MATERIAL AND EXPERIMENTAL DETAILS

This chapter describes the details of 45S5 bioglass used in the present study. The details of sample preparation steps have been discussed along with the specimen geometry. It includes casting, heat treatment, cutting, and polishing. This chapter also describes the equipment utilized such as portable heating setup, the elevated temperature scratch testing setup, using of AE setup with scratch testing, elevated temperature hardness test setup, surface roughness tester, optical microscope for scratches.

3.1 Material and sample casted

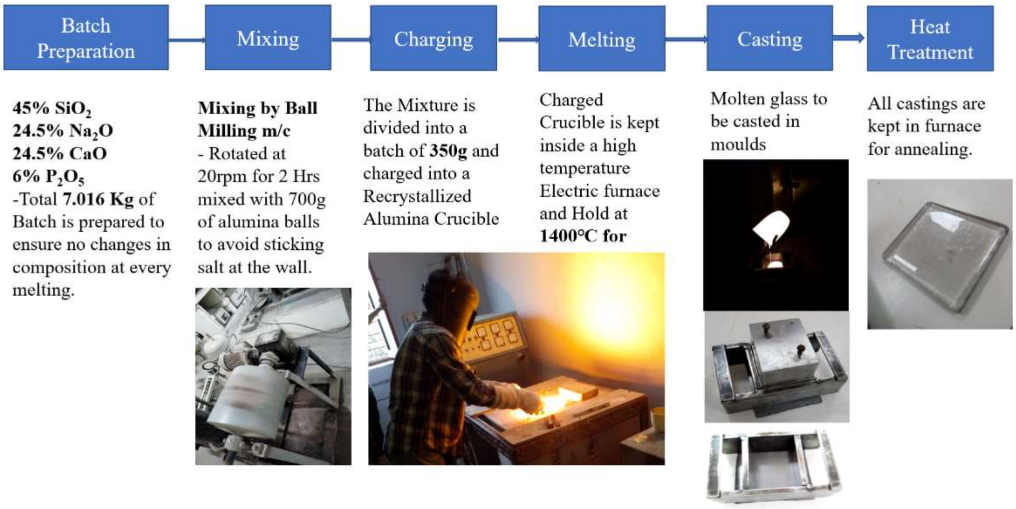


Figure 3.1: Casting process of 45S5 bioglass

A batch of 7.016 kg is prepared large enough to ensure minimum variation in composition at every melting process. The composition of 45S5 bioglass consists of 45% SiO_2, 24.5% Na_2O, 24.5% CaO, and 6% P_2O_5. Further, the mixing of the whole batch is done by a ball milling machine where the rotation speed is kept at 20 rpm for 2 h. The batch was mixed with 700 g of Alumina balls to avoid sticking of salt to the wall during rotation. After the successful mixing, the mixture is divided into a batch of 350 g and charged into a

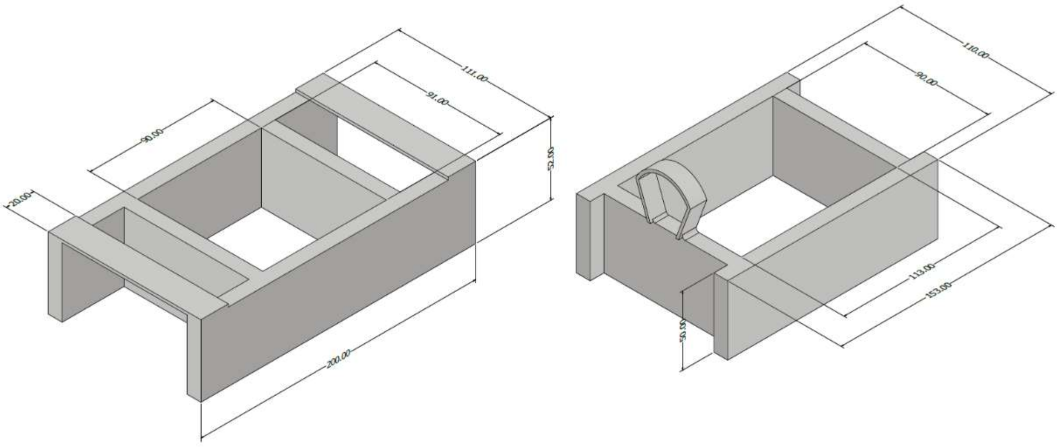


Figure 3.2: Different types of moulds used during casting of bioglass samples

recrystallized zirconia crucible. The charged crucible is kept inside a high temperature electric furnace and held at 1400 °C for 3 h which ensures that proper 45S5 bioglass is formed. Molten glass is cast in flat moulds designed in such a way that the output sample thickness is 10.5 mm. Figure 3.1 shows the overall casting process of 45S5 bioglass. There are two types of moulds used during the casting of the 45S5 bioglass. Figure 3.2 shows the types of moulds used for casting. The first (left) mould was designed to cast a slab size of 90 x 90 x 12 mm^3. Later, the mould is modified (Right) to cast a larger size slab of 90 x 113 x 12 mm^3. This resulted in more numbers of final-cut samples for testing.

Thereafter, all castings are kept in a furnace for annealing following the heat treatment curve as shown in Figure 3.3. The castings are kept at 540 °C for the first 15 min and then cooled for 95 min with a cooling rate of 1 °C/min, reducing the casting temperature to 445 °C. Then they are further cooled for 27.5 min at a cooling rate of 2 °C/min which reduces the temperature of casting to 390 °C. Furthermore, they are cooled to 70 °C for the next 32 min with a cooling rate of 10 °C/min. Afterwards, the castings are cooled in the furnace to the room temperature. This process resulted in an annealed casting ready to be cut into desired sample sizes.

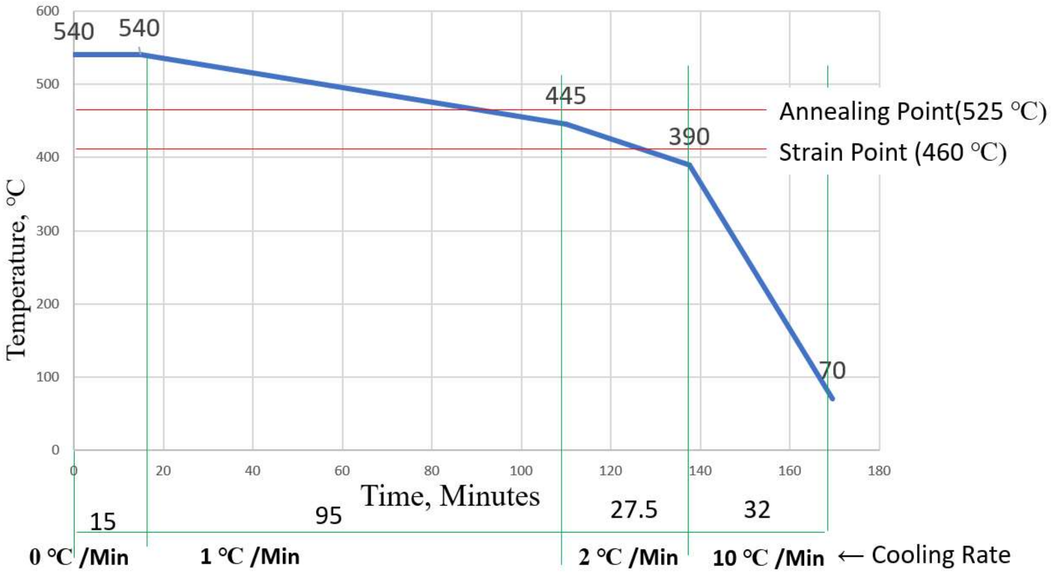


Figure 3.3: Typical Annealing Curve followed for heat treatment of castings

3.2 Sample preparation for study of traction forces at elevated temperature

45S5 bioglass samples are prepared with the help of the melting process. A total of 6 samples are cut in 23 x 21 x 10 mm^3 size and polished with the help of emery sheets of grit size 220, 320, 1000, 1500 and 2000 subsequently. Hence, the average surface roughness is kept between a very close range from 0.1164 µm to 0.1478 µm for all samples as shown in Table 3.1. The average surface roughness is the average surface roughness taken along sample length and sample width. Mitutoyo SV-2100 have been used for surface roughness measurement. While measurement, the sampling length is kept at 0.8 mm and the evaluation length is 4 mm, as well as the traverse length of the probe,

Meas Cont	Meas Value	Judg	TolRslt	Error	U Tol	L Tol
☐ Ra	0.1274um	NG(16%)	0/5...5/5		0.0000um	0.0000um
☐ Rq	0.1940um	NG(16%)	0/5...5/5		0.0000um	0.0000um
☐ Rz	1.3492um	NG(16%)	0/5...5/5		0.0000um	0.0000um
☐ Rt	2.7925um	NG(16%)	0/1...1/1		0.0000um	0.0000um
☐ Rz1max	2.7925um	NG	2.7925		0.0000um	0.0000um

Figure 3.4: The typical roughness plot along the length of the first sample

which is kept at 4.8 mm. Subsequently, Figure 3.4 shows the typical roughness plot along the length of the first sample.

Table 3.1: Surface roughness of polished samples

Sample No.	Along Length (µm)	Along Width (µm)	Average Roughness (µm)
1	0.1274	0.1681	0.1478
2	0.1317	0.1504	0.1411
3	0.127	0.1057	0.1164
5	0.1443	0.1479	0.1461
6	0.1836	0.1032	0.1434

3.3 Sample preparation for study the effect of temperature on brittle-ductile transition

To obtain the brittle-ductile transition zone through the scratch tests, it is necessary to have a high degree of surface finish. Therefore, these samples are polished with diamond paste with 1800 grit size. It resulted in a high degree of surface finish that falls between

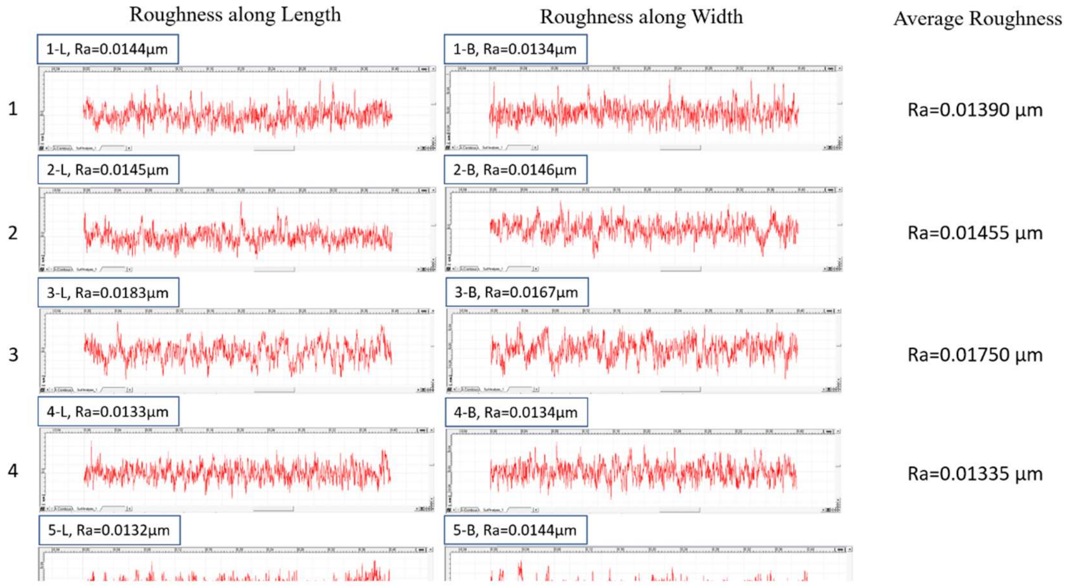


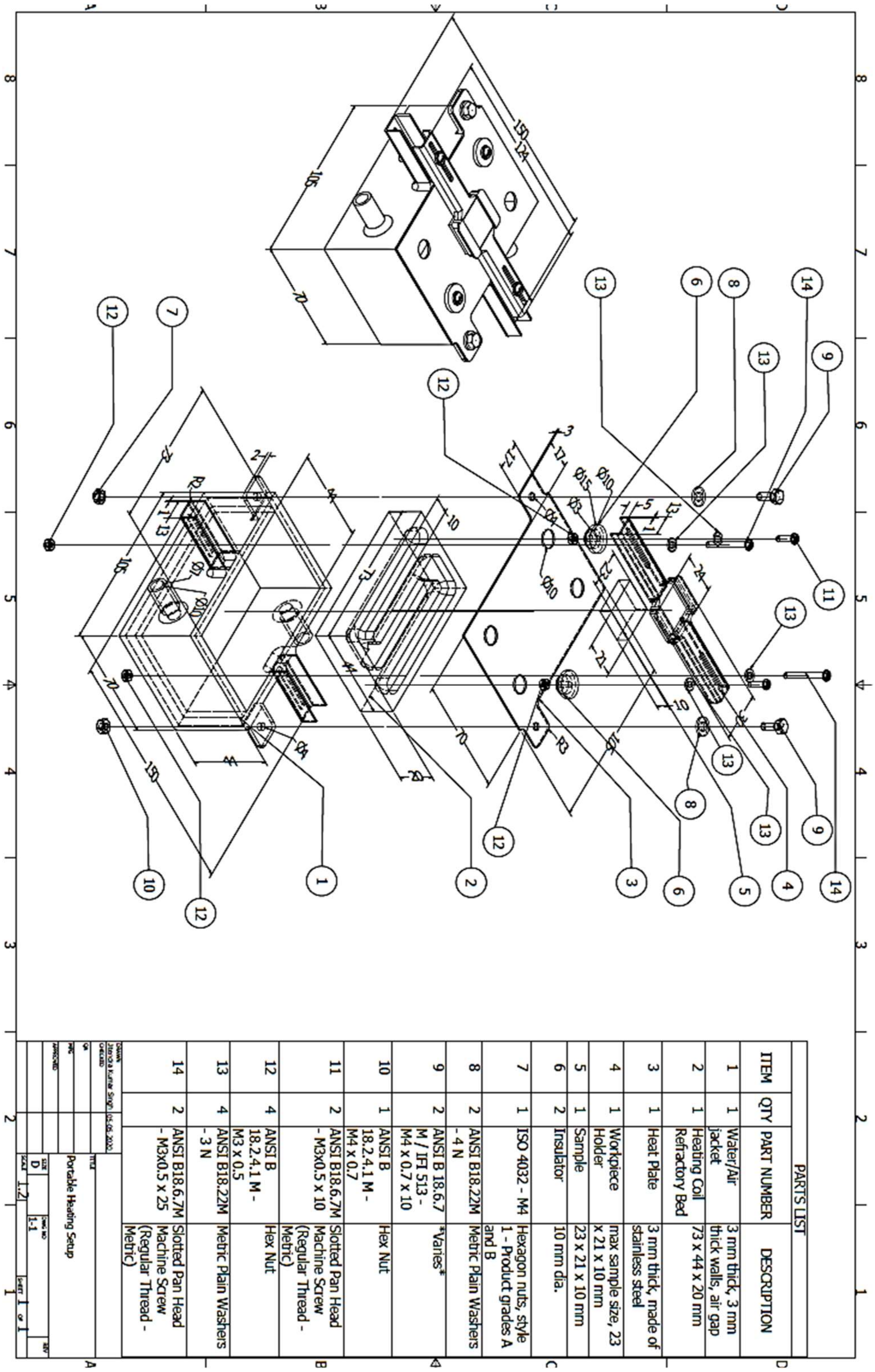
Figure 3.5: Surface roughness evaluation of prepared samples

0.01335 µm and 0.01750 µm in terms of R_a. The evaluation of the surface roughness is done on Mitutoyo Surftest (SV-2100). The surface roughness is measured along the length and width direction of the prepared samples. This evaluation of surface roughness for 45S5 bioglass samples is shown in Figure 3.5.

3.4 The portable heating setup

This portable heating setup is developed to heat the samples and hold them. A generic controller is used to control the current input to the heating coil. Figure 3.6 shows the assembly drawing of the portable heating setup, and Figure 3.7 shows the full sectional view of the setup. The setup consists of the following parts: (1) water/air jacket, (2) heating coil refractory bed, (3) heat plate, (4) workpiece holder, (5) sample, and (6) insulators, and other things are fasteners with metric threads.

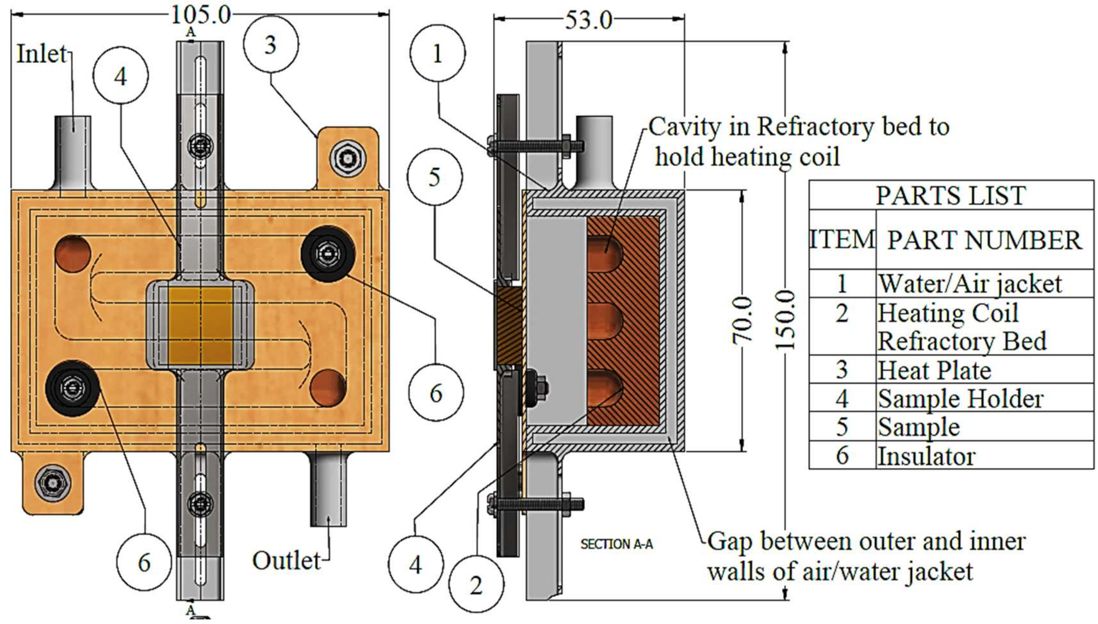
The water/air jacket is made of stainless steel to avoid corrosion. This part is shown as part number 1 in Figures 3.6 and 3.7. It also works as the base for the heat plate. It has a water/air gap between walls so that it insulates the heat transfer between the heater and the outer surfaces of the water/air jacket. That air gap has two openings so that we can maintain water flow inside the walls of the setup for high-temperature experiments. This air gap is shown in Figure 3.7. There is a heating coil refractory bed, which is made of refractory brick. This part is shown as part number 2 in Figures 3.6 and 3.7. There is an appropriate cavity to hold the heating coil, as displayed in Figure 3.7. This bed works as a thermal and electrical insulator between the heating coil and water/air jacket. A nichrome wire heating coil is used to produce heat. The arrangement of heating coil and the refractory bed are placed in the given space of water/air jacket. A heating plate, which is shown as 3 in Figures 3.6 and 3.7, is mounted above the heater with the help of insulators (shown as 3 in Figures 3.6 and 3.7) and fasteners (shown as 8–14 in Figure



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Water/Air jacket	3 mm thick, 3 mm thick walls, air gap
2	1	Heating Coil Refractory Bed	73 x 44 x 20 mm
3	1	Heat Plate	3 mm thick, made of stainless steel
4	1	Workpiece Holder	max sample size, 23 x 21 x 10 mm
5	1	Sample	23 x 21 x 10 mm
6	2	Insulator	10 mm dia.
7	1	ISO 4032 - M4	Hexagon nuts, style 1 - Product grades A and B
8	2	ANSI B18.22M - 4 N	Metric Plain Washers
9	2	ANSI B 18.6.7 M / IFI 513 - M4 x 0.7 x 10	*Varies*
10	1	ANSI B 18.2.4.1 M - M4 x 0.7	Hex Nut
11	2	ANSI B18.6.7M - M3x0.5 x 10	Slotted Pan Head Machine Screw (Regular Thread - Metric)
12	4	ANSI B 18.2.4.1 M - M3 x 0.5	Hex Nut
13	4	ANSI B18.22M - 3 N	Metric Plain Washers
14	2	ANSI B18.6.7M - M3x0.5 x 25	Slotted Pan Head Machine Screw (Regular Thread - Metric)

Figure 3.6: Assembly drawing of Portable Heating Setup (all dimensions are in mm)

3.6). The sample is shown as 5 in Figures 3.6 and 3.7. The test sample can be placed above the heating plate with the help of a workpiece holder. This part is shown as 4 in Figures 3.6 and 3.7. The sample holder has two slotted flanges, which are fastened against the flanges on the air/water jacket. The purpose of the sample holder is to hold the sample on a heat plate for such applications, which have some load on the sample surface.

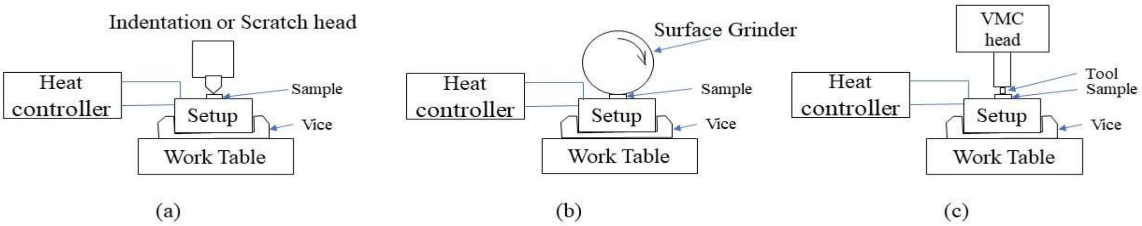


PARTS LIST

ITEM	PART NUMBER
1	Water/Air jacket
2	Heating Coil Refractory Bed
3	Heat Plate
4	Sample Holder
5	Sample
6	Insulator

Figure 3.7: Full sectional view of setup (all dimensions are in mm)

The overall heating effect is generated by Joule's effect on the heating coil. The heat plate is placed above the heating coil, and therefore, it will be heated by the conduction effect. A voltage variac is used as the heat controller. Since the heat controller controls the supply of current to the heating coil, we can easily achieve different heating effects. The base dimensions of the product are 105 × 70 mm^2, and it must be mounted on the work table. The overall dimensions of the product are 105 × 150 × 53 mm^3, as shown in Figure 3.7. This setup can hold a fixed-size sample. There is a need to change the holder according to the new sample size and applications. Due to its portable size and easy to use characteristics, this setup can be used to heat samples for multiple applications, as shown



(a) (b) (c)

Figure 3.8: Schematic diagrams of multiple uses of the portable heating setup: (a) with indentation or scratch tester, (b) with surface grinder, (c) with vertical milling center

in Figure 3.8. It can be mounted on a scratch or an indentation tester to perform tests at elevated temperatures as well, as depicted in Figure 3.8(a). It can be mounted on the surface grinder to perform operations at elevated temperatures, as shown in Figure 3.8(b). It can also be mounted on a vertical milling centre (VMC) to perform operations at elevated temperatures, as shown in Figure 3.8(c). Due to its small working space, its uses are limited to laboratory activities only, but it can be made with scale up in size for industrial usage.

Descriptions of the heating coil, heat plate, and heat controller are given as follows:

3.4.1 Design of heating coil

The heating coil is made of nichrome wire. Its wire diameter is 0.45 mm and the coil diameter is 6.0 mm. The resistance of this coil is set at $R = 2.8\ \Omega$. The coil has a maximum current capacity of 5 A. The workpiece holder can hold $23 \times 21 \times 10\ \text{mm}^3$ of sample size, but the sample size used is $23 \times 18.5 \times 10\ \text{mm}^3$ for determining the sample surface temperature variation. Heat flow generated through the heating coil is

$$q_1 = I^2 \cdot R \tag{3.1}$$

The heating coil is placed on the refractory bed. The size of the refractory bed is $73 \times 44\ \text{mm}^2$. Therefore, the projected area of the heater is

$$A_1 = 73\ \text{mm} \times 44\ \text{mm} = 3212\ \text{mm}^2. \tag{3.2}$$

Figure 3.7 shows the full section of the device with insight into the setup.

The contact area of the sample and heat plate is

$$A_2 = 18.5\ \text{mm} \times 23\ \text{mm} = 425.5\ \text{mm}^2. \tag{3.3}$$

Heat flux passing through the sample;

$$q = \frac{A_2}{A_1} q_1 = 0.132 q_1 \tag{3.4}$$

3.4.2 Design of heat plate

The design objective for the heat plate is to perform the stress analysis on the heat plate under a point load to ensure that the heat plate does not undergo any permanent deformation under the maximum indenter load normally applied on the sample mounted on the heat plate. The shape and dimensions of the heat plate are shown in Figure 3.6. The thickness of the plate is 3 mm. During the elevated temperature scratch test, the maximum point load on the plate during various operations is expected to be a maximum of up to 40 N. Therefore, simulations are carried out on 200 N point load considering the factor of safety (FOS) as 5. For simulation, the software used is Autodesk Inventor Professional 2019. The plate is made of stainless steel, yield strength is 228 MPa, ultimate tensile strength is 540 MPa, Young's modulus is 190.3 GPa, Poisson's ratio is 0.305, and the shear modulus is 72.9119 GPa. Additionally, a tetrahedron mesh is selected for this purpose. The average element size taken is 0.100, the minimum element size as a fraction of the average element size is 0.200, the grading factor taken is 1.5, and the maximum turn angle taken is 60°. The general objective of the stress analysis is to perform a single-point static load analysis on the heat plate. The top surface of the heat plate is selected

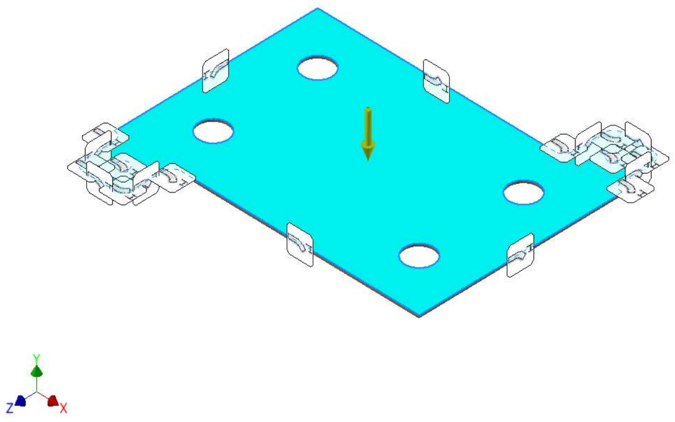


Figure 3.9: Selected face of heat plate for stress analysis

for the application of 200N normal single-point load and the mounted areas of the plate are considered as fixed surfaces as shown in Figure 3.9. The physical attributes of the heat plate are calculated where the mass of the plate is 47.81 grams, the surface area is 15738.5 mm^2, and the volume is 7589.78 mm^3.

The stress analysis for the heat plate is carried out on above mentioned settings and concerned results are obtained. Figure 3.10 shows the von-Mises stress simulation results. When a material's maximum von-Mises stress value is less than its yield strength, the material will not yield. The von-Mises stress is an equivalent stress value that is used to determine if a certain material will begin to yield. The red color in the color scale shows the maximum stress zones whereas the blue color shows the minimum stress zone. The

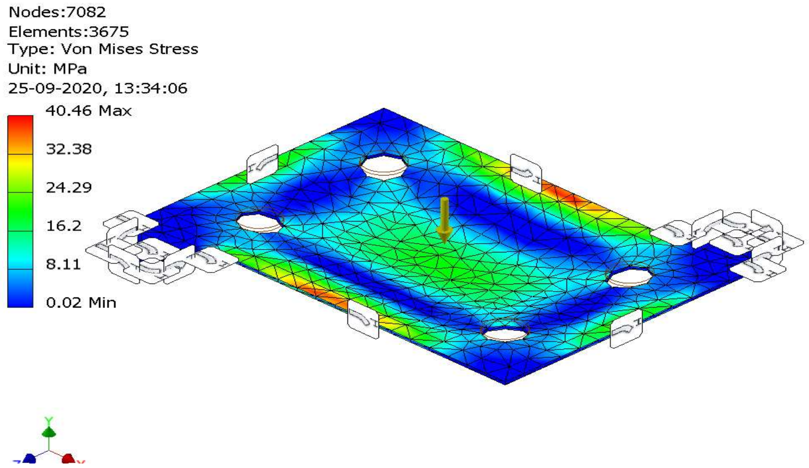


Figure 3.10: Von Mises Stress simulation results

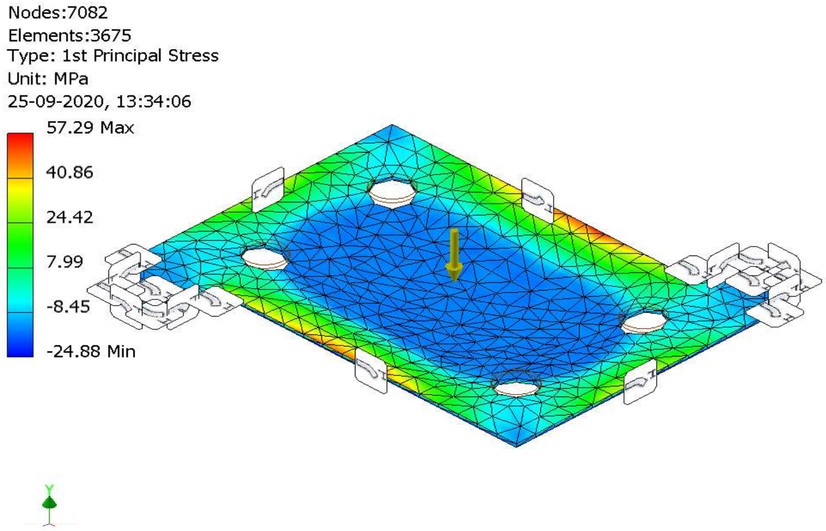


Figure 3.11: 1st Principal Stress simulation result

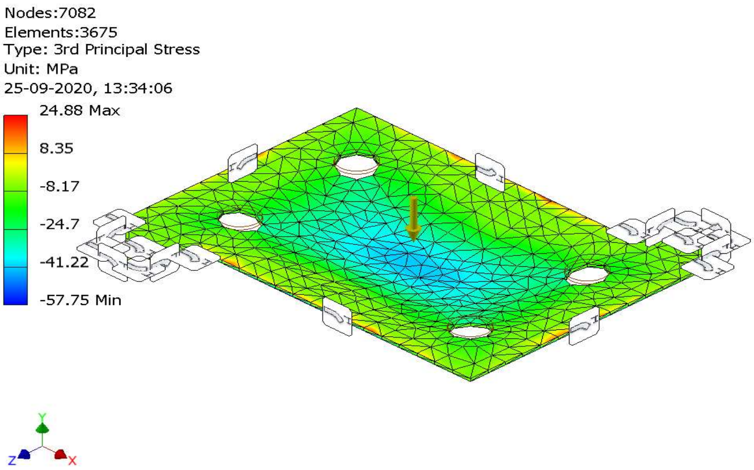


Figure 3.12: 3rd Principal Stress simulation

maximum von-Mises Stress value is 40.46 MPa as shown in Figure 3.10 which is less than the yield strength of the heat plate material. Figure 3.11 shows the 1st principal stress simulation result. The 1st principal stress gives the value of stress that is normal to the plane in which the shear stress is zero. The 1st principal stress helps to understand the maximum tensile stress induced in the part due to the loading conditions. The maximum Tensile stress on the heat plate is 57.29 MPa as shown in Figure 3.11. Figure 3.12 shows the 3rd Principal Stress simulation. The 3rd principal stress acts normal to the plane in which shear stress is zero. It helps to understand the maximum compressive stress induced in the part due to the loading conditions. The maximum compressive stress on the heat plate is 24.88 MPa as shown in Figure 3.12. None of the simulated stress values are more than the yield stress value of the heat plate material. Therefore, it implies that the heat plate would not undergo permanent deformation. Figure 3.13 shows the displacement simulation. The color scale shows the different gradients between blue and red. The blue color represents zero deflection zones and the red color represents the maximum displacement zones. Figure 3.14 shows the factor of safety throughout the stress analysis. Blue in the color scale represents the maximum factor of safety zones and the red shows the failure zones in the simulation. There are no red zones available in the simulation as shown in Figure 3.14. So, the heat plate is safe to be used under the mentioned load.

Since the load is applied in the Y-axis as shown in Figure 3.9, the maximum elastic deflection in the Y-axis is 5.56027 x 10^{-9} m as shown in the detailed report for stress analysis (Please refer to Annexure-IV). Since there is no permanent deformation, the plate is suitable for a 200 N load. Thus, the heat plate is safe to hold 40 N of load, and operations under 40 N load on the setup can be performed with no permanent deformation. The following are the details of the stress analysis.

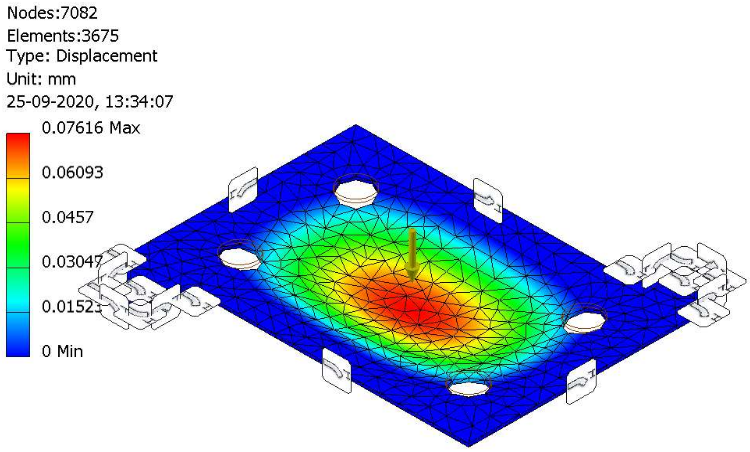


Figure 3.13: Displacement simulation

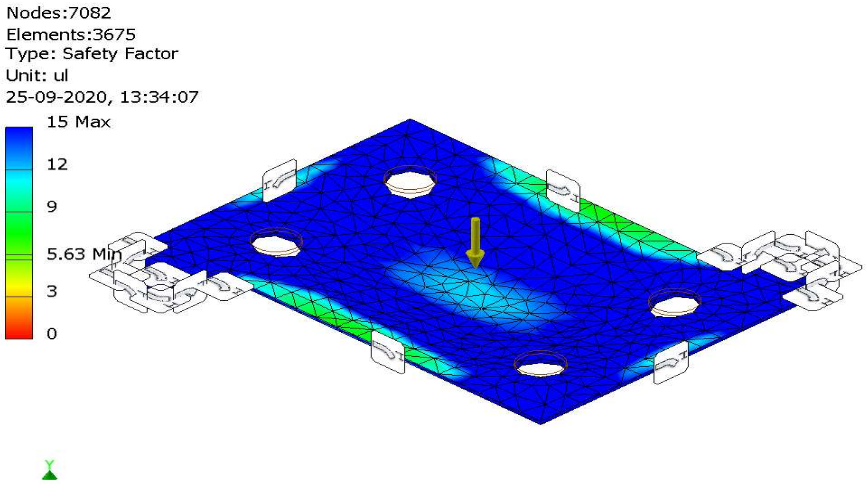


Figure 3.14: Factor of safety

3.4.3 Design of heat controller

Figure 3.15: Heat controller with insight of setup

A generic voltage variac has been used to vary the voltage in the circuit. This variac has voltage regulation from 10 V to 220 V AC and a rated current value of 25 A–45 A. The generic voltage variac is shown in Figure 3.15, which has been used to vary current in the heating coil. Additionally, Figure 3.15 provides insight into the setup without a heat plate to understand the placement of the heating coil in the refractory bed. The heat plate is installed above the heater for further experimentation process. The sample is placed on

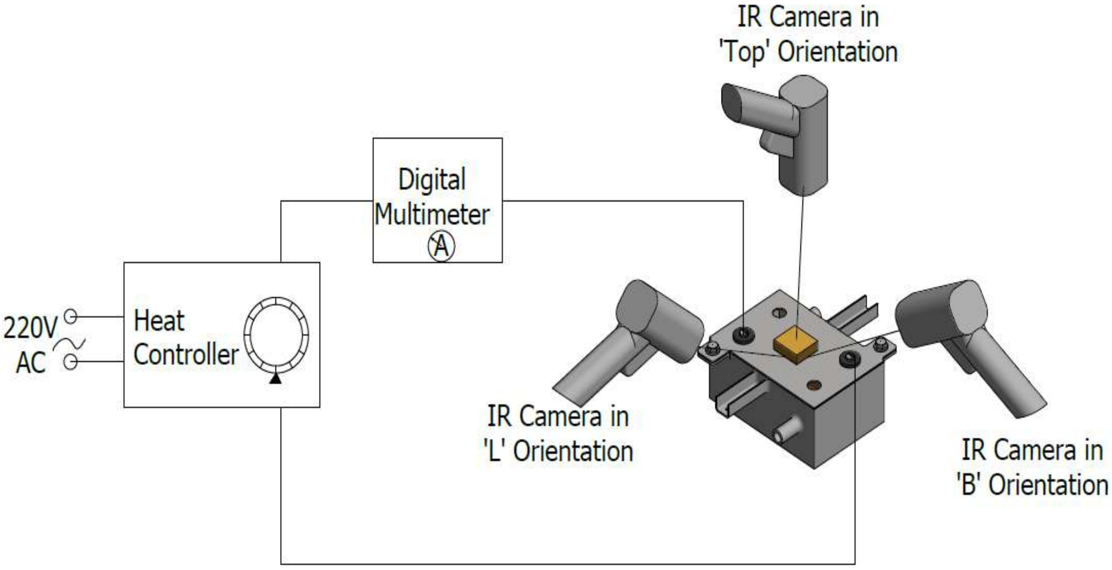


Figure 3.16: Schematic diagram for determination of sample surface temperature variation

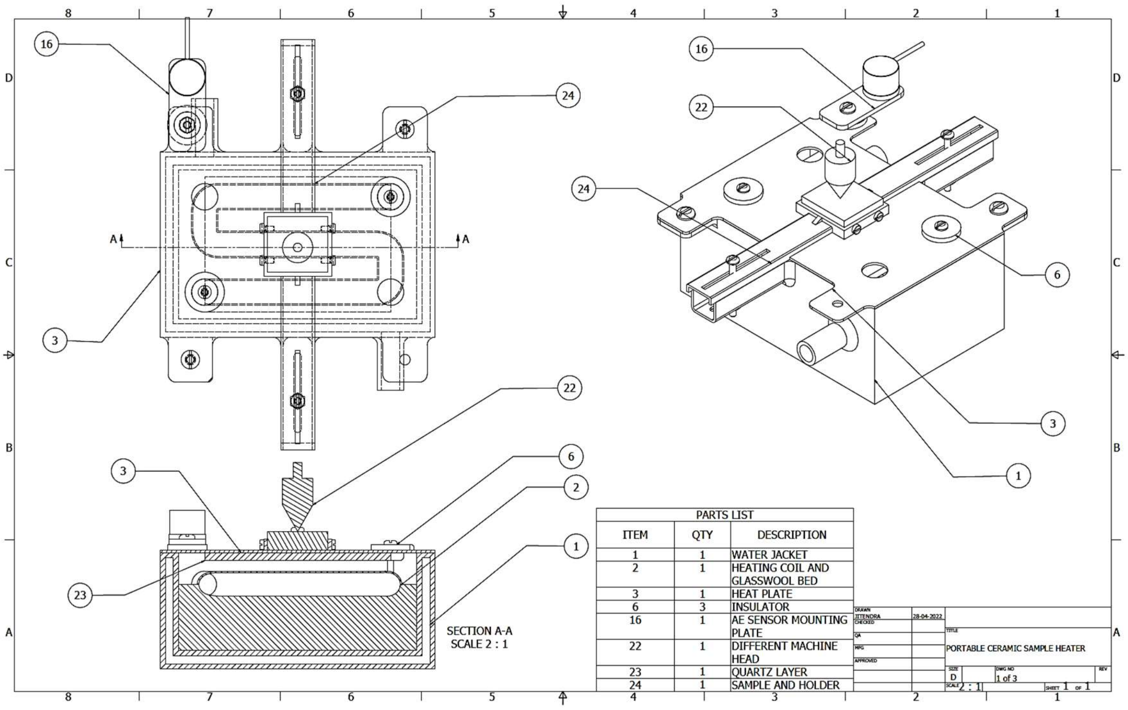
the heat plate during the heating process. Figure 3.16 shows the schematic diagram for the determination of sample surface temperature variation. The current in the coil is measured with the help of a digital multi-meter. The sample is kept on the heat plate. The temperature of the required surface and edges are taken with the help of an infrared (IR) camera in different orientations. The heating coil used has a constant resistance. Due to the variation in the supply voltage, different currents in the heating coil are obtained. Accordingly, different heat flow on the coil is obtained. To determine its heating effect according to the change in current, experiments are performed. Below 1.5 A, the coil did not produce significant heat, and above 4.5 A, there were more chances of a breakdown of the coil as its maximum capacity is 5 A. Therefore, the experiment is performed between 1.5 A and 4.5 A current. Thermal images of the heating setup and samples were taken with the help of an IR camera (FLIR E75). This IR camera has a thermal infrared resolution of 320 × 240 pixels and an image resolution of 640 × 480 pixels. An object distance of 1 m and an emissivity of the order of 0.95 has been selected, as suggested in the user manual for an unsure value of the emissivity of the material. The field of view of the camera is 14° × 10°, which describes the spatial resolution of the image. Thermal images are taken at different currents; for instance, 1.5 A, 2.0 A, 2.5 A, 3.0 A, 3.5 A, 4.0 A, and 4.5 A. Images are taken at every steady state of temperature. Since the setup is aimed for multipurpose use, it is decided to test it in an exposed environment rather than a vacuum chamber.

The experiments have been performed in still air at room temperature. Room temperature will influence the convective heat transfer from the exposed surfaces of samples. There will be more heat transfer from the surfaces with lower room temperature. It will affect the time to attain a steady state. The room temperature was affected by the heating setup, but this variation was 30.5 °C–31.5 °C for the experiment time duration of 35 min.

Therefore, the average room temperature has been taken at 31 °C. The motive of the experimentation was to find the time required to reach a steady state at each current value and the corresponding suitable values of the sample surface temperature. After taking readings at each current value, the heater has been switched off to achieve an initial room temperature condition. The steady-state time has been recorded by keeping the IR camera in a continuous mode and waiting for the next 10 min with no further temperature rise from the last temperature value. No further rise in temperature shows that the heat generated by the heating coil is equal to the heat transferred to the environment. This satisfies the condition to achieve a steady state. Furthermore, the sample surface temperature variation has been measured to justify the use of the setup for multipurpose elevated temperature testing or machining such as scratch test, indentation test, milling, and grinding, among other things.

3.5 Modification to the portable heating setup

The previously made portable heating setup was able to heat samples to 420 °C only. This heating capacity limits the application of the setup. Usually, the glass transition temperature is in the range of 520°C to 660°C. The next phase of the experimentation was intended to perform the experiment covering the afore mentioned temperature range. Keeping this range in mind, the modification was done to the existing portable heating setup. This portable heating setup is modified to heat the samples up to 1000°C and hold them. A 220 V AC controller is used to control the current input to the heating coil. Figure 3.17 shows the assembly drawing of the portable heating setup, and Figure 3.18 shows exploded view showing the arrangement of an air/water jacket, glass wool bed, heating coil, quartz layer, and heat plate with sample holder assembly of the setup. The setup consists of the following parts: (1) water/air jacket, (2) heating coil and glass wool bed, (3) heat plate, (4) Sample and sample holder, (6) insulators, (16) AE sensor mounting plate, (22) different machine heads, (23) quartz layer and other things are fasteners as per industry standards.



PARTS LIST		
ITEM	QTY	DESCRIPTION
1	1	WATER JACKET
2	1	HEATING COIL AND GLASSWOOL BED
3	1	HEAT PLATE
6	3	INSULATOR
16	1	AE SENSOR MOUNTING PLATE
22	1	DIFFERENT MACHINE HEAD
23	1	QUARTZ LAYER
24	1	SAMPLE AND HOLDER

Figure 3.17: Assembly of the portable ceramic sample heater

The water/air jacket is made of stainless steel to avoid corrosion. This part is shown as part number 1 in Figure 3.17. It also works as the base for the heat plate. It has a water/air gap between walls so that it insulates the heat transfer between the heater and the outer surfaces of the water/air jacket. That air gap has two openings so that we can maintain a water flow during high-temperature applications, which have some load on the sample surface. There is a heating coil glass wool bed, which is made to provide insulation between the air/water jacket and the heating coil. This part is shown as part number 2 in Figure 3.17. A nichrome wire heating coil is used to produce heat. A heating plate, which is shown as 3 in Figure 3.17, is mounted above the heater with the help of insulators (shown as 6 in Figure 3.17). There is an additional AE sensor mounting plate provided to comply with the AE analysis, shown as part number 16 in Figure 3.17. Part number 22 represents the machine head for any machine as shown in Figure 3.17. There is a quartz

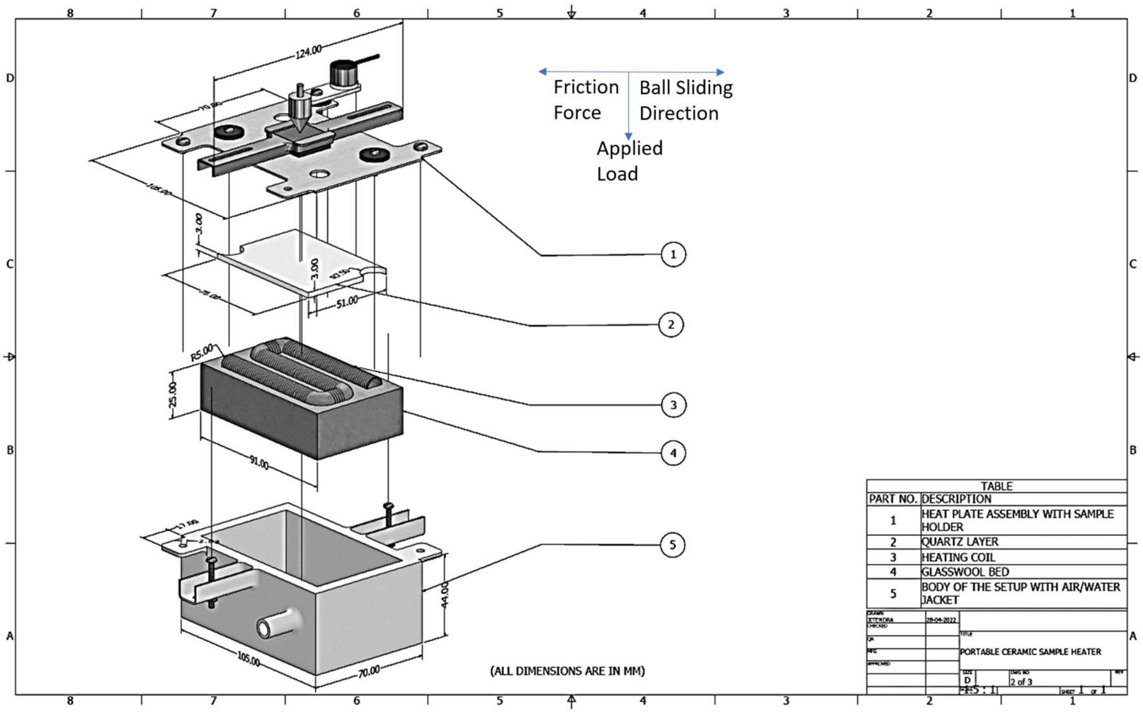


Figure 3.18: Exploded view showing the arrangement of Air/water jacket, glass wool bed, heating coil, quartz layer and heat plate with sample holder assembly

layer placed between the heat plate and the heating coil to avoid electrical shock while performing operations. The quartz layer is shown as part number 23 in Figure 3.17. The test sample will be placed above the heating plate with the help of a workpiece holder. This part is shown as 4 in Figure 3.17.

Subsequently, Figure 3.18 shows the exploded view of the setup assembly. It shows the arrangements of the components. The assembly of the heat plate and sample holder along with the sample is shown as part number 1 in Figure 3.18. The quartz layer is placed below part number 1 and shown as part number 2 in Figure 3.18. The heating coil is placed just below the quartz layer, shown as part number 3 in Figure 3.18. This heating coil is supported by glass wool placed below it. It is shown as part number 4 in Figure 3.18. Part numbers 2, 3, and 4 will be placed inside the air/water jacket which is shown as part number 5 in Figure 3.18.

The sample holder has two slotted flanges, which are fastened against the flanges on the

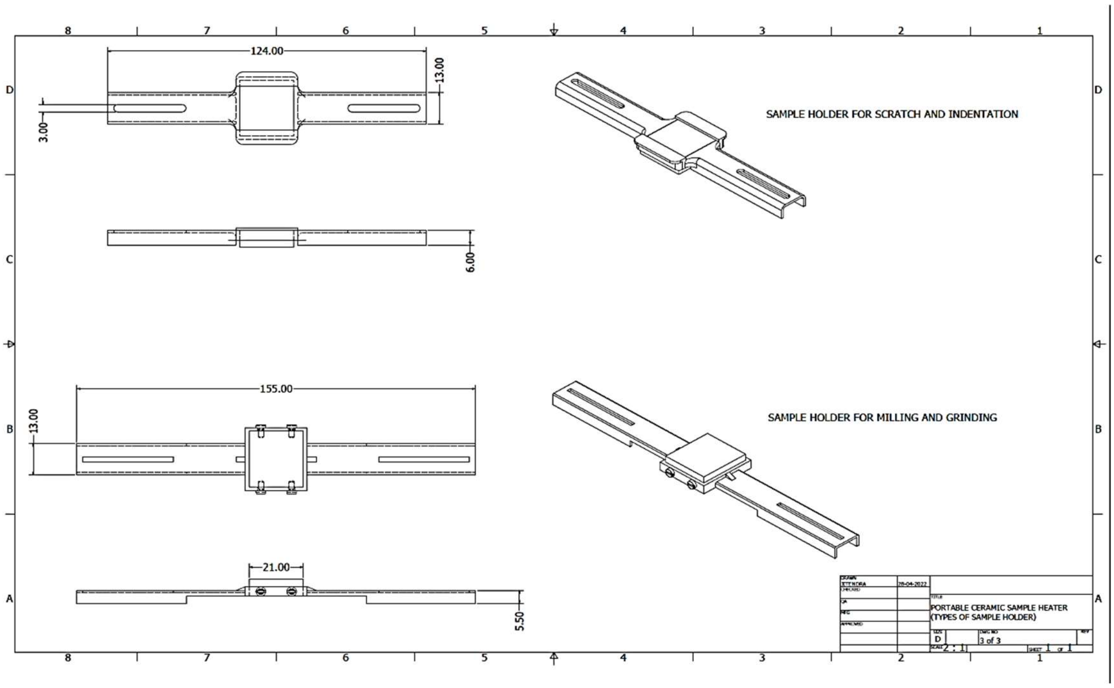


Figure 3.19: Types of samples holder

air/water jacket. The purpose of the sample holder is to hold the sample on the heat plate placed above the heating coil, and therefore, it will be heated by the conduction effect. A voltage variac is used as the heat controller. Since the heat controller controls the supply of current in the heating coil, we can easily achieve different heating effects. Due to its

Figure 3.20: Schematic of using the portable bulk heater on scratch tester

portable size and easy-to-use characteristics, this setup can be used to heat samples for multiple applications.

There are two types of sample holders designed. The first one is for scratch and indentation purposes. And the other one is for milling, grinding, etc. Figure 3.19 shows both types of sample holders. Subsequently, Figure 3.20 shows the schematic of using the portable bulk heater on a scratch tester. The detailed CAD drawings of the major parts of the portable heating setup are given in Annexure-I.

3.6 The experimental setup for the study of traction forces at elevated temperatures during micro scratch tests on 45S5 bio-glass

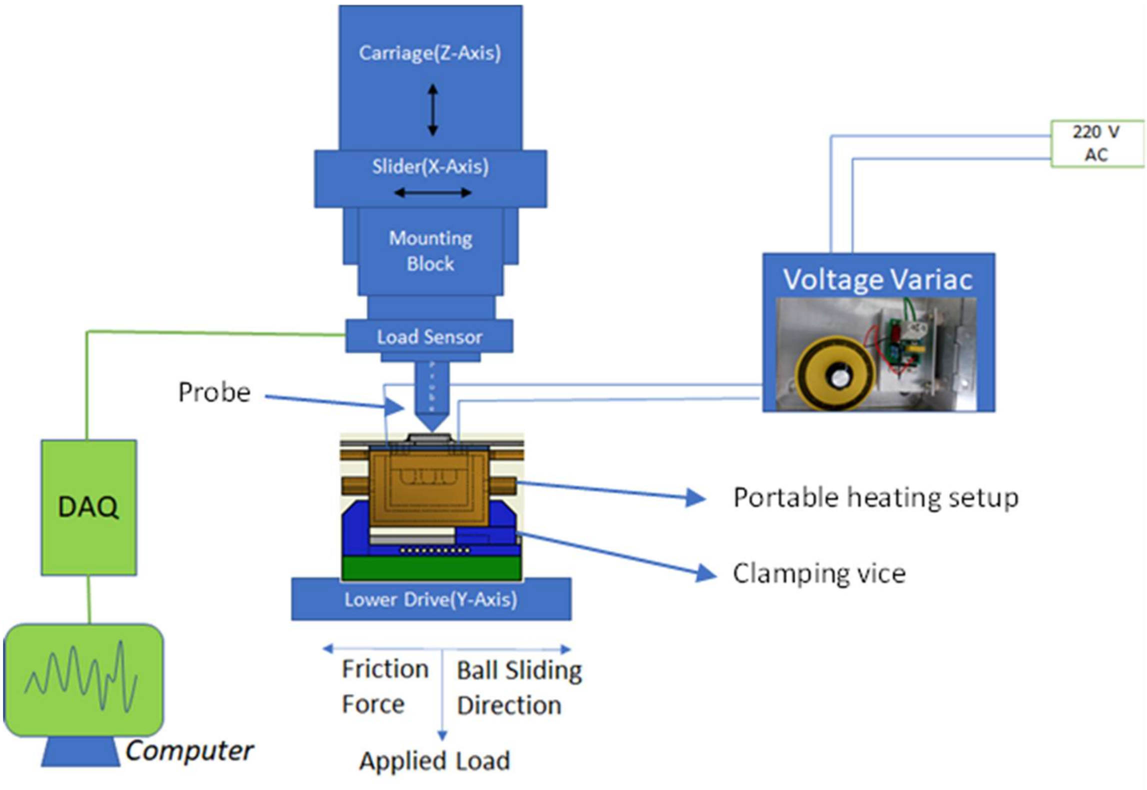


Figure 3.21: Schematic diagram of elevated temperature scratch testing setup

The experimental setup consists of a micro scratch tester (DUCOM, TR-101) and a portable heating setup as shown in Figure 3.21. The micro scratch tester is consisting of a probe which is directly mounted on a load sensor. A C-type Rockwell indenter of 200-micron tip radius is used as the probe. The machine has two types of load sensors, one has a load range of 0 - 20 N and the other has a load range of 20 - 200 N as well as a ball indenter, used as the probe. There are two types of sliders, the X-axis slider and the Y-axis lower drive. The purpose of the X-axis slider is to provide motion for scratch or ball sliding whereas the Y-axis lower drive is used to move the sample in a perpendicular direction to the scratch direction to reorient the probe for new scratch in XY-plane. Subsequently, the machine is consisting a mounting block which holds the load sensor and connects it to the Z-axis carriage. The function of the Z-axis carriage is to move the probe towards the sample surface and apply the required load for scratch tests. All drives for X, Y and Z axes along with the load sensors are connected to DAQ (Data acquisition system). Apparently, they are operated through a computer connected to the DAQ. The 45S5 bioglass samples are mounted on a portable heating setup with the help of a sample holder. Further, the assembly of the sample and the portable heating setup is mounted on the clamping vice of the micro scratch tester and the electrical connections are made between voltage variac and the portable heating setup (Figure 3.21). The voltage variac will work as the heat controller for the portable heating setup and it will be operated on 220V AC [74]. Furthermore, the temperature of the sample is observed with the help of an infrared thermometer (Fluke 572-2).

3.7 Experimental setup for effect of temperature on brittle-ductile transition and critical depth of cut for 45S5 bioglass

The portable heating apparatus, 45S5 bioglass samples and the micro scratch tester make up the entire experimental setup for elevated temperature micro scratch tests. Figure 3.22(a) depicts the setup's schematic which is quite similar to previous section. 1-20 N load cell used for this setup. Apparently, the samples used in this setup are finished in the range of 0.01335 μm to 0.01750 μm in terms of R_a.

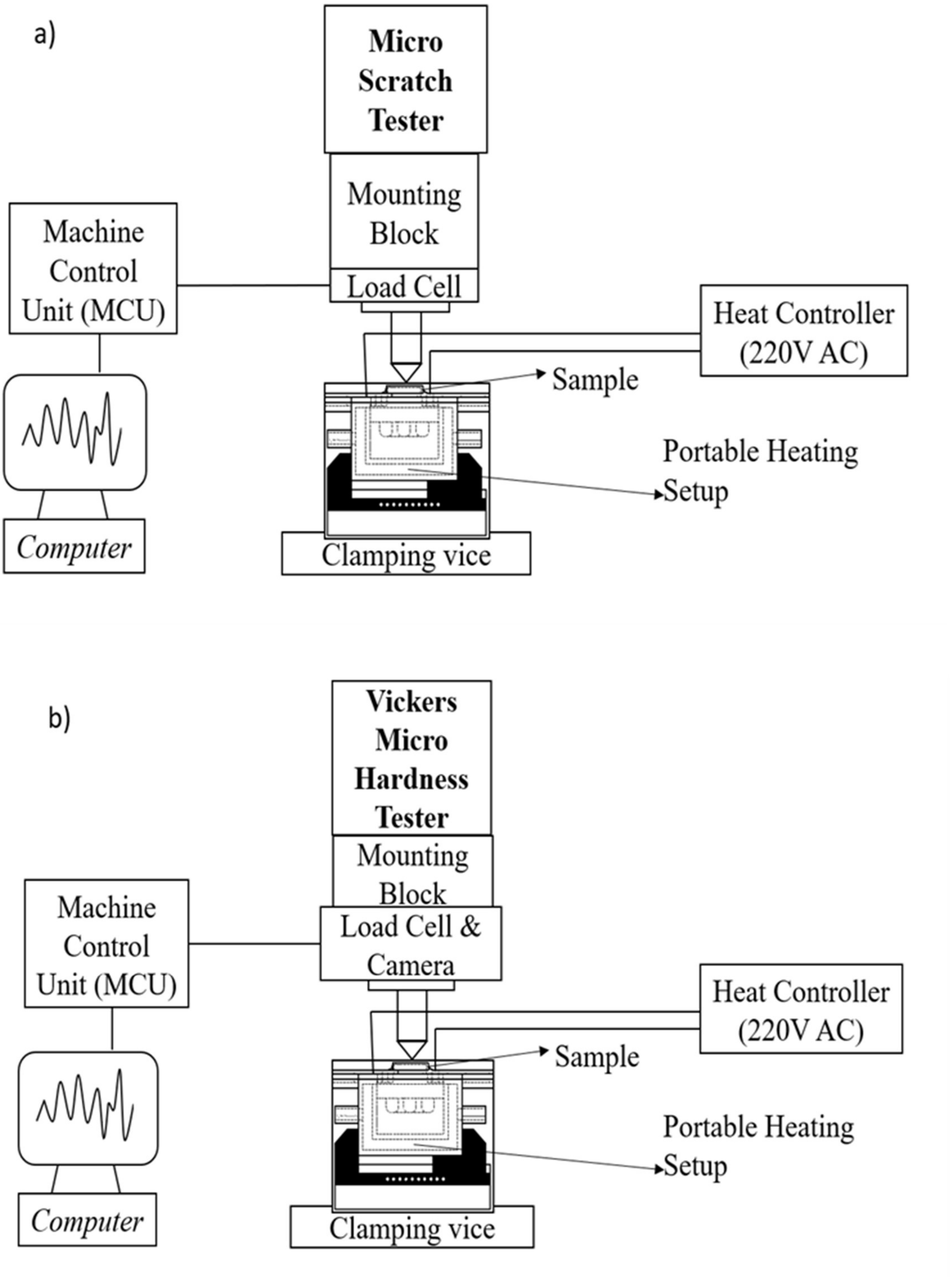


Figure 3.22: Schematic diagram of setup for; (a) Elevated temperature micro scratch tests, (b) Elevated temperature micro hardness tests

Substantially, the portable heating setup, 45S5 bioglass samples and the Vickers microhardness tester make the entire experimental setup for the elevated temperature micro hardness test and depicts the setup's schematic as shown in Figure 3.22(b). The load sensor and microscopic camera are attached to the mounting block, and the indenter is mounted to the load sensor. A machine control unit that is connected to a computer is used to manage the sample motions during the indentation and evaluation of hardness and crack length. On both setups, as depicted in Figure 3.22(a), the portable heating setup is positioned on the clamping vice. The 45S5 bioglass sample is then mounted in a different sample holder that is accessible on a portable heating setup. Throughout the whole experiment, a Fluke 572-2 infrared (IR) thermometer was used to measure the temperature.

3.8 Experimental setup for study of acoustic emission (AE) output During elevated temperature scratch test on 45S5 bioglass

The complete experimental setup consists of the micro scratch tester (DUCOM, TR-101), a portable heating setup, and an AE sensor (Vallen Systems, VS 150 M) with DAQ (Vallen Systems, ASCO-DAQ2). The base signal strength of the sensor is 1.500 mV, the sampling rate is 10000 Hz, the sensor capacity is 350 pF, and the channel time offset is 1/48000 s. The schematic of the setup is shown in Figure 3.23. The portable heating setup

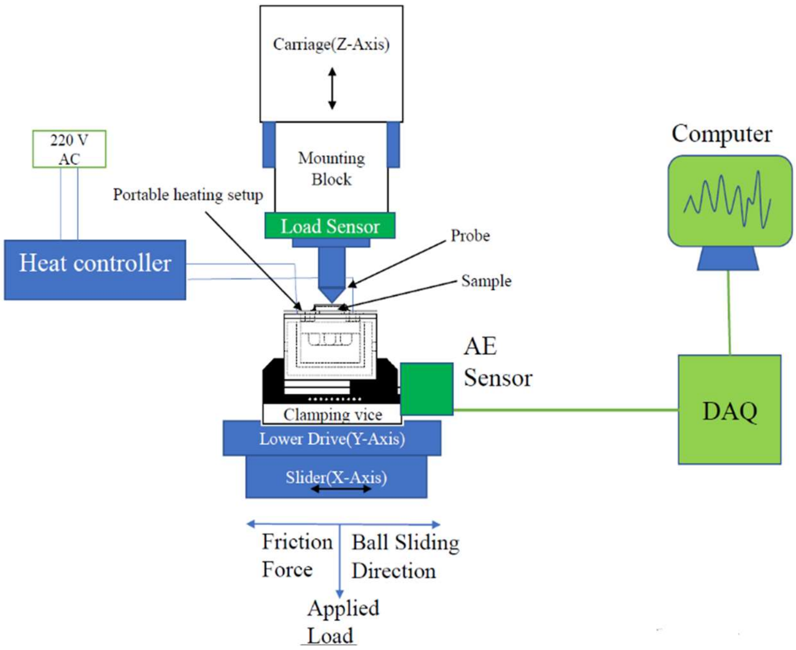


Figure 3.23: Schematic diagram of elevated temperature scratch testing along with AE monitoring

is mounted on the clamping vice as shown in Figure 3.23. Subsequently, the 45S5 bioglass sample is mounted in a separate sample holder available on a portable heating setup. Moreover, Figure 3.24 shows insight into the arrangement of the heating setup, indenter, and AE sensor placement. An infrared (IR) thermometer (Fluke 572-2) has been used to monitor the temperature during the whole of the experimentations. The placement of the AE sensor is very crucial for getting a high response. It must be mounted to the nearest position from the excitation source. Subsequently, the operating temperature of the AE sensor should not exceed 100 °C. Therefore, the AE sensor is mounted on a sensor mounting plate which is having a bolted connection from the heat plate. There is a ceramic heat insulator placed between the sensor mounting plate and heat plate and fastened through the bolted connection as shown in Figure 3.24. The use of the ceramic insulator is to prevent heat transfer from the heat plate to the AE sensor mounting plate which will reduce the effect of heat on the system accuracy of the scratch tester. Further, the AE sensor is connected to the DAQ. During the scratching process, the DAQ acquires and processes the raw signals and it provides acoustic peak (APK) values along with average

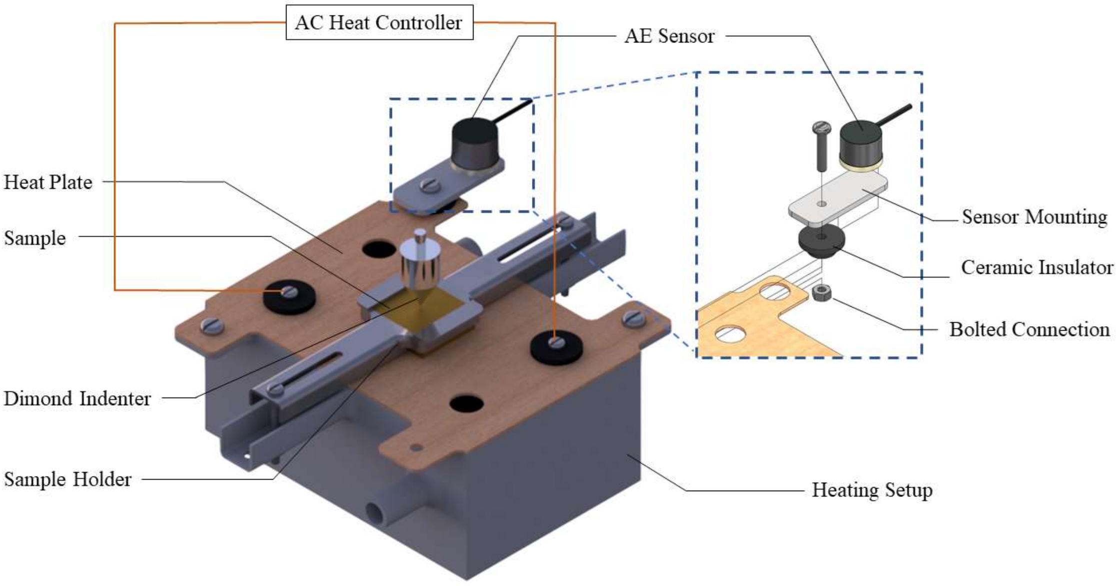


Figure 3.24: Insight of the arrangement of heating setup, indenter, and AE sensor placement

signal level (ASL) values. These APK and ASL values are continuously recorded and displayed on a computer so that the complete process can be monitored during scratch tests being performed.

3.9 Summary

In this chapter, one of the tasks was to prepare 45S5 bioglass samples for different experiments. These samples are prepared with casting method followed by heat treating, cutting, and polishing. The other task was to design and development of a portable heating setup for elevated temperature experiments. Therefore, an advanced lab-made portable multipurpose heating setup is developed to perform numerous elevated temperature operations on hard and brittle materials, such as machining, elevated temperature scratch and indentation tests, grinding, etc. The heating coil and controller used in the portable heating are designed to work with domestic electricity connection i.e. 220 V AC and 15 Amp. The heat plate of the setup is designed using the Autodesk Inventor stress simulation module. The further tasks were to develop different experimental setups using this portable heating setup. Therefore, the experimental setup for the study of traction forces at elevated temperatures during micro scratch tests, the experimental setup for effect of temperature on brittle-ductile transition and critical depth of cut, and the experimental setup for study of acoustic emission (AE) output During elevated temperature scratch test are also described in this chapter.