CHAPTER 2: EXPERIMENTAL SET UP OF FLOW FORMING

The literature survey discussed in chapter 1 provides the basis for designing of experimental setup using inhouse facilities. The results proposed by different researchers such as optimum attack angle for roller, roller feed rate, mandrel RPM etc., are taken into consideration while planning for the designing of experimental setup. The current chapter discusses the experimental setup used in the flow forming of samples and the design and fabrication of the elements of flow forming setup viz. roller assembly, preform design and other attachments.

2.1 Planning of Flow forming

The objective was to design a setup that can economical yet effective to perform the flow forming operation with the present facilities generally present in a fabrication shop. The main challenges were:

i. Identify a machine that can provide strength and torque so as to perform flow forming on aluminium samples.
ii. Holding of mandrel
iii. Holding of roller assembly which can move provide relative motion of tool with rest to a workpiece.
iv. Designing the mandrel
v. Designing of preform so that it can be held on the mandrel
vi. Type of flow forming- forward or backward flow forming.

2.2 **Selection of Machine Tool:**

The requirement of relative motion between the workpiece and tool is similar to the motion provided by lathe operation. So a lathe machine NH12 was chosen for the experimentation.

2.3 **Design of Preform**

The dimension of the preform was decided based on Lathe specification and on the material availability. The preform of Al6101 T6 was fabricated from the material that was supplied by M/s Hindalco in the form of pipe of thickness 5 mm and internal diameter of 72 mm. The preform of Al2014 and Al7075 was fabricated from the material that was supplied in the form of rod by M/s All India Metal Corporation, Mumbai.

The preform dimensions of Al6061T6 is shown in Figure 2.1

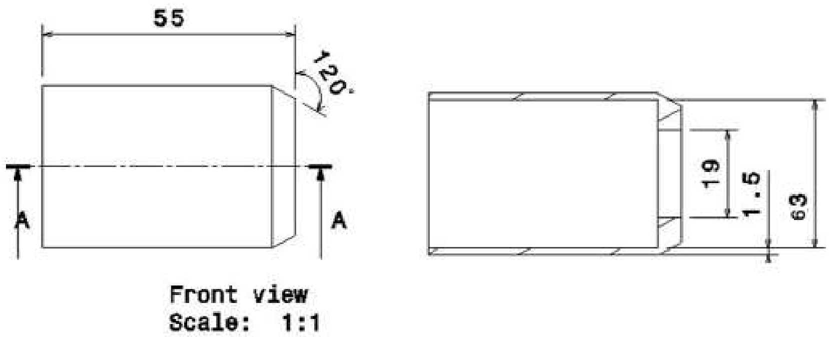


Figure 2.1: Preform dimension of Al6101

The preform dimension of the preform of Al2014 and Al7075 is shown in Figure 2.1. The design dimensions were decided based on supplied material from M/s All India metal Corporations. The materials were supplied in the form of rods of diameter 38mm. The inner diameter was limited by the mandrel dimension. Mandrel was fabricated from a rod of SAE 4340 material with the outer diameter of about 34 mm. The final dimension of mandrel after turning and grinding operation was adjusted to 32.4 mm as shown in Figure 2.4.

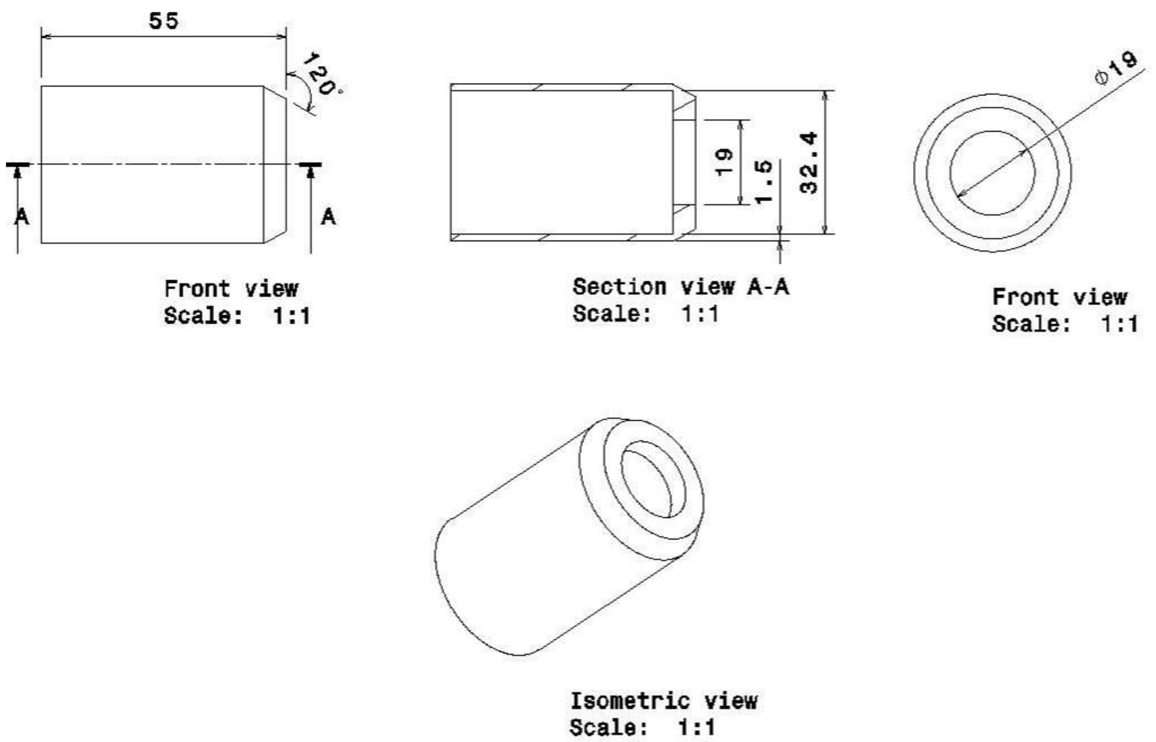


Figure 2.2: Preform dimension for Al7075 and Al2014

The fabrication of the preform was done inhouse. The process steps of fabrication followed to fabricate the preform was

i. Cutting of rods in length around 150mm using a band saw
ii. Hold the workpiece in a lathe machine and perform facing and surface turning of job to maintain OD to maintain 2 mm more than final OD dimension.
iii. Drilling of preform by ¾ inch drill. The length of drilling with ¾ inch (around 19mm) drill was done to distance greater than length of preform to about 53-55 mm (around 3-5 mm more) to ensure through hole in the preform.
iv. Drilling of preform by 1 inch drill. The length of drilling with 1 inch (around 25 mm) drill was done to maintain ID upto a distance of 45 mm . This resulted a stepped internal diameter of 1inch diameter upto 45 mm and diameter of ¾ inch diameter for the remaining preform length.
v. Maintain the inner ID by using a single boring tool.

vi. Maintain the thickness of the preform by OD turning to final dimension

vii. Now cut the workpiece of length 1mm more than required length. Cutting of job was done using Parting tool and hack saw.

Similarly perform the process steps (ii) to (vii) to obtain 3 sets of preforms.

viii. Reverse and Hold the fabricated preform in the chuck of lathe. Use soft thin metal strips in between chuck jaw and workpiece to avoid impression of chuck on the finished surface of preform.

ix. Perform the face turn on the back face which was rough due to hack saw cutting.

x. Finally, the chamfer angle was maintained equal to roller attack angle.

The wall thickness of preform was reduced to thickness 2 mm or less to ensure that flow forming forces are within the permissible limit that can be taken by the selected lathe machine.

The relief angle was taken as same as attack angle of the roller. This angle was provided to ensure the force exerted by the roller is gradually increased.

2.3.1 **Process plan of fabrication of Preform of Al6101 T6**

The preform of Al6101 T6 was fabricated from a thick pipe section. The fabrication process plan followed was:

i. Cut the pipe sections of length 60 mm from the supplied pipe**.**

ii. Hold the cut section in lathe chuck and maintain the inner ID using single boring tool upto 55 mm length. This ensured a stepped formation.

iii. Maintained the thickness by OD turning.

iv. Reversed the workpiece and performed face turning.

The prepared preform are shown in Figure 2.3

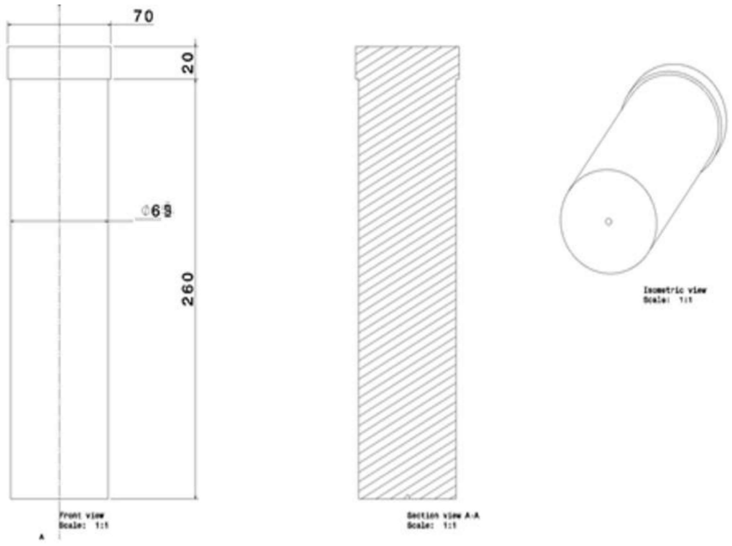
(a) (b)

Figure 2.3: Fabricated preform (a) Al2014 (b) Al6101

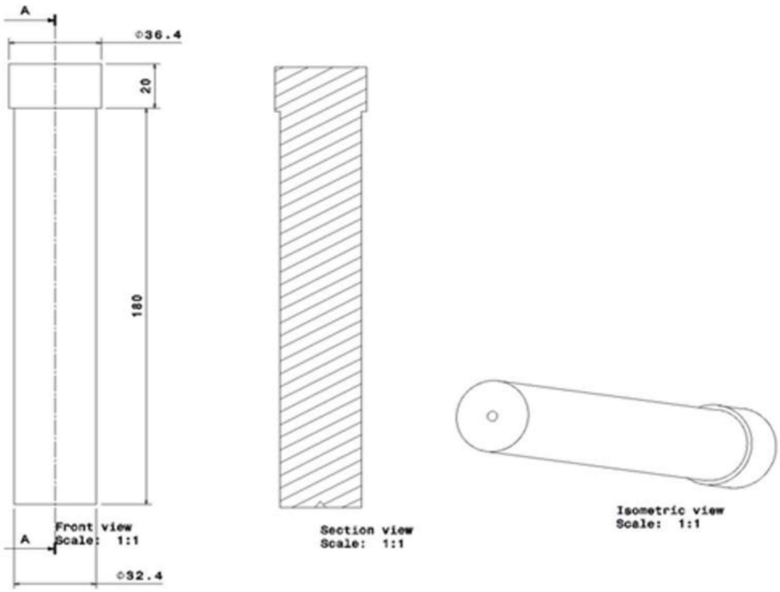
2.4 **Design of Mandrel**

Design of mandrel was done based on the design of preform and the estimated force for the operation. The mandrel was chosen in form of a solid mandrel. The material of the mandrel was taken as SAE4340 steel.

Two sets of mandrel were designed – one with OD as 63 mm for preform of Al6101 and the other with OD as 32.4 for preforms of Al2014 or Al7075. The design of mandrel for Al6101 preform and Al2014 is given in Figure 2.4. The end of mandrel are knurled for proper gripping.



(a)



(b)

Figure 2.4: (a) Design of Mandrel (b) Design of Mandrel for Al7075 and Al2014 specimen

2.5 Design of Roller assembly

The roller assembly contains the roller which was perform flow forming operations. It consists roller assembly attached to Y frame with nut bolt arrangement. The design criteria for the roller assembly were:

i. it should be able to take the flow forming load and should not fail under the conditions.

ii. The roller should rotate freely with the preform.

iii. It should be easily mounted in place of tool post of the lathe machine.

iv. As forward flow forming operation was to be done, the width of the roller assembly should be less so that more space is available for forming operation before roller assembly just touches rotating mandrel.

2.5.1 Roller Wheel Assembly

Figure 2.5 shows the initial design of roller wheel assembly that had been used for fabricating the roller wheel assembly. Roller wheel was fabricated from SAE 4340 rod of diameter 63mm. The design of roller wheel is given in Figure 2.6. The initial design was based on idea that roller will be supported on stepped bolt which would be free to rotate while lateral movement was stopped by tightening with nut as shown in figure

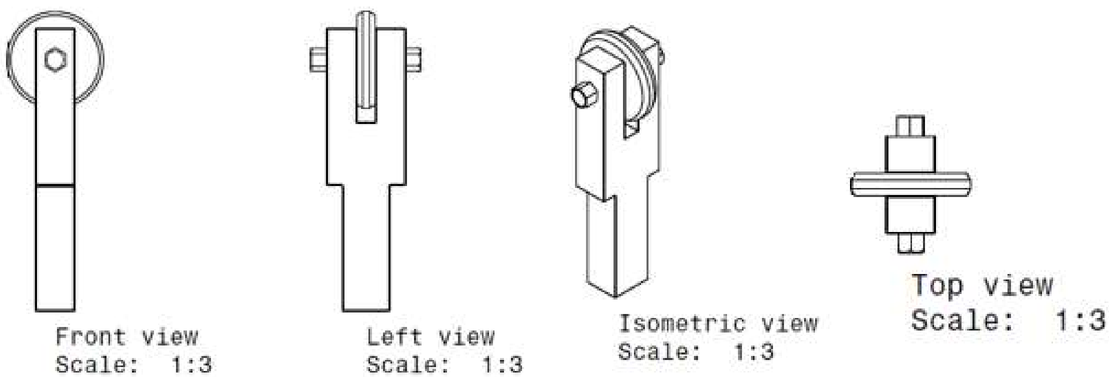
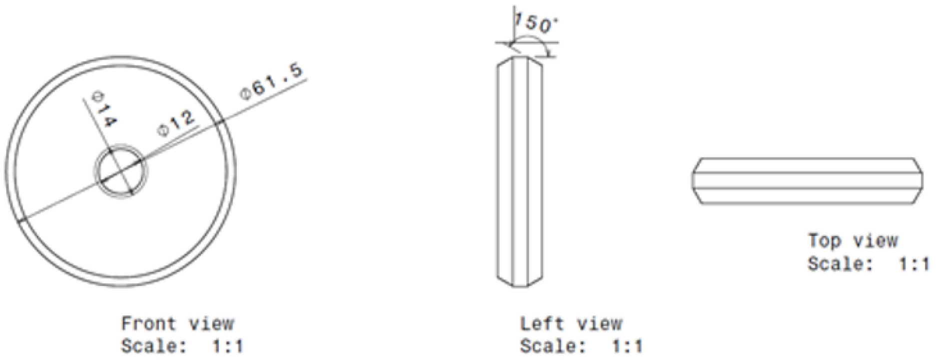
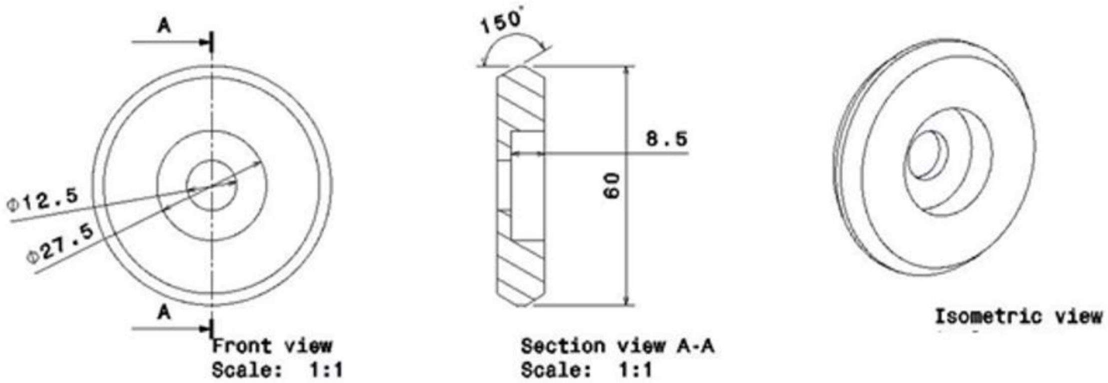


Figure 2.5: Initial design of roller assembly

The roller design used in initial roller assembly is given as Figure 2.6. The diameter of roller was decided based on literature and the limitations imposed by the setup and availability of material. A larger diameter roller would result in larger torque at center as the distance of interaction of roller – workpiece interaction would increase as diameter of the roller would increase. A counter bore of a diameter 14 mm was provided to position the roller. A sleeve of thickness 0.5 mm was used of OD 14 mm was used to position the roller and prevents its lateral movement along the bolt. The sleeve was inserted from the opposite side.



(a)



(b)

Figure 2.6: (a) Design of Roller (b) Modified design of roller

2.5.2 **Process plan for fabrication of Roller wheel**

The process steps followed in fabricating roller wheel were

i. Cutting rod of the thickness of about 13 mm

ii. Holding the part in the lathe and perform the facing operation at one side.

iii. Drilling a hole of 3/8 inch.

iv. Reverse the workpiece and then hold the workpiece in a designed stepped mandrel which was fabricated inhouse. Using nut tighten the mandrel from the other end as shown in Figure 2.7. Perform facing from both sides in same setting.

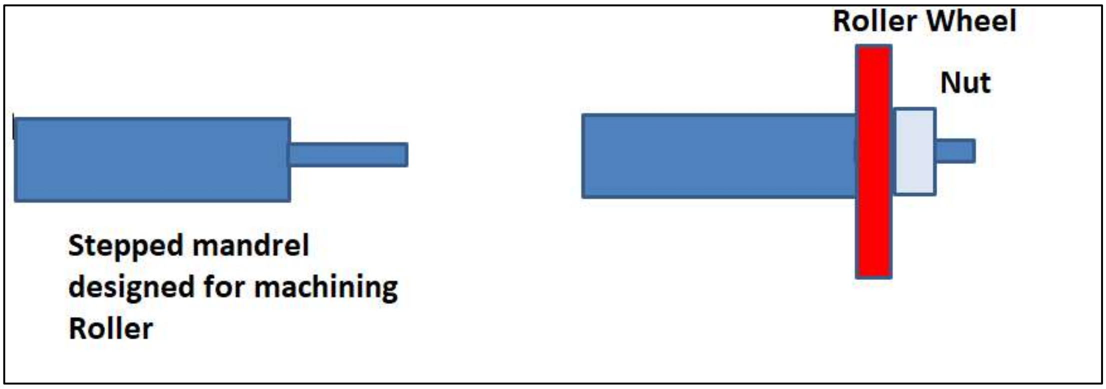


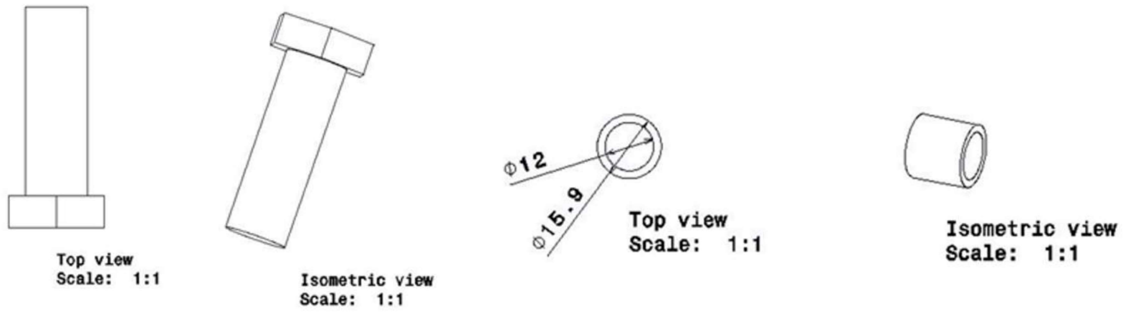
Figure 2.7: Fabrication Setup for Machining Roller

v. Without changing the setting, perform chamfering operation equal to attack angle from one side and equal to relief angle. In our case attack angle and relief angle are taken as same.

vi. Remove the sharp edges by a hand file and provide a round edge to reduce the possibility of stress concentration.

2.5.3 **Design of bolt and Sleeve arrangement**

Figure 2.8shows the bolt and sleeve. The bolts, nuts and sleeve were fabricated. The bolt and nut were used to hold the roller in the roller assembly. The sleeve would laterally adjust the position of roller.



(a) (b)

Figure 2.8: (a) Drawing of bolt (b) Drawing of sleeve

2.6 Design of Y Frame (Roller holder):

The Y frame is made from bright steel which was supplied in form of a plate of cross section 25mm X 50mm. The design of Y frame is given by Figure 2.9.

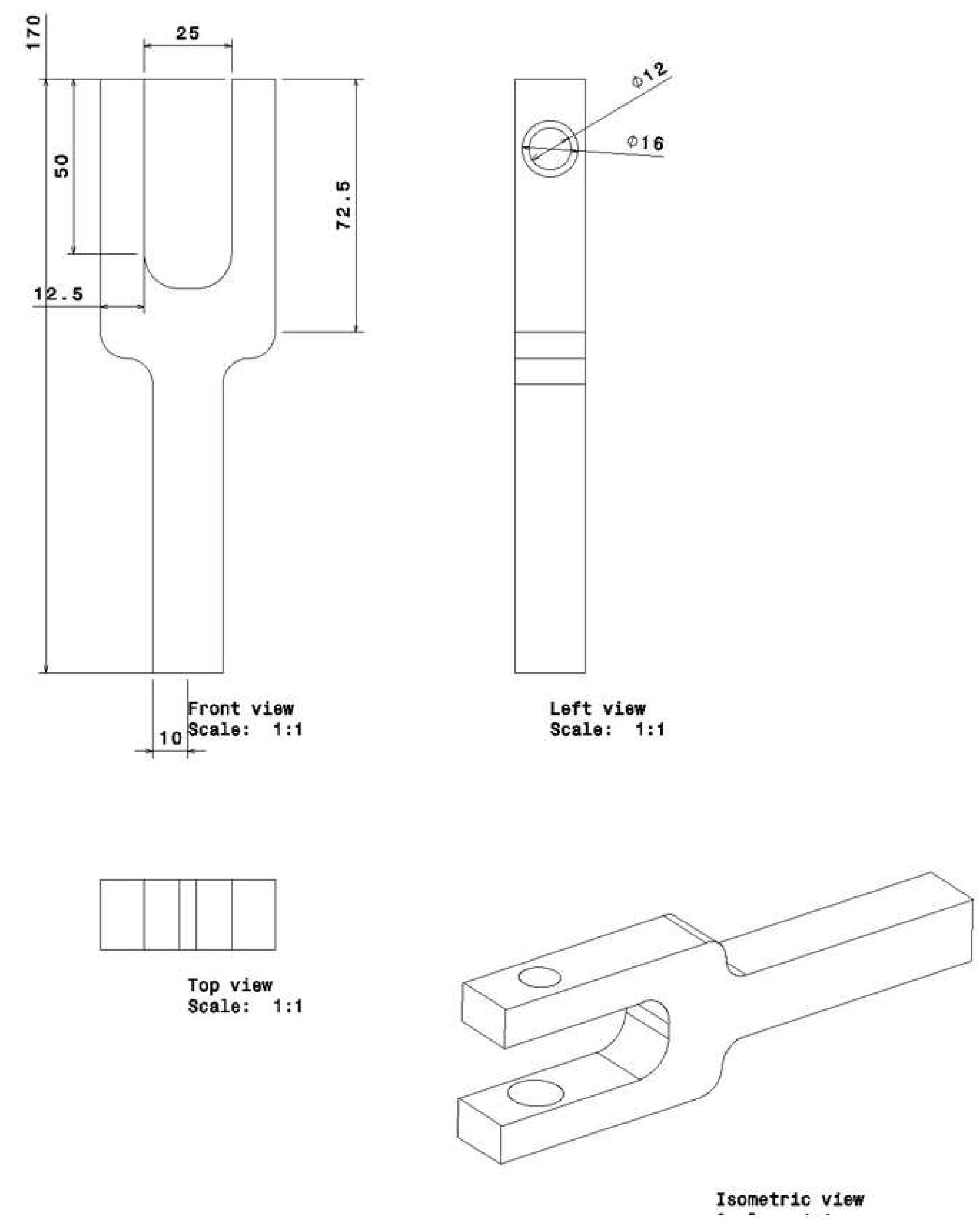


Figure 2.9: Design of Y Frame

2.6.1 **Assembly of Roller Assembly**

The Figure 2.10 shows the assembled roller assembly that was initially used for flow forming operation. Though the roller was free to rotate about the horizontal axis, during operation some play was generated. This resulted in rubbing of rollers with the Y frame flange and also freezing of rotation under loading condition which resulted in chip formation. These observations are discussed in chapter 5.

Figure 2.10: Roller assembly used for initial flow forming operation.

A modified roller assembly was then designed and use of thrust bearing and ball bearings were incorporated in the design which can take up axial and radial loads. Roller assembly and the Y frame was modified. The modified designs of roller and Y frame are given in Figure 2.6 and Figure 2.11 respectively.

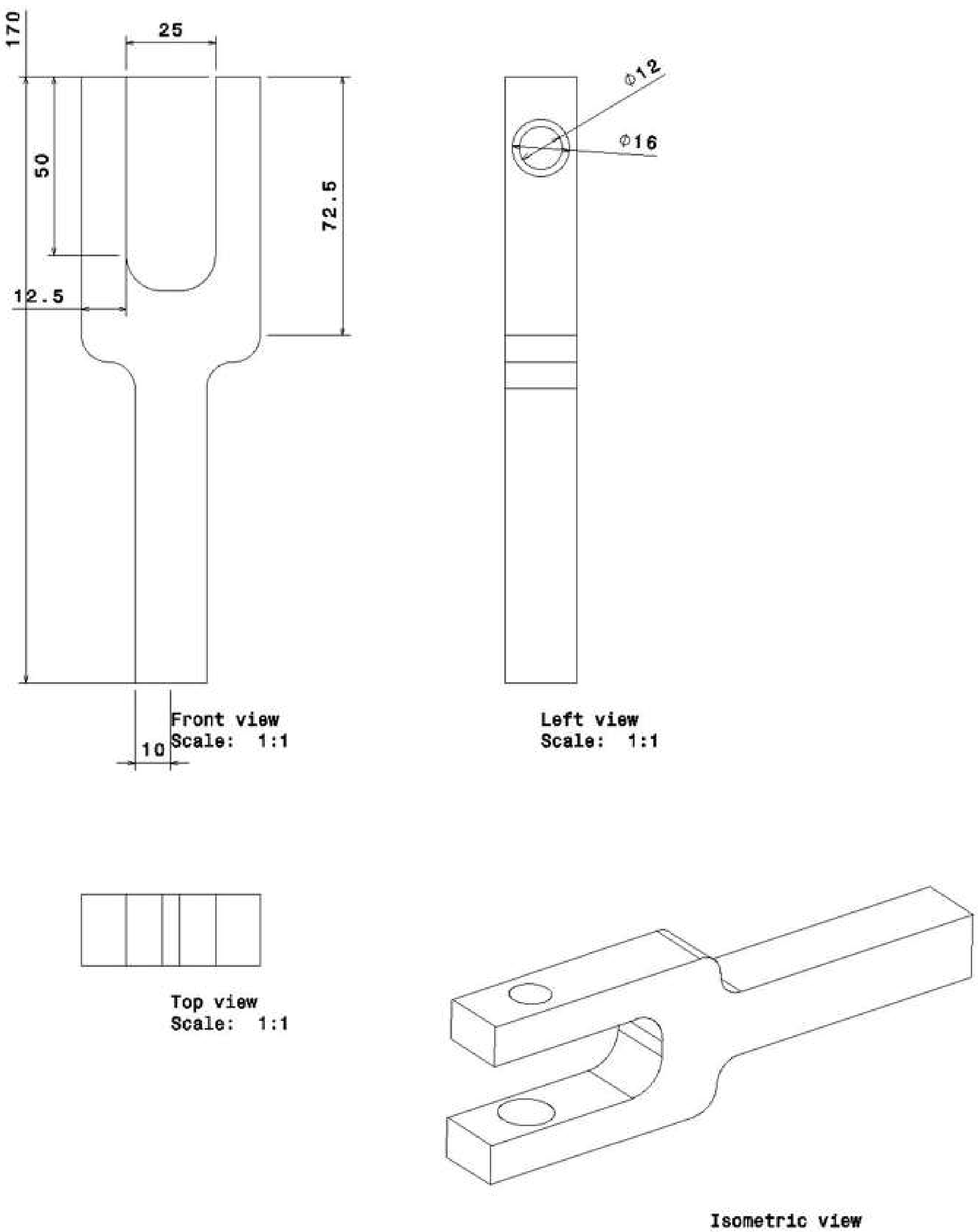


Figure 2.11: Modified design of Y frame

Figure 2.12 shows the different parts of the modified roller assembly and Figure 2.13 shows the complete roller assembly.

Figure 2.12: Parts of the modified roller assembly

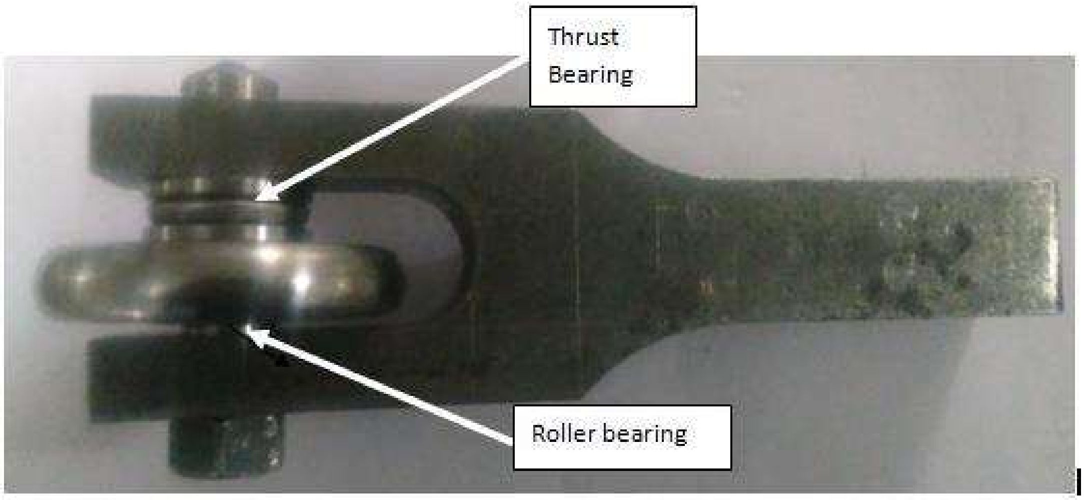


Figure 2.13: Modified Roller assembly

2.7 Flow forming Set up

Figure 2.14 shows the overall step up for the flow forming operation. The mandrel was held in the chuck and supported by the head stock. The preform was put over mandrel and held in chuck. The roller assembly was supported on the carriage by removing tool post.

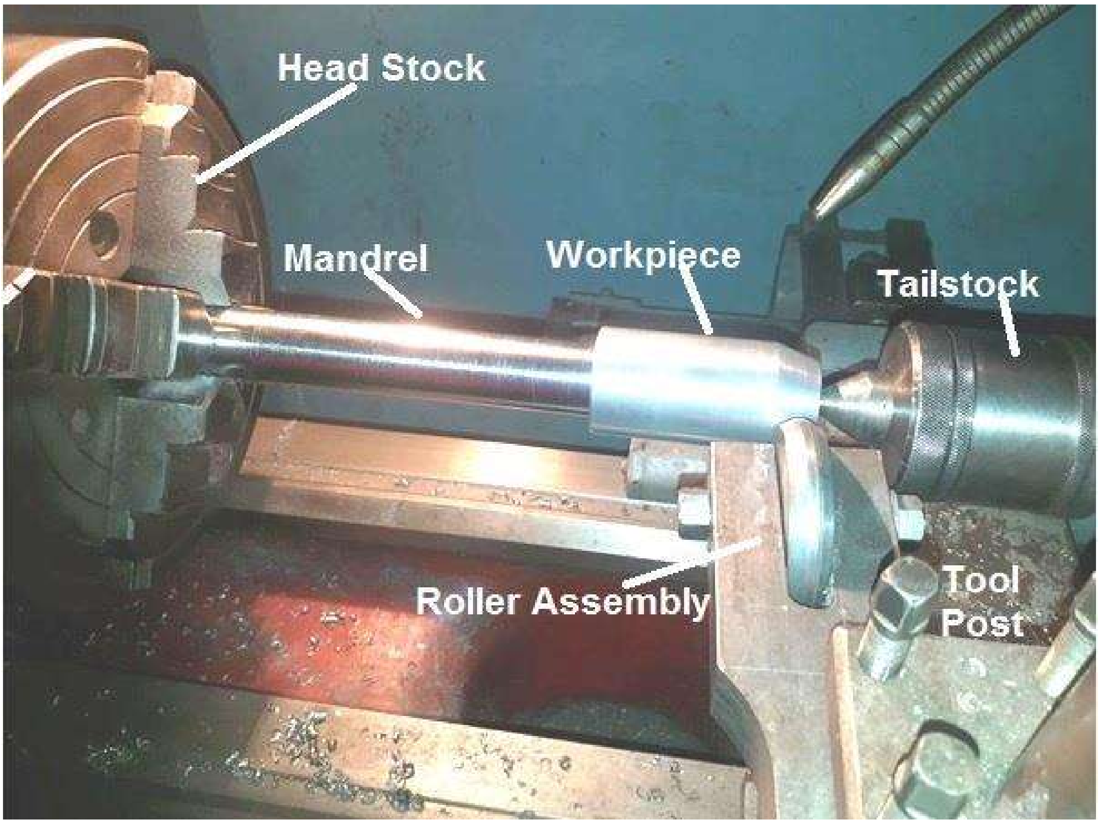


Figure 2.14: Flow Forming setup developed at IIT (BHU), Varanasi

2.8 Data acquisition system

A lathe dynamometer was set to measure the flow forming force. The Tool Dynamometer is a cutting force measuring instrument used to measure the cutting forces coming on the tool tip on the Lathe Machine. The lathe dynamometer was supplied by M/S TESTMASTER Howrah. The sensor is designed in such a way that it can be rigidly mounted on the tool post, and the cutting tool can be fixed to the sensor directly. This feature will help to measure the forces accurately without loss of the force. The sensor is made of single element with three different Wheatstone strain gauge bridge. Provision is made to fix 1/2" size Tool bit at the front side of the sensor. The tool tip of the tool bit can be grind to any angle required. Forces in X - Y - Z directions will be shown individually & simultaneously in three Digital Indicators Supplied. The different components of the lathe dynamometer is given in Figure 2.15

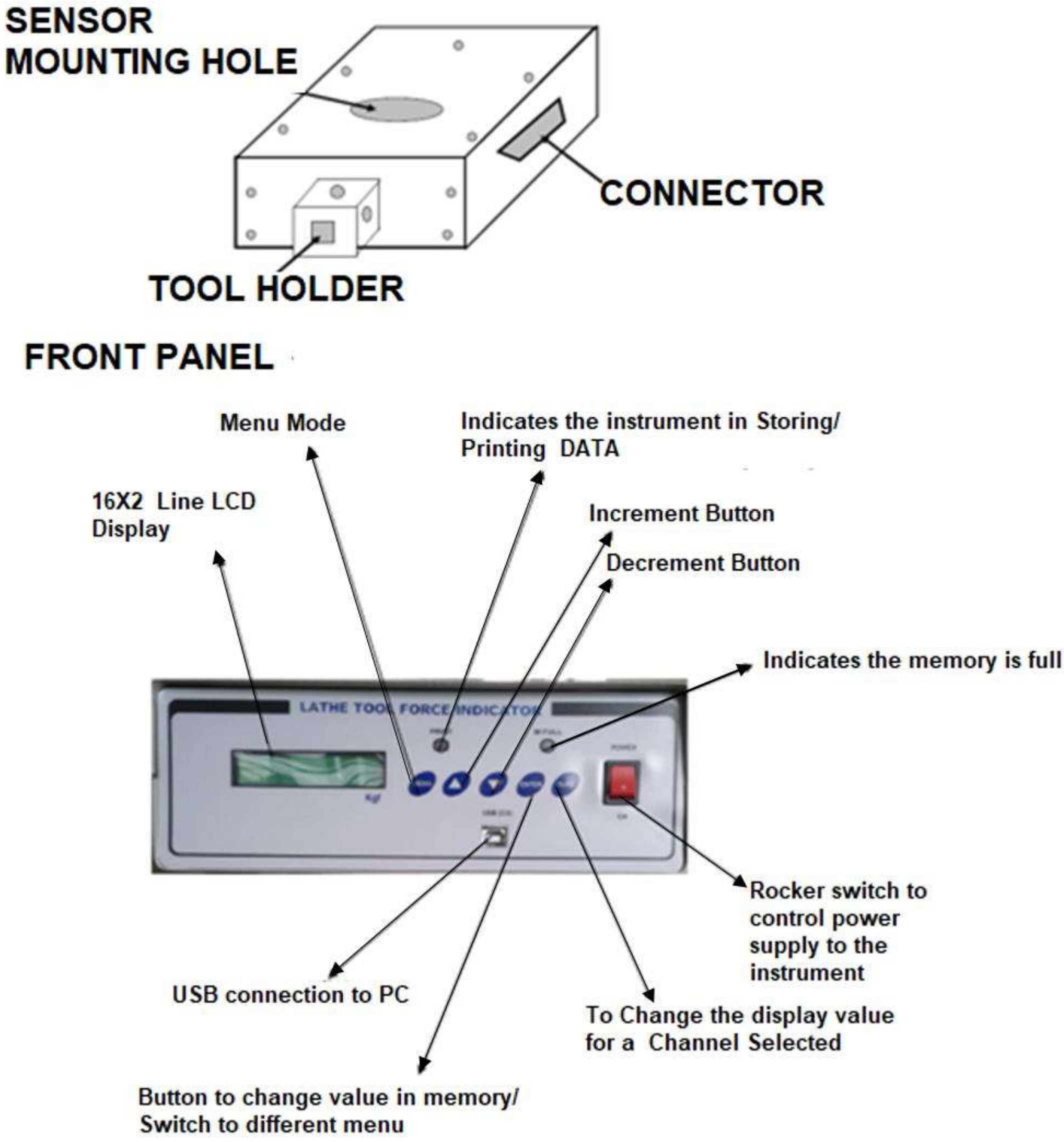


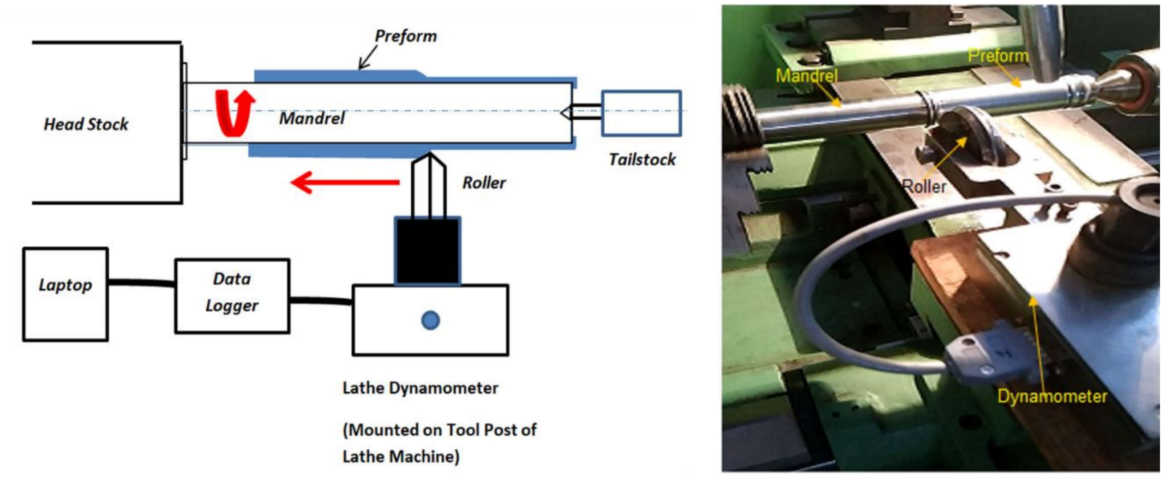
Figure 2.15: Lathe dynamometer (supplied by M/s Testmaster)

The specification of the lathe dynamometer is given in Table 2.1

Table 2.1: Lathe Dynamometer specifications

Lathe Dynamometer	
Manufacturer	Testmaster
Max Capacity (kG)	500Kg (in X , Y and Z)
Sensor Type	Strain gauge based 350 ohm bridge
Tool Mounting Type	Square hole of 20mmSq, 30mm Depth to mount cutting tool.
Sensor mounting	1 inch hole in the middle of the sensor

The layout of data acquisition system used is shown in Figure 2.16



(a) (b)

Figure 2.16: (a) Layout of data acquisition system (b) Actual measuring setup used during investigation with Lathe dynamometer

2.9 Heat treatment of Preform

The preform of Al6101 T6 are deformed in as supplied T6 condition while the preforms of Al2014 and Al7075 were deformed in as supplied condition as well as in annealed condition. The annealing was done by heating the samples at 470 ºC for 3 hours for Al7075 T6 and 413°C for 2 hours in Al2014 samples and then cooling the samples in the furnace. The samples were heat treated in heating furnace available inhouse.

Samples were cut from the specimen and XRD analysis, hardness testing and EBSD was done.

2.10 Experimental plan and analysis

Five samples of Al6101 T6 samples were prepared and process parameters used are summarized in Table 2.2

Table 2.2: Preform Condition and experimental process parameters for Al6101

Sample Name	Temper Condition	Process Parameters
FF01	T6	Mandrel RPM= 420 Feed rate = 0.04 mm/rev
FF02	T6	Mandrel RPM= 250 Feed rate = 0.04 mm/rev
FF03	T6	Mandrel RPM= 250 Feed rate = 0.06 mm/rev
FF04	T6	Mandrel RPM= 420 Feed rate = 0.06 mm/rev, 0.12mm/rev
FF05	T6	Mandrel RPM= 420 Feed rate = 0.06 mm/rev

Five samples of Al7075 was prepared under different temper condition. The temper conditions and the process parameters are summarized in

Table 2.3

Table 2.3: Temper Condition and Process parameters used in flow forming Al7075

Sample Name	Temper Condition	Process Parameters
7F01	T6	Mandrel RPM= 420 Feed rate = 0.04 mm/rev
7F02	T6	Mandrel RPM= 420 Feed rate = 0.04 mm/rev
7F03	Heat treated	Mandrel RPM= 250,420 Feed rate = 0.04 mm/rev
7F04	Heat treated	Mandrel RPM= 420 Feed rate = 0.04 mm/rev
7F05	Heat treated	Mandrel RPM= 250, 420 Feed rate = 0.08 mm/rev

Preform samples of Al2014 was prepared and following process parameters were used during flow forming operation.

Table 2.4: Temper Condition and Process parameters used in flow forming Al2014

Sample Name	Temper Condition	Process Parameters
2014-1	T6	Mandrel RPM= 420 Feed rate = 0.04 mm/rev
2014-2	Heat treated	Mandrel RPM= 420 Feed rate = 0.04 mm/rev
2014-3	Heat treated	Mandrel RPM= 420 Feed rate = 0.04 mm/rev
2014-4	Heat treated	Mandrel RPM= 250 Feed rate = 0.04, 0.08 mm/rev
2014-5	Heat treated	Mandrel RPM= 420 Feed rate = 0.04, 0.08 mm/rev

2.11 Mechanical and metallurgical testing of preform and flow formed samples:

During the flow forming operation, in situ force measurement was done with lathe dynamometer. Figure 2.17 shows the flowchart of mechanical and metallurgical test that has to be conducted. After the flow forming operation is complete then the microhardness test was done on samples. Further surface roughness test on some samples on mandrel and roller surface and preform inner and outer surface.

Tensile testing of the undeformed and deformed samples were done. Miniature tensile specimens were prepared based on Barba law.

XRD test analysis was done on undeformed, annealed and flow formed samples. XRD analysis was done on Bench Top X-Ray Diffraction (BT-XRD (Model: Rigaku Miniflex 600 Desktop X-Ray Diffraction System) available at central instrumentation facility IIT (BHU), Varanasi. Samples that failed during flow forming were selected for the XRD test. Small section of the fractured region was cut out and the analysis were done that samples. XRD analysis was also done on the fractured part of the tensile specimen to study the mode of failure.

EBSD analysis has been done to study the crystal orientation. For EBSD, the samples were first cut from the preform and flow formed components. The samples were then mechanically polished with abrasive paper from P400 up to P2000 abrasive papers. Then the samples were polished with fine alumina sol. The samples were then electro polished at IIT Bombay. The samples were then tested for EBSD on Fei Quanta 3D FEG at IIT Bombay.

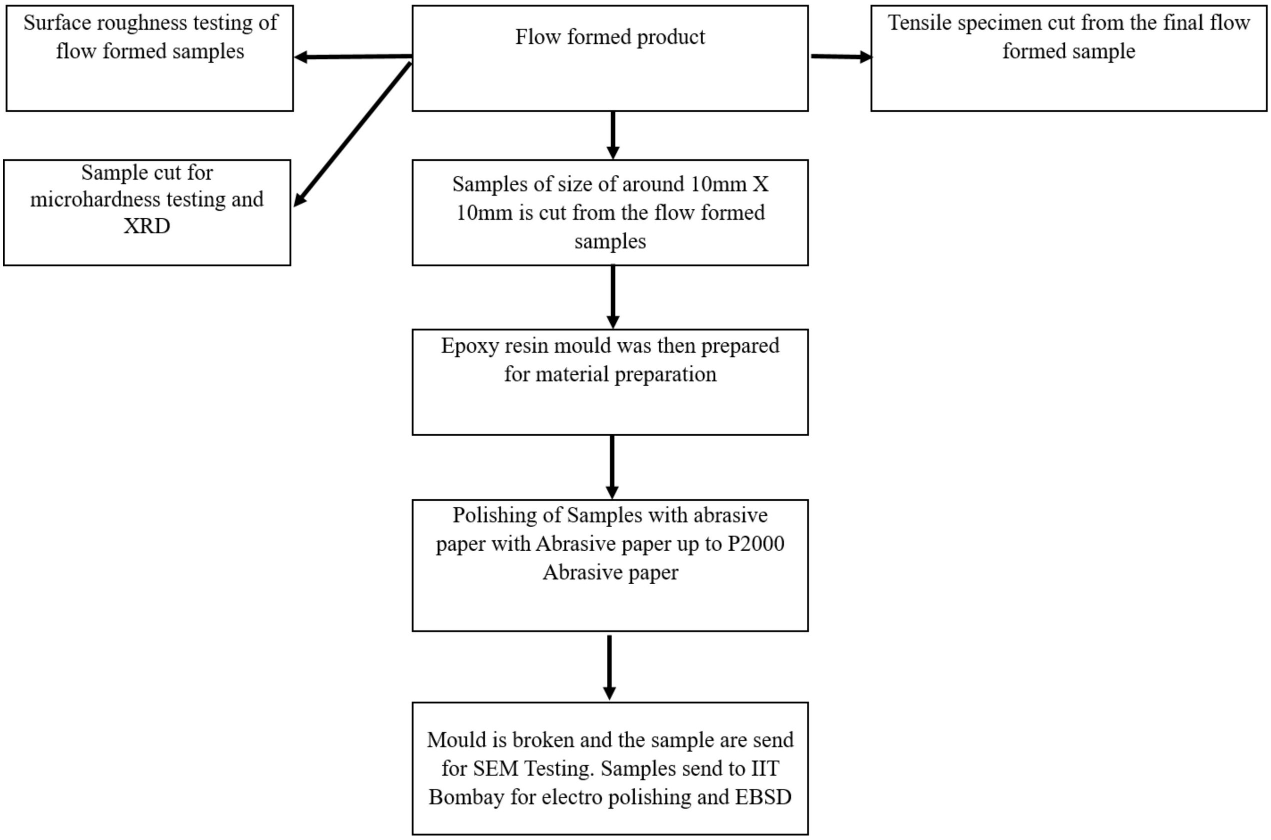


Figure 2.17 Flowchart for mechanical and metallurgical testing of flow formed product.