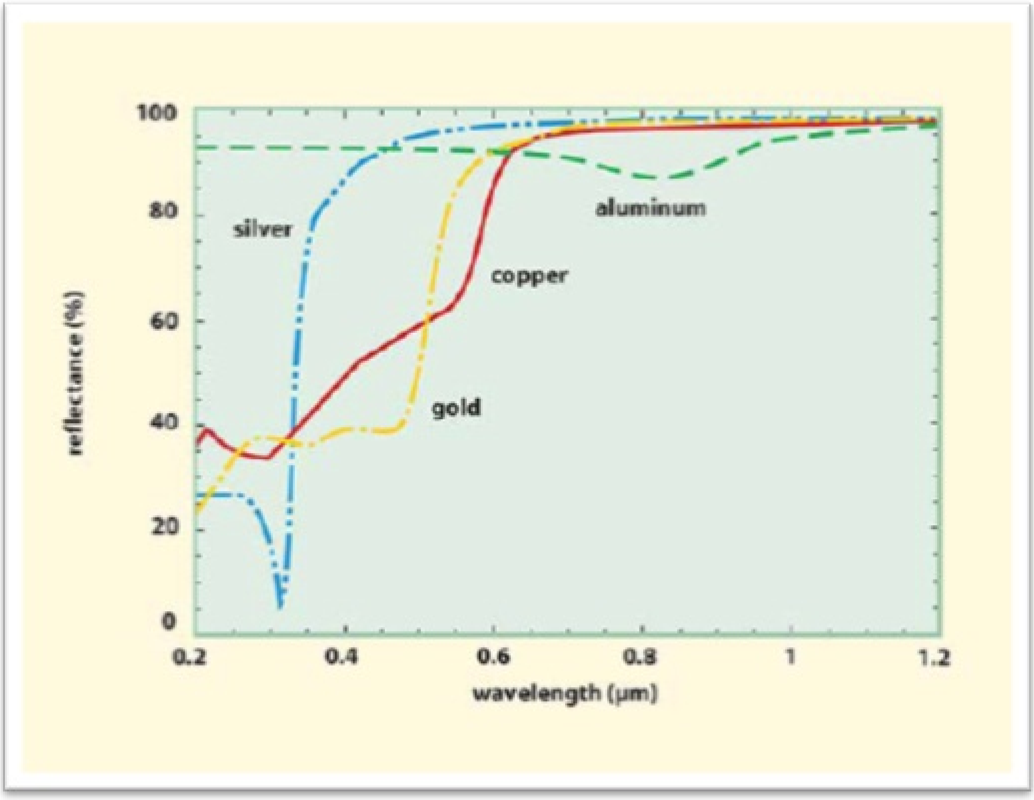


Figure 2.5: The reflectance of several shiny metals vs. wavelength from 0.2 to 1.2 μm.[12]

Gold and copper are good only in red and IR spectral regions. Based on requirement and application condition high strength and less shiny metal can be sufficient. For example, chromium is used in the rear view car mirror and rhodium is used for dental mirror.

Silver is not a stable unless it kept in a dry and contamination free environment and aluminum is not a stable mirror in every environmental condition. In Albuquerque, N.M. silver mirror degrade from the last few months and within day in Orlando, Fla. If the requirement is reflection beyond 0.6 to 0.7 μm gold is the best candidate because gold is environmentally stable. But unprotected gold and aluminum can't withstand cleaning with anything but generally camel hair brush or gentle cotton brush is used.

To overcome the degradation of mirror it will be overcoat with the dielectric material Which is harder than metal surface. In general silicon monoxide (SiO) material is used for overcoats. A mirror with a simple dielectric overcoat is known as protected metal mirror. Using of various overcoat layers environmentally stable silver mirrors can be made.

Reflectance of metal mirror can be increased by using a more complicated coating like more than one layer of dielectric layer with alternative low and high increase the reflectivity. This complicated coating is known as enhanced coating. In this coating, first layer is generally a low index and final layer is high index. Using four layers the reflectance can be enhanced several percent over a limit spectral region.

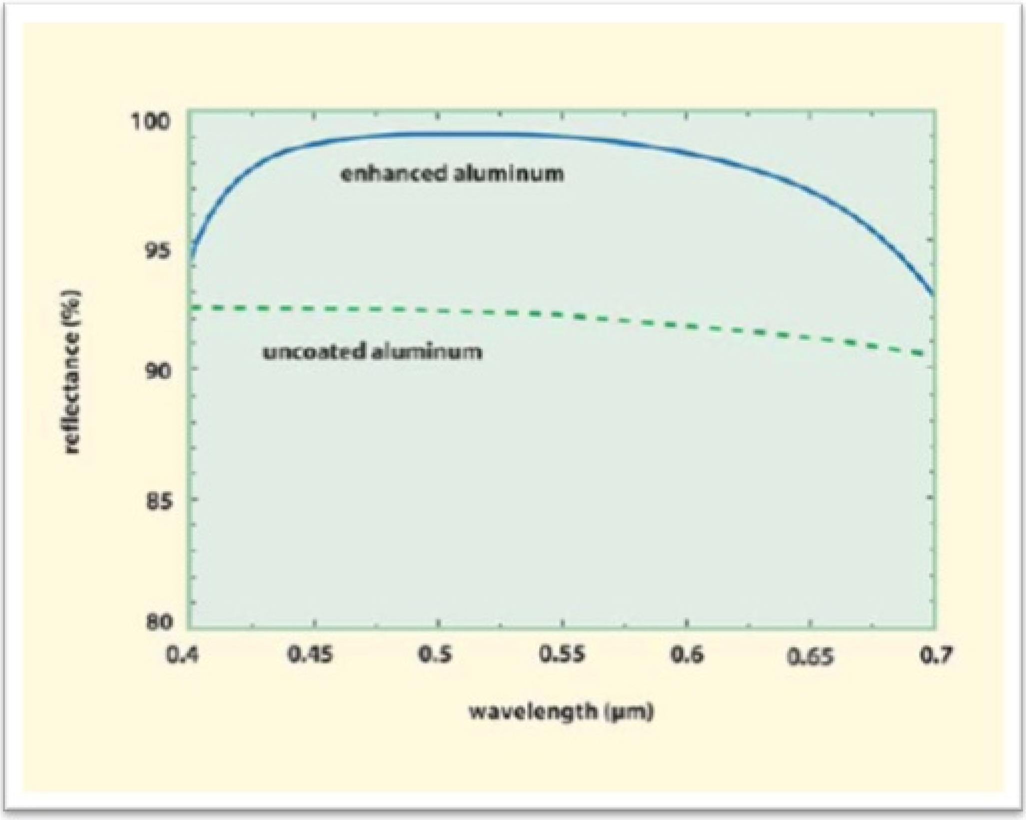


Figure 2.6: The reflectance of an enhanced aluminum mirror vs. wavelength compared with the reflectance of an uncoated aluminum surface. The enhanced mirror includes four alternating layers of silicon dioxide and titanium dioxide.[12]

The reflectance of an enhanced aluminum mirror vs. wavelength compared with the reflectance of an uncoated aluminum surface. The enhanced mirror includes four alternating layers of silicon dioxide and titanium dioxide.

Chapter 3

Glass Frit Bonding Technique

3.1 Introduction and Principle

In glass frit bonding technique the main principle is to use glass material for the bonding. In this technique glass use as an intermediate bonding layer, which have a low melting point. The glass which is available in the middle of two parts which need to joint is heated gradually. Due to the continuous heating viscosity of this glass material is decreasing. This heating process being continued until the glass material reached its wetting temperature. The wetting temperature is defined as the temperature point at which point the glass is soft enough and liquid enough to flow and wet the surface of the material to be sticking. In this process the melted glass material comes into contact with the surface of the material to be bonded at nuclear level and melted glass material is spread on surface roughness and surround the surface steps. Due to this type of bonding of liquid glass material leak proof seal bonding established in between the two surfaces so this process is also known as seal glass bonding. After the solidification of the glass between the two surfaces, as a result, form a mechanical strong completely air tight sealed bond. Because of outstanding flowing and bonding characteristics frit bonding is widely used in the microelecromechanical system (MEMS) for sealing under low pressure or vacuum condition.

3.2 Glass Material

Glass material is used between two surfaces for bonding in glass frit bonding method. This glass material has a low melting point. This glass material is very special which can reflow in the temperature range of 400 to $45\mathring{0}$ C. Deposition techniques of this type of special glass material is very critical or nearly impossible with conventional deposition techniques like spin-on deposition, chemical vapor deposition(CVD) or sputtering. In this bonding techniques for allow reflow of the glass layers thickness of glass material must be greater than or equal to 5μm. due to continuous heating glass will turn in to pastes form. This pastes form of glass has to spread on the one of surface which wants to joint, for that screen printing is the best method for spreading. The glass material which is used in this technique is a lead borate glass or a lead zinc silicate glass, which have low melting point. This glass material is available in power form, to form paste this glass material is mixed with an organic binder. For making proper mixing of this glass material and organic binder, milling tool is used. For getting excellent result of screen printing, solvent is added in paste to increase viscosity. The thermal expansion of the glass material is higher than the materials which want to stick with it, for getting final glass material for the glass frit bonding method filler particles are added in to the glass material. Because of high melting point than the glass material, these filler particles reduce the thermal expansion of that mixture. There are many venders available in the market which offered ready to use glass frit paste like Schott Glass, Ferro Corporation and DIMAT. There are large numbers of glass material available but most of them are came under the range of high temperature, for frit bonding low temperature range glass material are required and very few materials are available. Ferro FX-11-036 is the wieldy and most commonly used paste. Because of Ferro FX-11-036 is not tends to crystallization it is very popular. If the crystallization would accurse it will increase the reflow temperature due to that glass frit bonding would not be possible. This type of behavior of Ferro FX-11-036 supports the glass frit bonding process.

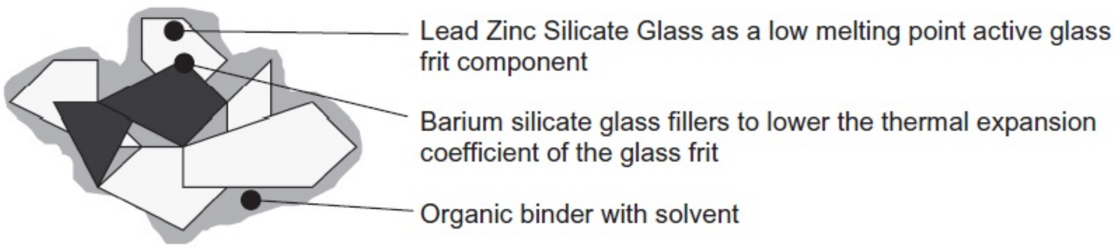


Figure 3.1: FX-11-036 paste componenents[13]

3.3 Screen Printing Process for Glass Frit Bonding

In the glass frit bonding process minimum thickness of glass layer is required for allow a reflow of the glass material. So that air tight sealing and stable structure bonding can be done. The thickness, which is required for glass frit bonding can easily bring with the use of screen printing technology. With this technique directly glass material can deposit on the work piece. In screen printing method the design layer which wants to print in the structure are created with photolithography method. Mesh structure is supported screen film, which is stretched into supporting frame. The print thickness is defined by the screen and screen wire thickness. The width of the mesh is depending on design print by paste. The mesh width is must be three times of the size of particles.

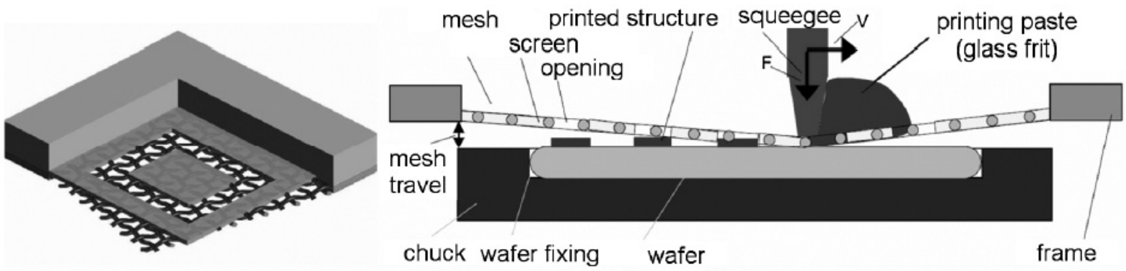


Figure 3.2: Screen Printing Process[13]

For the safe screen printing process minimum structure width must be included three meshes. For example, of the practical size is 15μm, wire thickness is 35μmwith mesh size 45μm and 10μm film thickness. In general polymer meshes are used. In this method object is placed under the mesh. The object is aligned using marks done on mesh. First of all glass paste is placed on the mesh. Then this paste is pressing, squeegee and moving over the mesh area. For perfect high precision glass frit bonding high precision screen printing is required. Screen printing is a very sensitive and sophisticated process. There are many parameters which have to consider in the screen printing process like squeegee force structure size, mesh travel, speed. Some paste properties like particle size and viscosity also considered. Placement accuracy and object definition also have to consider. In this process some tolerance has to consider, they are as follows.

- Misalignment at screen printing and misalignment by screen stretching.
- Increasing of structure at printing (underflow of paste to mesh).

- Mesh opening as designed.

In screen printing paste is wet the surface of a structure, but due to atomic attachment of paste and structure surface misalignment of paste will generate. For proper pasting of paste self-alignment solution will take. In that size of the structure is taking such that even if the mesh size is bigger, bring only required paste width.

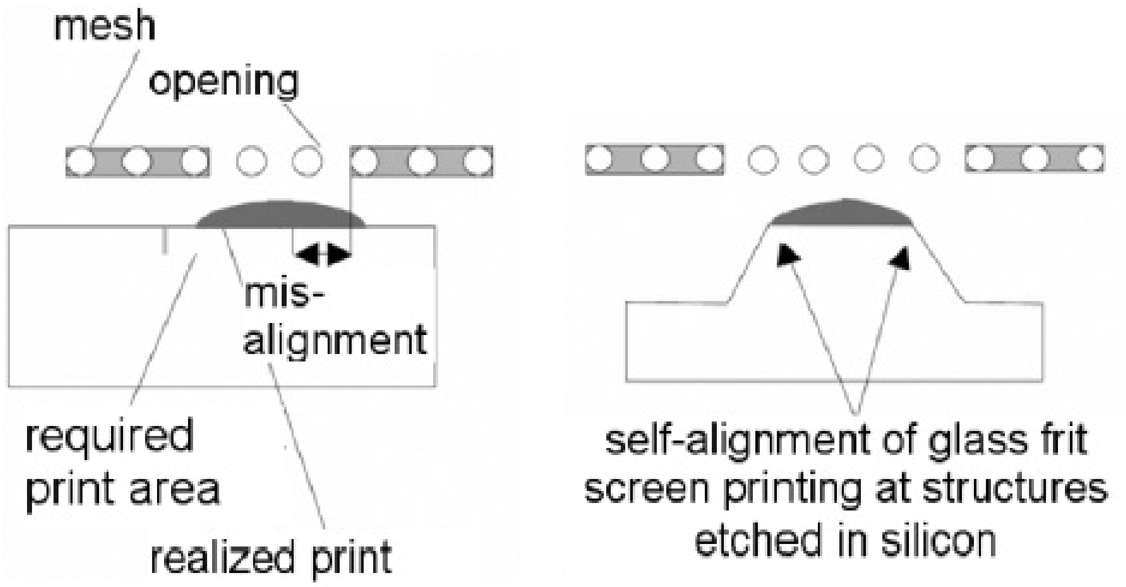


Figure 3.3: Self Align Screen Printing Principal[13]

Glass paste deposits with the use of screen printing have length, width and some thickness so it will consider as a 3D element. The main critical parameter of screen printing is thickness of glass which is basically mention by film thickness and wire thickness, although other some factor also has to consider. Due to that thickness of this bonding after the curing must be in the range if 5-15μm. So after the bonding, although the glass reflow behavior thickness control is critical due to some limitation of glass behavior. The main thing that considers for thickness is the width of the paste. For the small structure, it must have a uniform thickness of paste. Due to a small structure at the corner the paste thickness is more, but it must be kept within the limits of the glass flow.

3.4 Glass Frit Bonding Process Methodology

Glass frit bonding is the one of critical bonding techniques. Before start bonding the structures which want to joint are aligned and then after the shift that structure into special glass frit bonding chamber. This structure is heated up to the 450ºC which is near to wetting temperature of the glass material. Due to this temperature glass material and its mixture make a paste and flows. This melted glass wets the surface of the structure. Using the screen printing method with proper speed and pressure design made on structure. After that, another structure which wants to joint placed in that paste. As shown in fig the process of this bonding technique. Due to pressure of another structure and paste properties glass material wetted surface and flowed. When the whole assembly is cooled down the glass material will solidified and physically strong bond can be made.

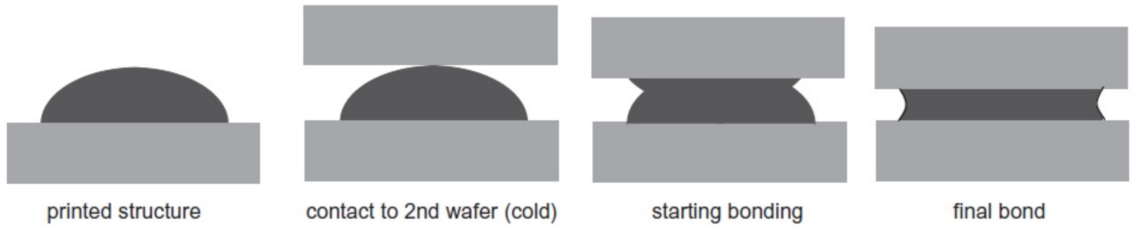


Figure 3.4: Glass Frit Bonding Process Steps[13]

Pressure and temperature are the most important and critical parameters in this bonding process. So carefully adjust this parameter for successful glass frit bonding. If these parameters are too less than either local bonding is generated or bonding will not form. If these parameters are too high, then glass material flow outside the bonding place and may be destroyed structure or glass material.
As per calculation and based on experimental data the value of the temperature and pressure will set. At the different temperature and different pressure the glass material pasting is shown in fig. Based on requirement optimized that parameter. For better glass material flow and get isometric bonding material properties both structures must be properly parallel.

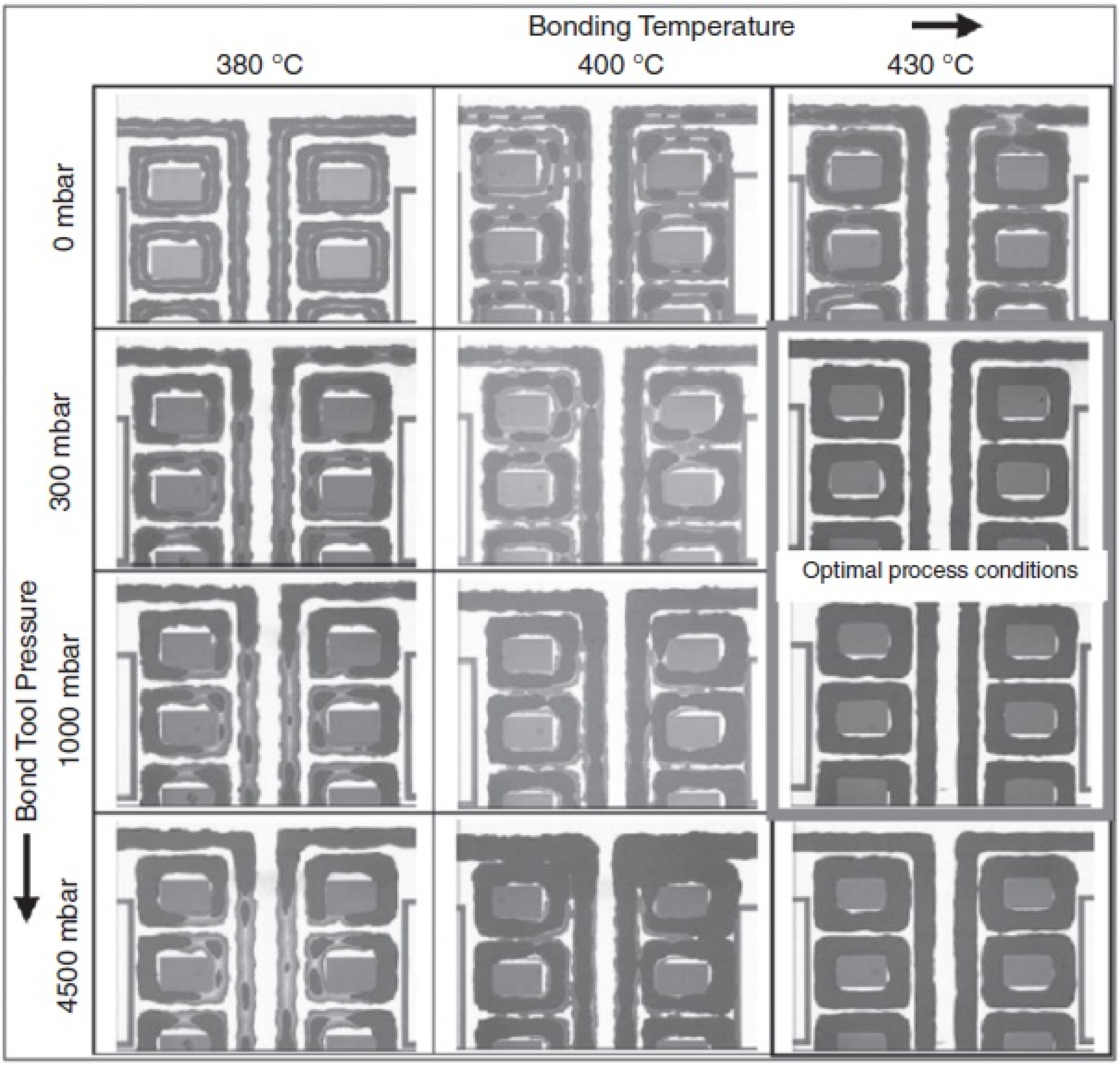


Figure 3.5: Frit Bonding Process at Different Perameter[13]

The surface on which the glass material flow must be proper rough and uniform so that glass material can flow easily flow and uniform bonding can take. Although for best bonding glass material heated at its required temperature.

In glass frit bonding one of difficult thing is to maintain alignment between structures. Due to heating of glass material, it will become a soft. So a small amount of force and disturbance can miss align that structures. To reduce the misalignment of the structure following things must be done.

- The structure should be clamped in fixture until the bonding will not take it proper strength.
- The structure and tool plate must be put, such that they are parallel.

- To reduce the misalignment due to thermal expansion tool and chuck must be made with the same material like silicon carbide or silicone.

By using above steps the best results take with proper align structure accuracy near to 5μm.

Chapter 4

CFRP Mirror

4.1 Introduction about CFRP

Due to continuous hard working ISRO gets huge success in the field of lunching different satellites and telescopes. From now ISRO think about towards telescope, which work in cryogenic temperature. Due to continuous quality and the quantity telescope satellite need to lunch, fast production of mirror for the telescope also needs to manufacture faster. One of best method for manufacturing large light weighted with the use of mirror replication process. In this technique, carbon fiber reinforced polymer (CFRP) is used to make mirrors.

In mirror replication process CFRP prepreg is laying up on the mandrel which has an optical level surface roughness. After that, this assembly will process in autoclaving for curing purpose. Due to a vacuum created in vacuum bag and pressure is also given from surrounding of autoclaving CFRP material get the optical quality of surface roughness same as a mandrel.

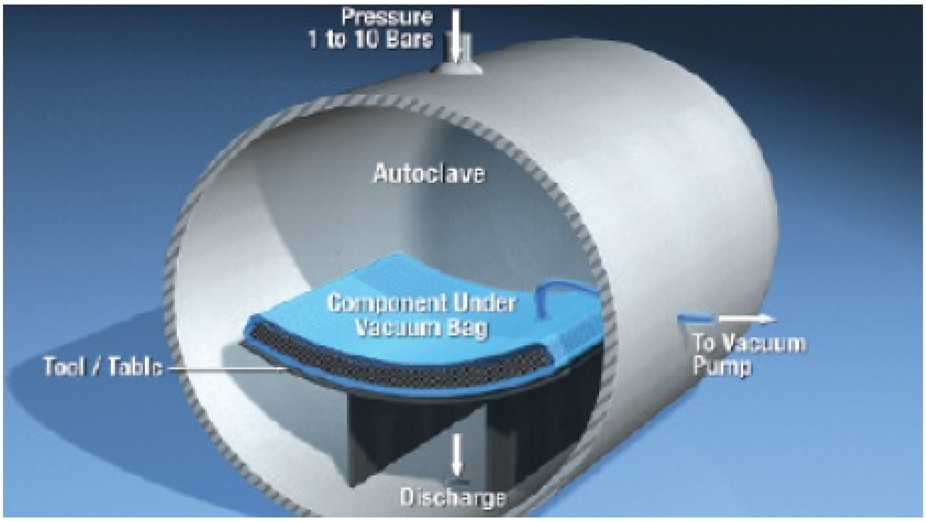


Figure 4.1: Autoclave machine[14]

In general CFRP is not a material which is used to make a space telescope mirror or other space application. Due to its low coefficient thermal expansion and low density all over the world space application and research centers are attracted toward this material. CFRP material available in high range of modulus, 200 to 600 GPa. CFRP material available in high range of strength, 2.7 to 6.3 GPa. CFRP material has high thermal conductivity. Mirror with properties of low thermal expansion and high thermal conductivity is the main necessity. So CFRP is the one of the best candidate for this type of space application.

4.2 CFRP mirror making process

CFRP mirror is making with the use of mirror replication process as shown in fig.

Figure 4.2: CFRP Mirror making process[15]

First of all mandrel is made with an optical surface finish. The prepreg which have high modulus, low coefficient of thermal expansion and low coefficient of moisture expansion is used for making mirrors. A release agent is used to easily remove of CFRP mirror after crying process complete. One by one layer of prepreg is laying on the mandrel. The prepreg CFRP which is used is unidirectional property.

This layer is laying up such a way that it makes quasi-isotropic property of that mirror. After finishing the laying up prepreg on mandrel peel ply, bleeder fiber and breather fiber are laied one after another.

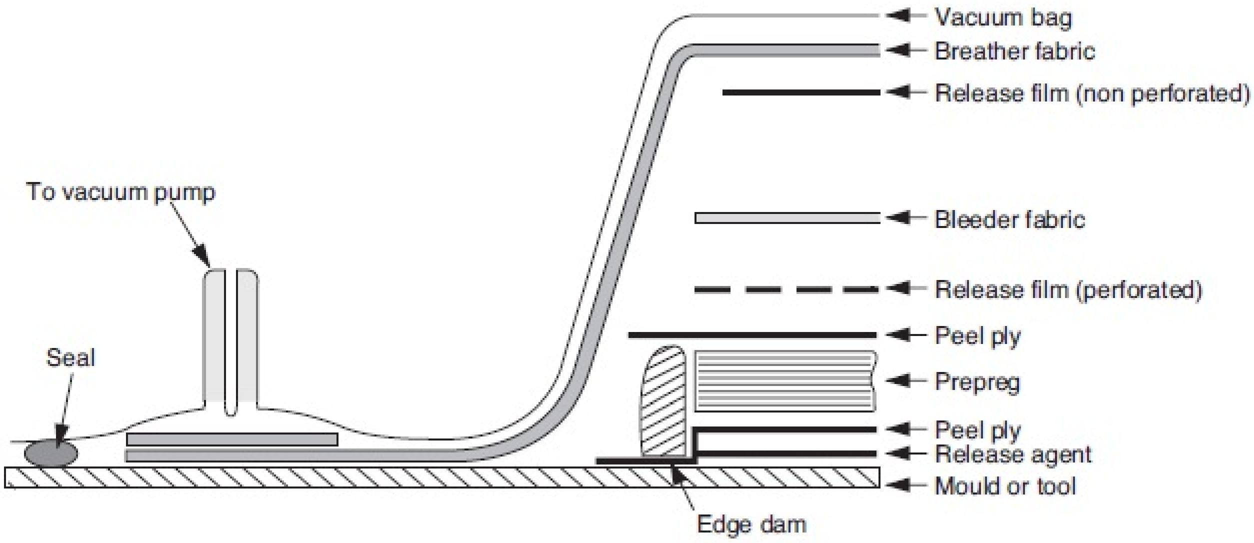


Figure 4.3: Full assembaly lay-up of mirror replication method[14]

This assembly is put in vacuum bag and then it will connect with vacuum pump. As per matrix used in prepreg required curing cycle is fitted in autoclave machine.

After successfully completion of curing cycle that assembly will take out from the autoclave machine. Slowly vacuum bag, breather fiber, bleeder fiber and peel ply will remove from that assembly. Now only CFRP and the mandrel is remaining in that assembly. Carefully remove CFRP mirror from the mandrel. Due to release agent it is not too hard to remove from the mandrel. After that CFRP mirror sends for machining, coating and testing and that mandrel are again reusing for making CFRP mirror after testing.

There is the main problem with CFRP mirror is the structural stability. CTE of the CFRP material is low so it is not that much affect structure. CME is the most affected parameter of structural stability. Some time deformation due to CME is more than CTE. So at the time of making and selecting a prepreg must select only that matrix which CME is low.

After completion of curing cycle, although high surface finish, taken but it has some high frequency surface error. As shown in fig the cross section of the CFRP mirror top surface. Surface roughness is the most important aspect of the mirror and in CFRP material that type is surface roughness is taking with proper fiber

print through.
There are many parameters which affect the fiber print, but some are more dominate. They are

1. Shrinkage of matrix during curing process.

2. Different CTE of fiber and matrix, so that expansion and shrinkage with change in temperature.

3. Due to evacuating resin (resin bleeding) matrix contain in prepreg will reduce.

As per the previous research the maximum surface roughness which gets in CFRP mirror was 20 Angstroms. There is no such a perfect data available which tell that how to maintain the affecting factors like CTE mismatch, matrix shrinkage or other factors like temperature affect, autoclave pressure and fiber diameter. By doing different experiments with different parameter the relationship can develop between different parameter. With these experiments also different overall surface roughness of mirror can get.

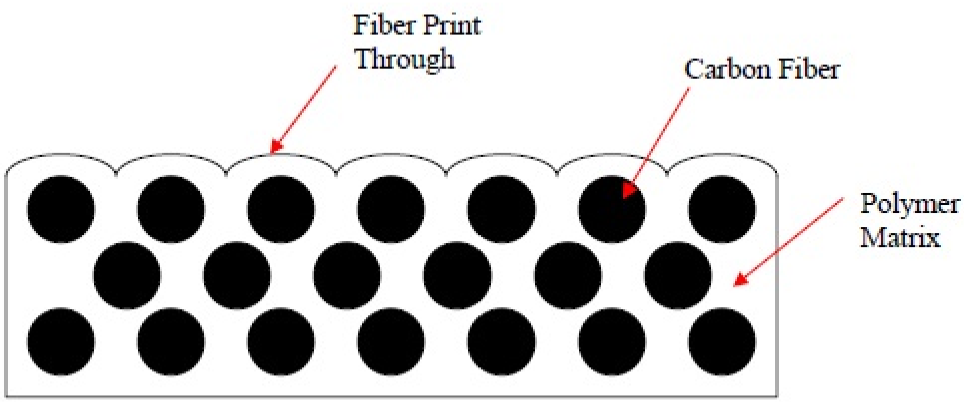


Figure 4.4: CFRP lay-up cross section[16]

In the process of mirror replicate technique the master surface of mandrel must be placed face up. In the process due to temperature and pressure resin flow and it changes the surface roughness. To prevent it bleeder is used which is not allow resin to flow in the cure cycle.
CFRP is a material which has different property in different directions based on direction of the fiber. But for light weight mirror manufacturing isotropic material property is required. But CFRP single layer is an anisotropic property, although multiple layer of CFRP lay-up such a way those full materials act as isotropic

material which is known as Quasi-isotropic. There are many fiber arrangements with that quasi-isotropic property can take like [0, (+-60)2, 0]s, [0, +-45, 90]s.

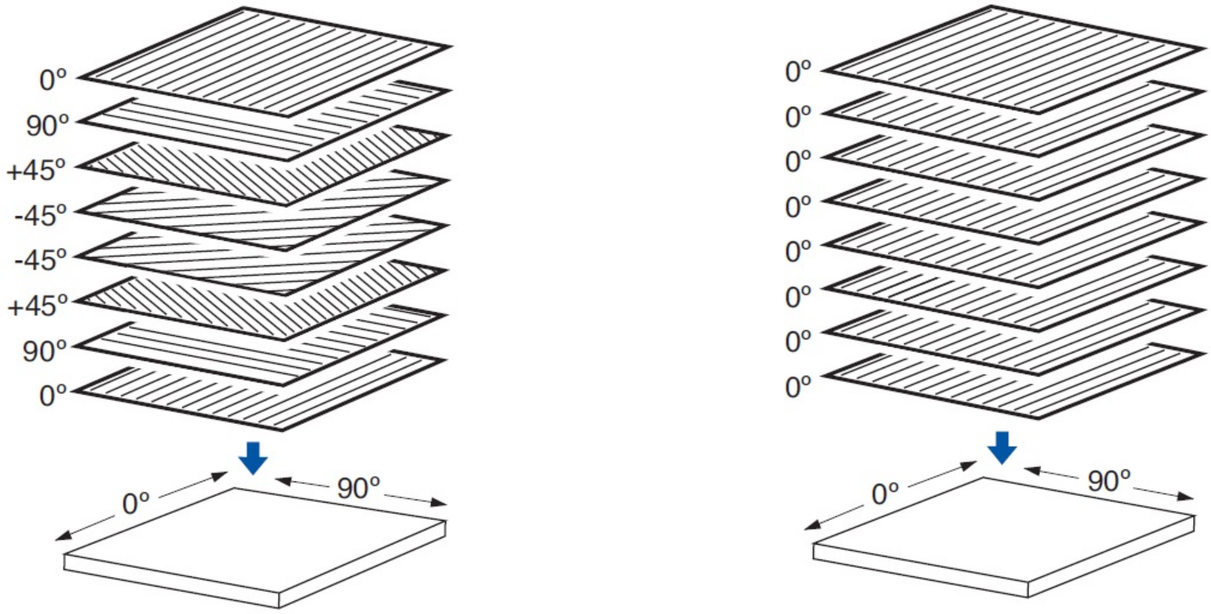


Figure 4.5: Quasi-isotropic lay-up and Unidirectional lay-up[14]

For increasing the surface roughness of the fiber print some other things will do. One of the most common and easiest technique is used to add a pure resin rich layer on the reflected surface of the mirror. As shown in fig. the additional resin layer will improve the surface roughness after completing autoclaving. This additional layer of resin can also be polished to more improve the reflected surface. The different techniques are ultraviolet light cure, high temperature cure and high temperature cure resin etc.

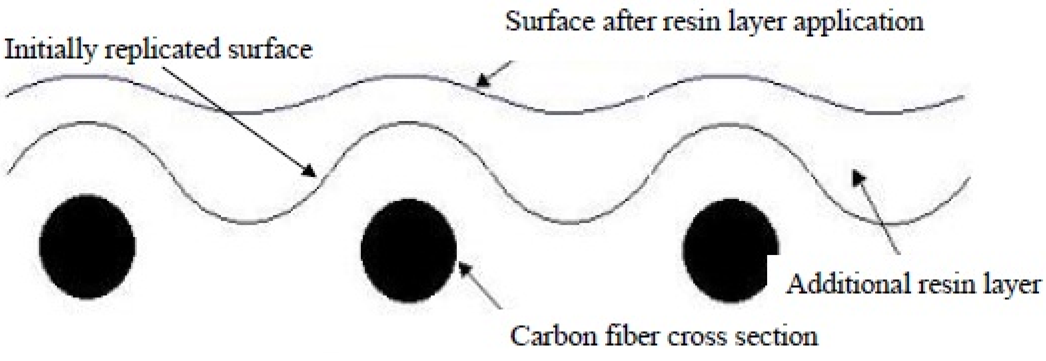


Figure 4.6: Adding extra layer of resin layer[16]

For more improve the surface roughness coating is done on the reflected surface. There are mainly two different types of Physical Vapor Deposition method use for coating CFRP mirror, Evaporation and DC Planar Magnetron Sputtering. In this both the techniques the material which want to deposit will vaporize in vacuum chamber and it will uniformly deposited on the activated mirror surface. Most of the time Aluminum use as the coating material. The coating thickness must be in the range of 1000 to 3000 angstrom.

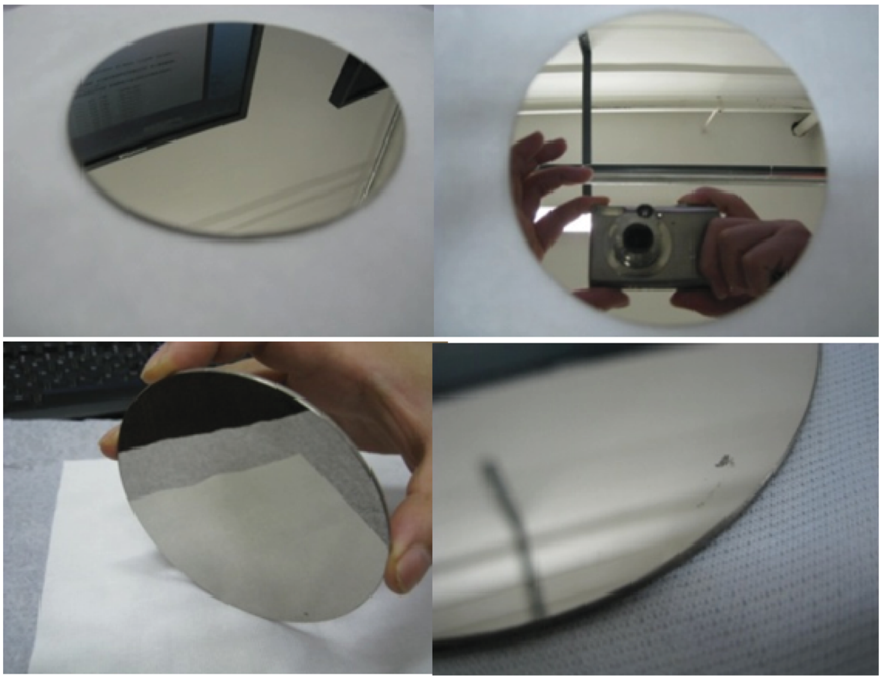


Figure 4.7: Aluminum Coated CFRP mirror[17]

Chapter 5

Hydroxide Bonding

5.1 Introduction

For making high precision devices and instrument with bonding techniques, choosing bonding material is very critical. For a selection of bonding technique the bonding method is reliance on its application, the mechanical strength, the chemical properties, in terms of the precision, the thermal properties and the process simplicity of the bonding. The much known bonding techniques are frit bonding, epoxy bonding and optical contacting.

Optical contacting is the method in which no bonding material used at room temperature. This type of bonding is established only on that material which has a high surface finish. Due to high surface finish strength bond can generate. This bonding can't withstand thermal shock. After first time bonding if it is failed than surface will destroy so re-bonding can't be done. The bonding strength of this type of bonding method is less compared to other techniques.[33]

Epoxy bonding is a room temperature bonding technique. In this process bonding material is placed between two layers at room temperature. Due to change of temperature and chemical environment condition strength and thickness of bonding will change. This type of behavior is not withstood on high precision components.

Glass frit bonding is a high temperature bonding technique. In this process low melting glass material is used as a bonding material. In this technique due to high temperature operation, alignment of objects and other problem generated. Although the bonding strength with this method is high, thermal stress will produce in the component. This technique is high costly.

For optical space application required, such technique which is done at room temperature, has less thickness, high strength, less sensitive with temperature, pressure and other environmental aspects. Hydroxide bonding technique is a technique which full fill this entire requirement.

5.2 Principle

In hydroxide bonding, bonding between two surfaces will be achieved if the material containing silica or silicate like network can be created between two surfaces. Example of materials is ULE glass, silica, fused silica, Zerodur etc. For achieving bonding between two silica based material alkaline bonding solution is used. The alkaline solution which are mainly used are NaOH (Sodium Hydroxide), KOH (Potassium Hydroxide), Na2SiO3 (Sodium Silicate) which are dissolved in water. In hydroxide bonding there are mainly three steps for successful development of the bond.[34]

Step1:-

In the 1st step dissolved hydroxide chemical is placed on the material. OH- ions which react present in the hydroxide chemical react with the silica present on the material surface.

$SiO_2 + OH^- + 2H_2O \rightarrow Si(OH)_5^-$

Step2:-

Reduction of OH- ions and due to the hydration pH of the solution was decreased. If the pH is decreased (<11), the silicate ions which are formed, are not stable and dissociate.

$Si(OH)_5^- \rightarrow Si(OH)_4 + OH^-$

After that siloxane chain and water formed.

$2Si(OH)_4 \rightarrow (HO)_3SiOSi(OH)_3 + H_2O$

This siloxane chain is the main bond which makes this joint rigid and gives strength.

Step3:-

The last step of hydroxide bonding is dehydration. At the end of 2nd step the water, which is produced is evaporated slowly. During the time of evaporation, the strength of the bond increased and the thickness decreased.

Hydroxide bonding will also bond which material surface has an oxide layer like silicon carbide (SiC), Aluminium, PZT or oxide material (sapphire).

5.3 Methodology of bonding

For increasing the success rate of the bonding process hydroxide bonding process is done in a clean room. All the component, including the material has to be cleaned first and then transported into a clean room. Optically for cleaning purpose methods which are used like CO2-snow cleaning, RCA cleaning, deionized air cleaning, spins cleaning with various cleaning agents and/or solvent, ultrasonic cleaning, solvent rinsing, solvent touch-off etc.

The surface roughness is one of the important criteria for hydroxide bonding. The surfaces of the pieces are well polished and figured. Approximately the peak and valley of that piece must be less than $\lambda/4$ where λ=633nm. (The results of measuring surface roughness are attached in appendix) First of all deionized hydroxide chemical with water at the proper ratio. This solution is now spread on one of the clean surfaces of the workpiece with the help of a dropper. Now the other workpiece is placed on the piece on which solution is sprayed, after the wetting both the surface of the pieces. Now put the piece in such a way that the lower piece is holding the upper one with the use of gravity. After that, as per requirement the alignment can be done. For that setting time is nearly 30 minutes, which is more than enough for any space optical instrument to align.[35] For optimal use different parameter in different form and as per results get the best strength of the bond. The different parameters are ratio of hydroxide chemical and water, hydroxide chemical which is used, RMS value object, curing process time, curing temp etc.

Figure 5.1: Zerodur pieces bonded with sodiyam silicate

After properly aligned the piece it will put at the room temperature at least 24hr for complete the chemical process and reached its normal strength. Slowly when the water is evaporated from the bond, thickness of the bond is decreased and the strength of the bond is increased. After 48hr of bond for conforming the fully evaporating of water, it will put in oven. The bonded piece is put in the oven for 24hr at the temperature of 350K. After completion of the oven cycle 24hr at room temperature curing is done in a clean room and then bond finally got its proper strength. After taking out form oven it is required to object must be cured at room temperature at least 1 week. If the pieces fully cured at room temp, maximum bond strength will reach within 8 weeks.

5.4 Properties of Hydroxide Bond

The bond thickness of hydroxide bonding is anywhere between 10nm to 10μm. For measuring such a small thickness special measuring instrument required like scanning electron microscope and atomic force miscopy. In Gravity Prob B the bond thickness, which they get was near to 200nm.

The strength of the bond is different for different material, different for different solutions, its concentration all other parameters affect. For zerodur maximum bond strength can get when the sodium silicate solution is used with the concentration of 1:4 with water. The strength which get as per literature is near to 6-8 MPa.

5.5 Testing of Bonding Strength

For measurement of strength of the hydroxide bond with lap shear techniques on UTM. For high accuracy purpose these pieces are tested in ATIRA, Ahmedabad. Zerodur pieces are cannot clap in a vise or chuck because the holding force of vise or chuck will destroy the piece of zerodur. To overcome this problem special ‘T’ clamps manufacture and with the use of glue Epoxy EC2216 this ‘T’ clam is stick on zerodur piece.

Figure 5.2: 'T' Clamp

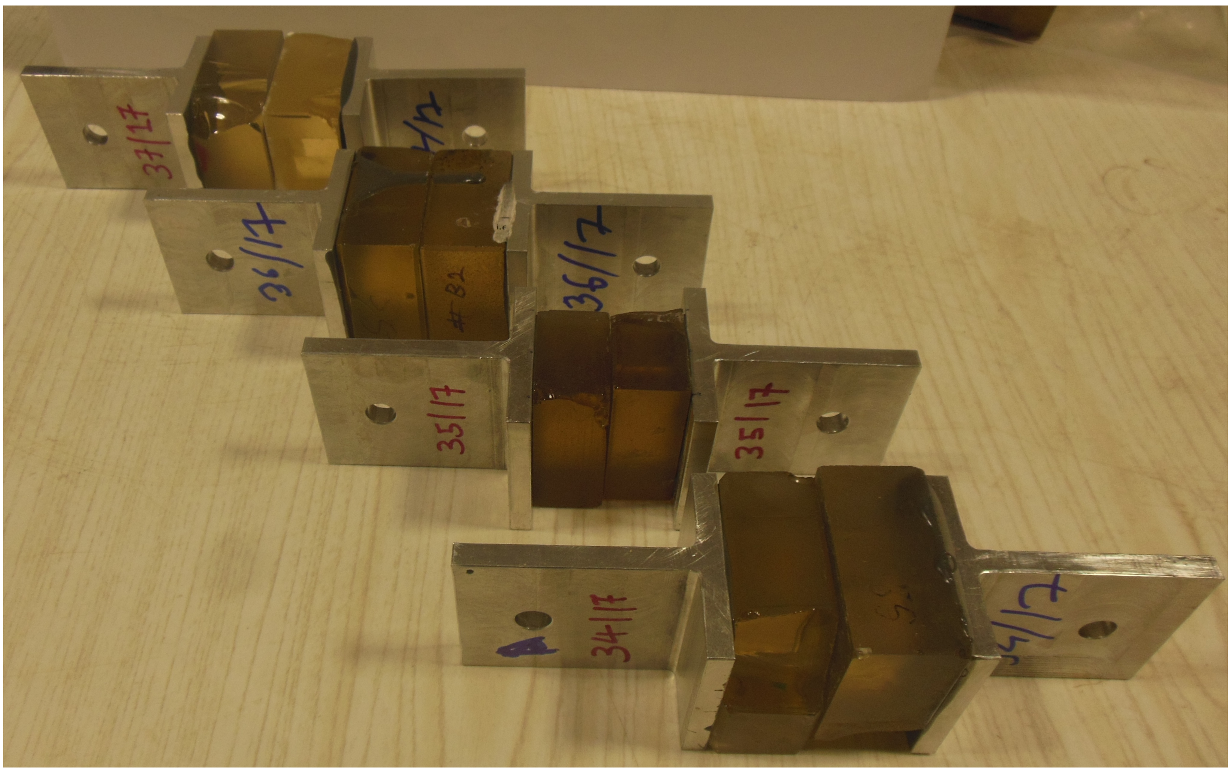


Figure 5.3: Testing Compinenet

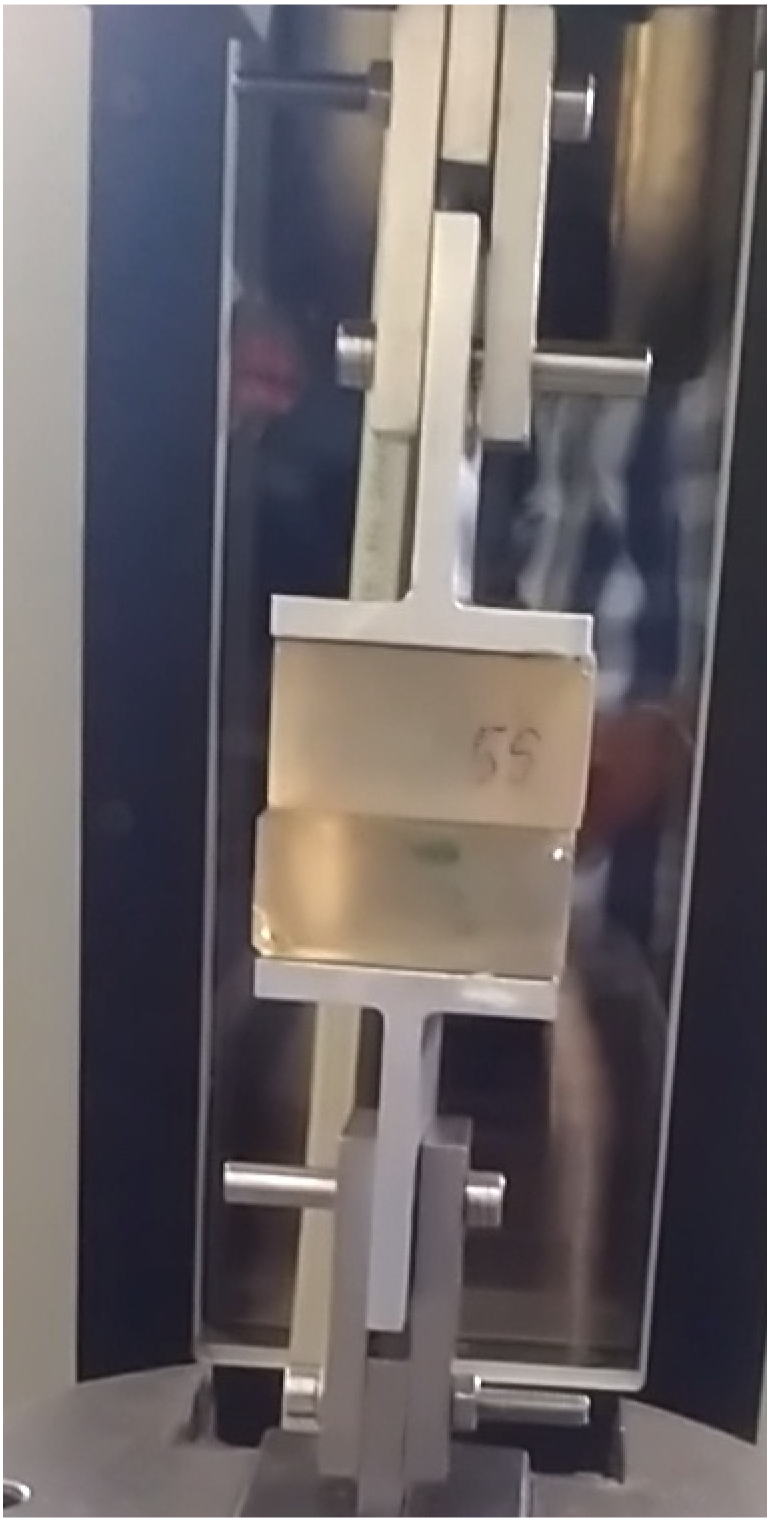


Figure 5.4: Testing on UTM

After completion complete the curing time of EC2216 the component of zerodur is ready for testing. The testing result which given by ATIRA, the strength of the bond is near to 2MPa.

Chapter 6

Concusion & Future Scope

Concusion

As the sensitivity and requirement quality of space based mission are increasing day by day. So, material and bonding technique selection is very critical of an optical component. In this type component strength as well as dimensional stability both are needed. And when the component is made with bonding techniques, these two are more sensitive parameter. Inver, SiC, Zerodur and CFRP are commonly used material for the mirror. Hydroxide bonding techniques are the effective as well as simplest technique for making a primary mirror with bonding. Because of its less thickness and stable room temperature process, the Hydroxide Bonding is dimensionally stable. Based on testing the strength of Hydroxide bonding is admirable for making optical component like primary mirror.

Due to High strength and low CTE CFRP material is a good candidate for making optical primary mirrors. For making the light weight and high accuracy, stable CFRP mirror can be manufactured with replica technique. Different orientation of CFRP lay-up gave different deflection and generated different stress at the time of curing. Based on experiment and simulated calculation optimum results get at which very less deflection and stress was generate. Surface roughness of the CFRP mirror can improve by adding an additional resin layer or using coating techniques. After the study and doing all experiment best quality CFRP optical mirror can be manufactured.

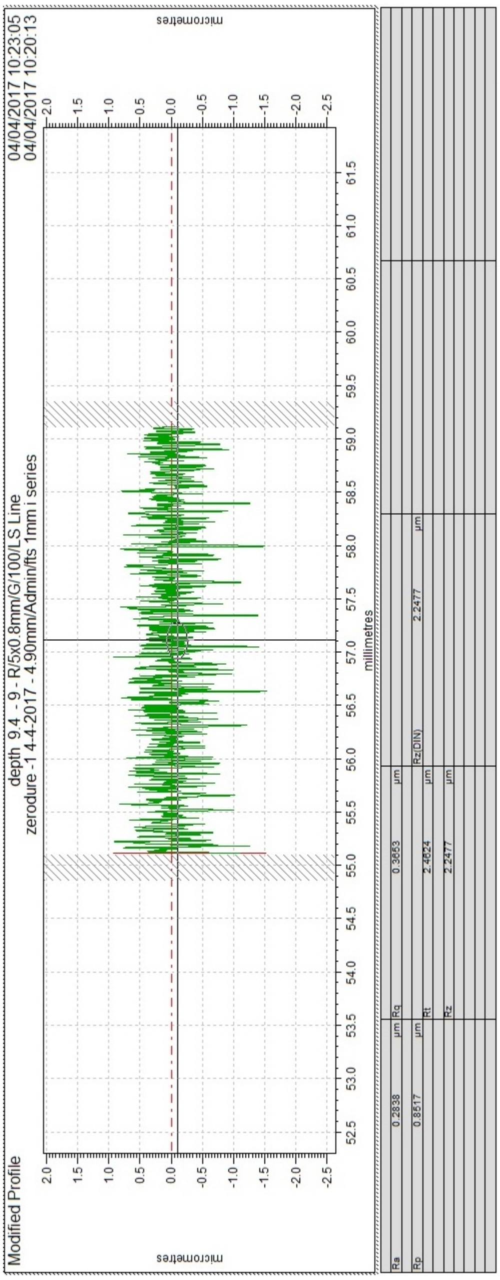
Future Scope

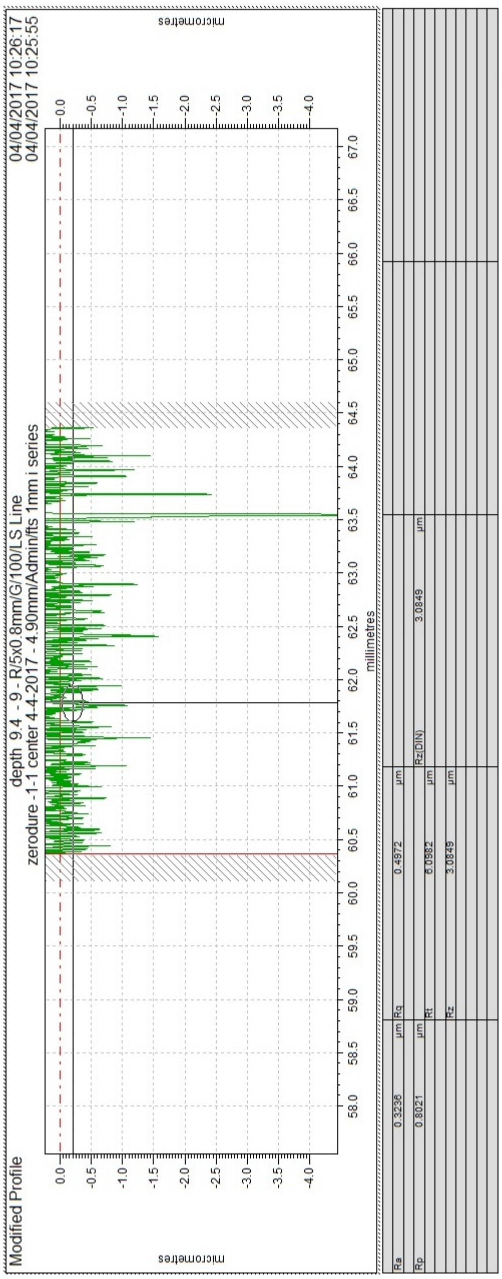
Present work on the telescope primary mirror is consists of following future Scope.

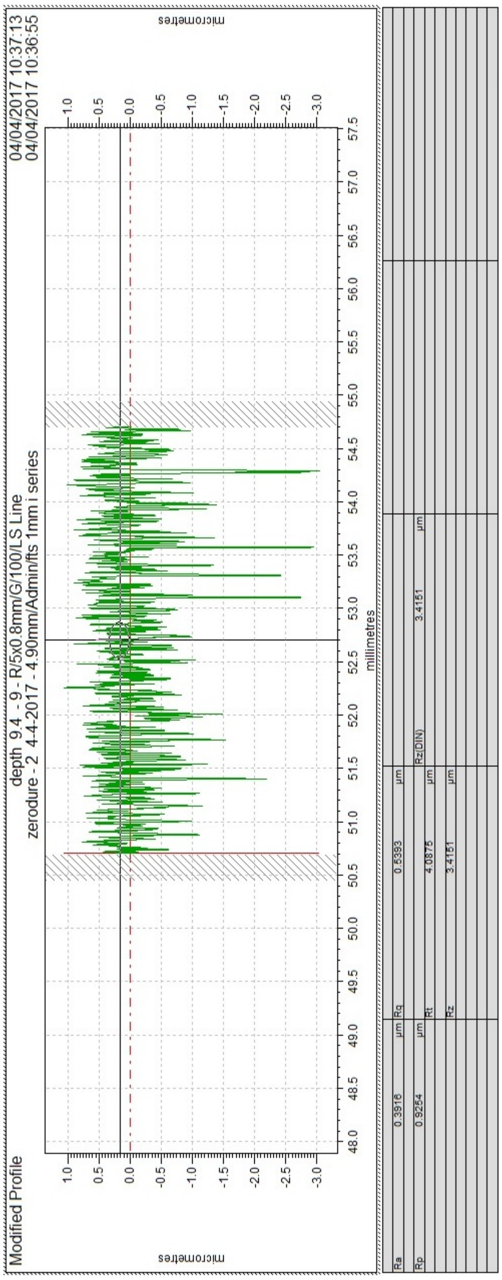
- Find the optimum parameter at which the Hydroxide Bonding gives better strength
- As per given suggestion Mirror manufacturing with the use of Hydroxide bonding
- Mirror manufacturing of CFRP material with Mirror replicate method.
- As per suggested method surface roughness will be increased and tested further to get optimum results.

Appendix A

Test Results of Surface Roughness for Zerodur



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04/04/2017 10:36:55
micrometres
millimetres
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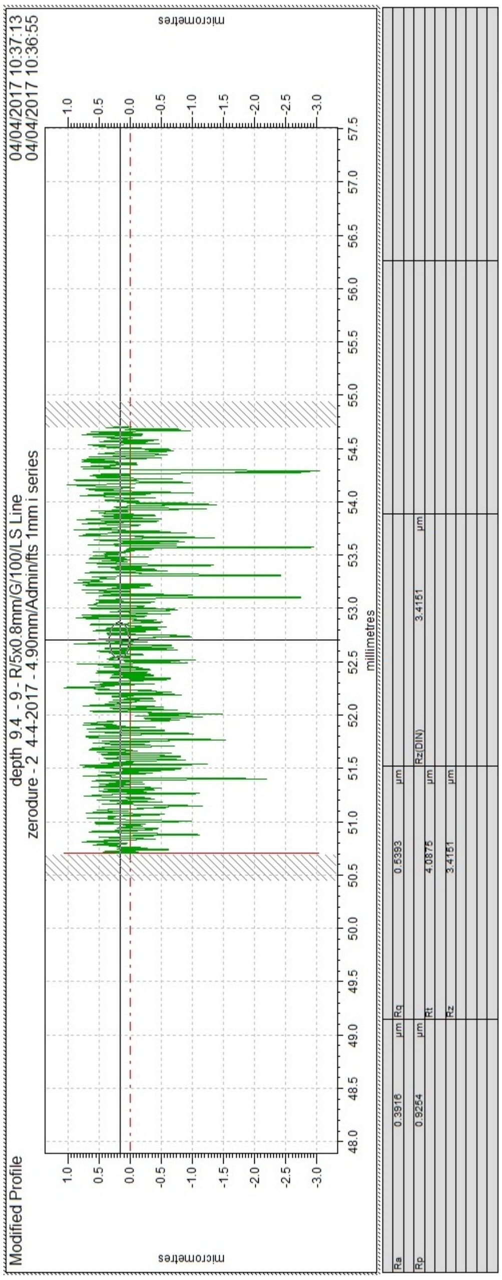
Rq 0.5393 µm
Rz(DIN) 3.4151 µm
Rp 0.9254 µm
Rt 4.0875 µm
Rz 3.4151 µm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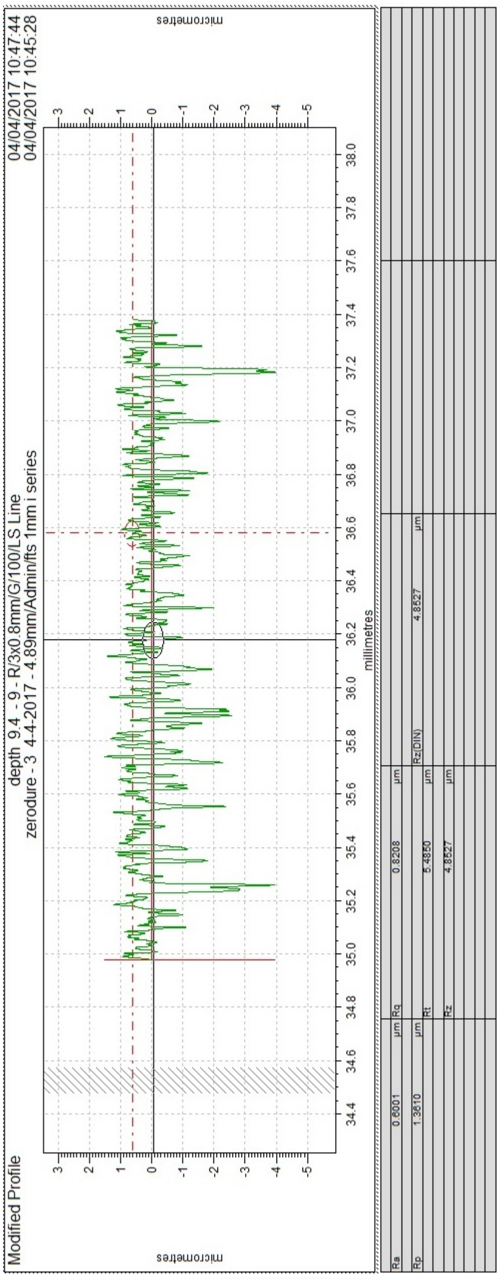
04/04/2017 10:36:55
micrometres
millimetres
Ra 0.3916 µm
Rq 0.5393 µm
Rz(DIN) 3.4151 µm
Rp 0.9254 µm
Rt 4.0875 µm
Rz 3.4151 µm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millimetres
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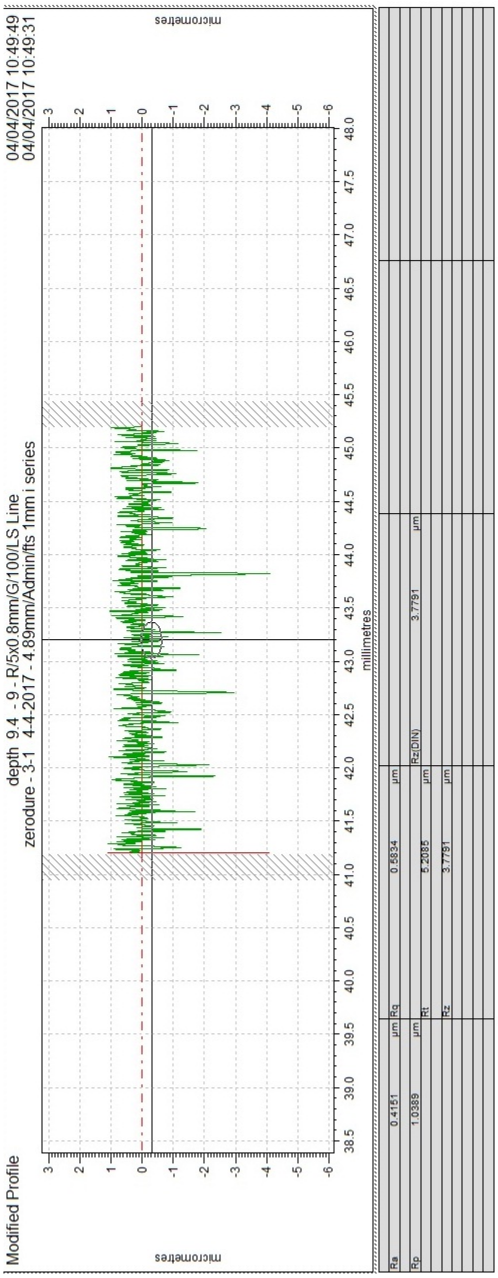
Rz(DIN) 4.8527 µm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micrometres
millimetres
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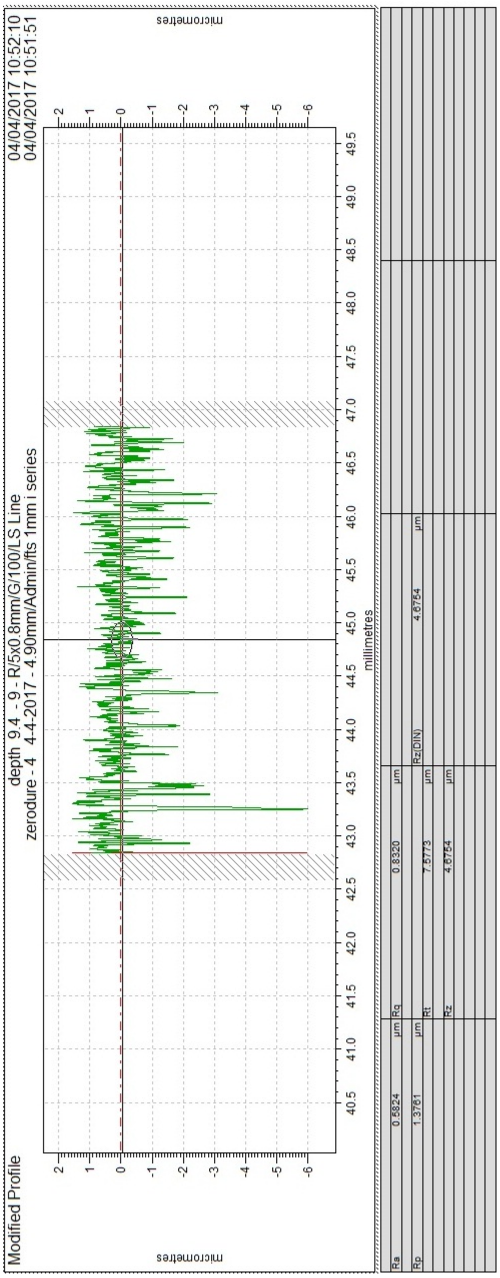
Rz(DIN) 3.7791 µm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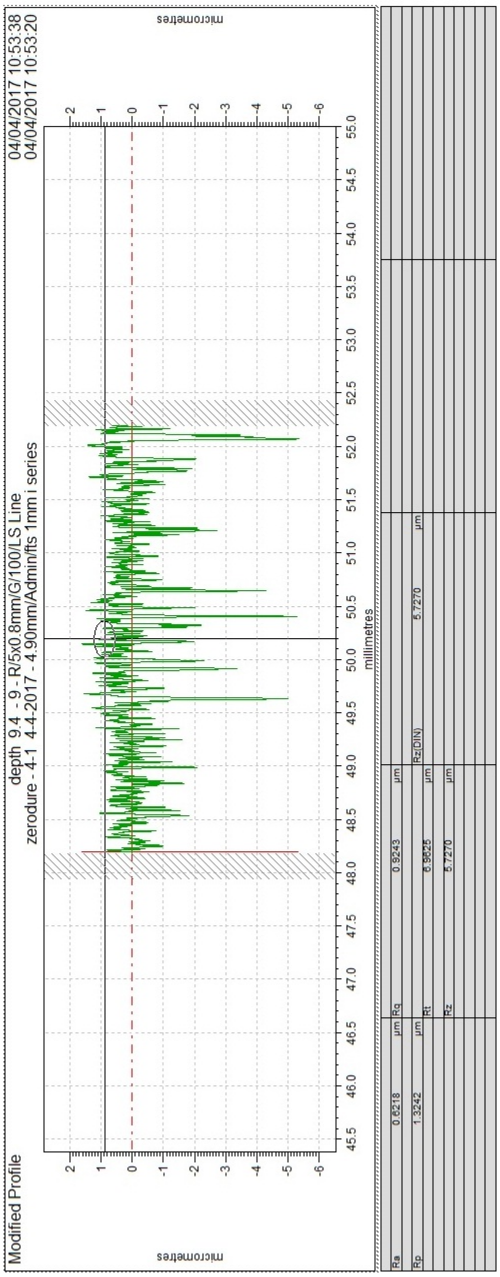
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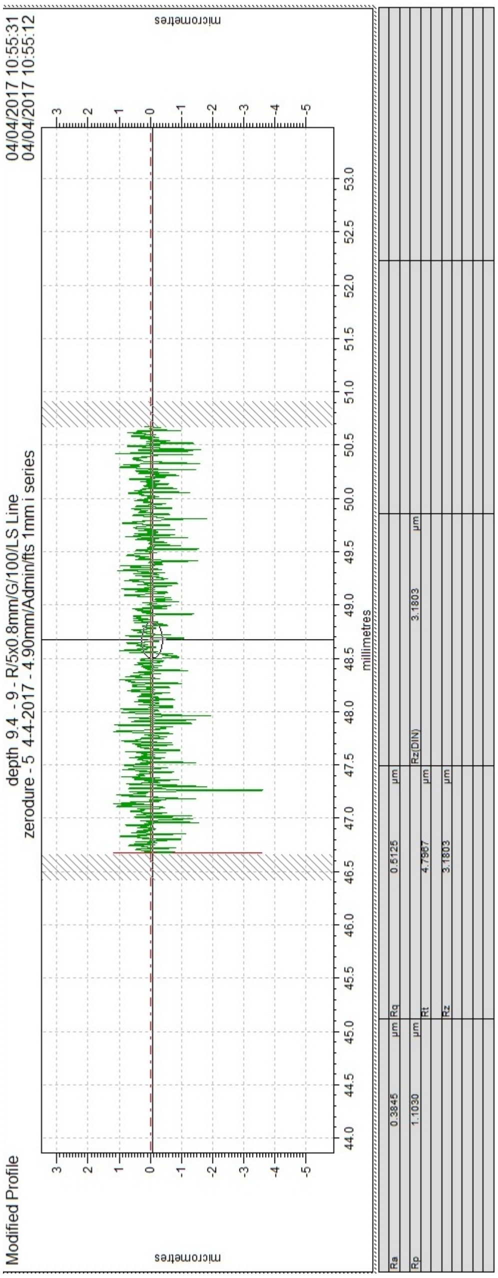
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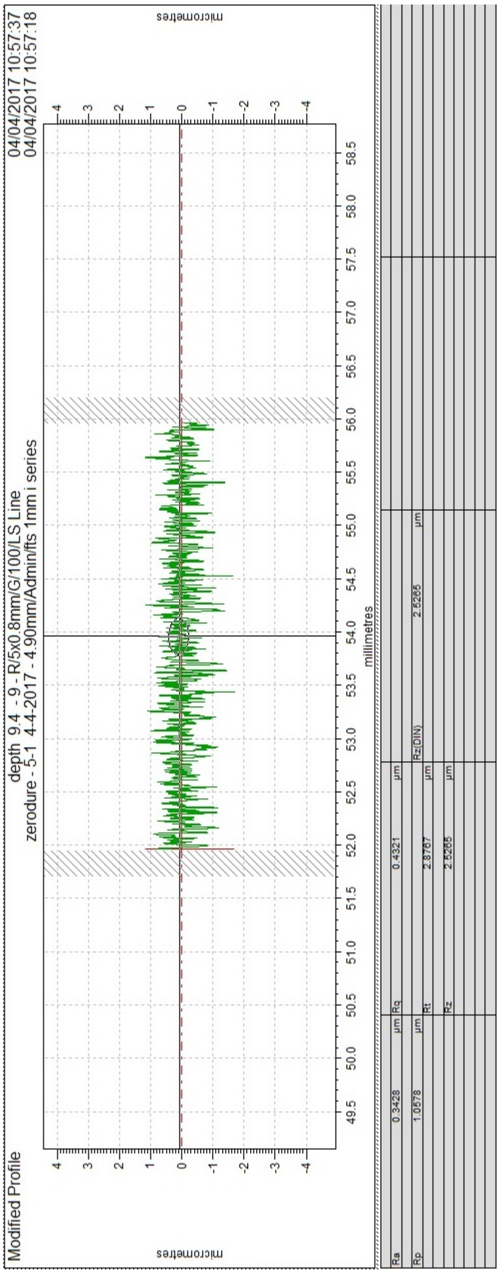
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micrometres
millimetres
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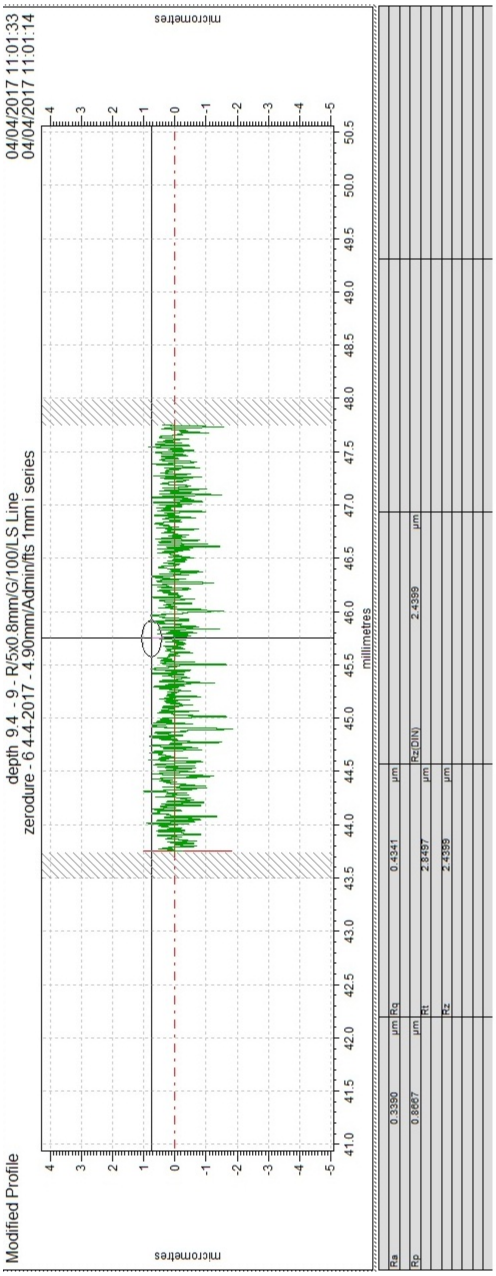
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micrometres
millimetres
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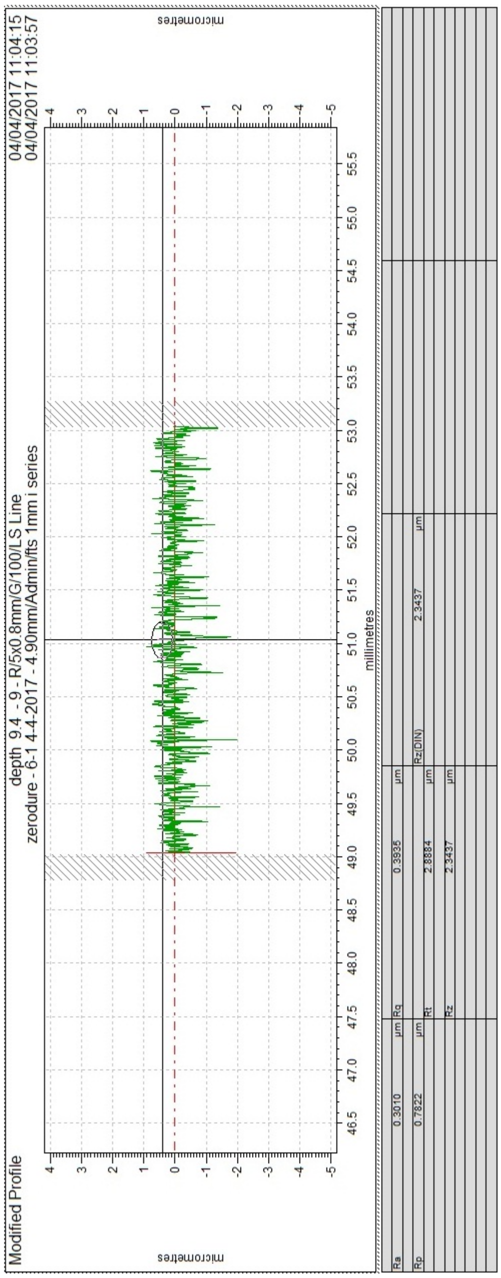
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micrometres
millimetres
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Rq 0.3935 µm
Rp 0.7822 µm
Rt 2.8884 µm
Rz(DIN) 2.3437 µm
Rz 2.3437 µm

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