Use of Medium Density Fiberboard fixtures for Welding of a Formula SAE Vehicle

Khush Furia[1], Hrishikesh Damania[2], Gaurav Parekh[3], Jay Dagha[4]

[1-4] Student, Dept. of Mechanical Engineering, K.J. Somaiya College of Engineering, Mumbai, Maharashtra, India

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Abstract - *As a Formula student team, it was necessary to manufacture components of the vehicle accurately to fulfill the team's goals and meet each component's original design requirements. Our team had decided to go for a car with a space frame chassis and since it is the skeleton of the car, we had to make sure that the chassis withstands all the loads acting on it. Along with a good design, it had to be manufactured accurately using cost-effective methods. Therefore, our aim was to come up with a technique that is both flexible as well as accurate in welding. As we also had to weld other components of the car along with welding the whole space frame. Hence, to ensure the overall structural rigidity of the chassis, welding accuracy was of major importance. Medium Density Fiberboard (MDF) provides a much flexible and accurate method of welding the chassis, as the MDF does not get warped under heat and its machinability is simpler as compared to the metal fixtures. MDF fixtures were designed using SolidWorks® as per the requirements different techniques and methods were used to accurately locate and weld different components. Using 3-Axis CNC machine fixtures were fabricated and the tool path was assigned to the machine using Autodesk® Fusion 360. After complete fabrication, we also validated with the CAD model using Coordinate Measuring Machine (CMM) and the results obtained were quite satisfactory. Moreover, when compared to previous methods it was more accurate where the maximum deflection observed was less than 2mm. In addition, this method is reusable and can be used again with alterations in the principle design and for any kind of repair or change in the original model. Thus, MDF provides a wider scope in welding and other manufacturing processes.*

Key Words: Medium Density Fibreboard, Fixture, Milling, 3-Axis CNC, Welding, Steering Wheel, Accumulator, FSAE.

1. INTRODUCTION

The chassis for a formula student vehicle is a framework that supports and protects the driver and various components present on the vehicle [1]. Therefore, for this purpose, a chassis design through an iterative process consisting of different computer-simulated analysis is done and the final model is finalized [2]. After completion of this step, the next step is manufacturing the chassis. Manufacturing accuracy is a major factor in determining if the chassis is manufactured in the best possible replica of the final CAD model [3, 4]. As the inaccuracies while welding of the space frame can lead to shifting of the nodes, which would be contributing to the modulation of the overall stiffness of the chassis [5]. Here, welding accuracy not only plays an important role to hold the chassis nodes in a precise location but is also important while welding the mounts for different components and also the individual welding of those components [4, 5, 6]. A minute shift in the joining point of the welding or warping or deformation of the part/parts during the process can affect the overall working of the system. For example, if there is a slight angular or positional change in the mounting points of the suspension bays the overall kinematic definition of the suspension changes, and in short, the dynamics of the vehicle changes [3, 5, 7]. Another example is the placement of the aerodynamics elements that are attached to the vehicle, if those attachment points are inaccurate with reference to the chassis the overall aerodynamic performance may get hamper due to it [7]. Thus welding must be done with utmost accuracy. Welding generally requires fixtures. Fixtures hold the part to be welded in the required position and do not allow any deviation during or after welding [8]. However, there are also fixtures, which assist in performing various other kinds of machining as well. The initial method of welding we followed included the use of metal fixtures. Where the only advantage we discovered with metal fixtures is the ease of manufacturing of these fixtures in a short period. In addition, disadvantages while working with these fixtures for manufacturing of different components are warping of these fixtures because these fixtures need to be welded first on a metal sheet base, where ensuring that these fixtures were at the right angle with respect to the base was a tedious task. Next, these fixtures were designed as two-dimensional hence for the tubes of the space frame it only provided a line contact to hold these tubes in place, and for some long tubes, multiple holding fixtures became necessary. Welding of some components requires days to finish, where over a period due to the self-weight metal fixtures tend to bend which makes it difficult to manufacture and in short leads to inaccuracies. Then the overall cost of manufacturing metal fixtures got exorbitant for the components that were not uniform as the tubes therefore we needed to mill fixtures out of the metal block using 4-Axis or 5-axis milling machines. MDF fixtures are not hard as metal therefore can be machined easily on a simple 3-axis milling machine [9, 10]. In addition, it provides an additional advantage to machine intricate shapes effortlessly and smoothly at high machining speed without hampering the part. Even though the material cost of the MDF sheets is higher as compared to metal fixtures, its proficient, reliable, and fast manufacturing makes it better to weld components and helps in reducing needless errors and failures due to its composition [9,10]. Using MDF fixtures, we were able to provide enough area contact to hold the tubes and discard redundant multiple fixtures that were needed with metal fixtures. Then the issue of warping metal fixtures can be eliminated with MDF when two or multiple fixtures needed to support each other. These initial ideas pushed us to opt for MDF as our golden material using which we emerged with many unique ideas ahead.

2. MATERIAL AND TOLERANCE CONSIDERATION

2.1 Material Selection

We had two options for the type of Medium Density Fiberboard (MDF) Sheets:

Interior Grade MDF: It has a very smooth surface, density and the structure is consistent. This makes it more suitable for the application which requires more painted, lacquered and routed finish [10].

Exterior Grade MDF: It provides a better finish than its interior counterpart, making it suitable for laser cutting and milling operations. It has the added benefit of being moisture resistant [10].

We decided to go ahead with Exterior Grade MDF because of its moisture-resistant nature.

2.2 Fits and Tolerances

As no manufacturing procedure is completely accurate, we had to consider the fits and tolerances of the fixtures while designing them. To ensure the stability of the fixtures once assembled, we required a transition fit.

To achieve a tight fit, we carried out a tolerance test where we manufacture one male part according to the CAD, and 9 different female parts. The different female parts had varying tolerances from -0.20mm to +0.20mm, with an increment 0.05mm.

It was found that the best fit was achieved with a tolerance of +0.05mm. Thus, all female parts in the fixtures had a tolerance of +0.05mm.

3. ACCUMULATOR CONTAINER FIXTURE

The welding of the accumulator container must be accurate because we want the internal walls of the container to fully support the cell stacks. If there were too much clearance, the stacks would be pulled by the bolt and not be properly supported. On the other hand, if the clearance is too less, the cell stack will cause wear and tear on the insulating cover of the inside walls of the accumulator due to rubbing while assembly and disassembly of the pack. This may cause exposure to the metal surface, which is very undesirable to maintain the insulation and safety of the battery pack. The overall dimension of the pack is also very important since the mounting points must be precisely located to match those points on the chassis side.

The accumulator container was going to be manufactured using aluminum sheets by welding them together like an open box. To do so a fixture set up with a particular pattern was made as in Fig -1, which would ensure the sheets are oriented properly and they are not displaced while welding. It was designed to have these slots made in an MDF sheet along with holes as shown in Fig -1. The aluminum sheets to be welded would be arranged in these slots and the holes would have blocks made up of MDF to make sure this arrangement does not change before as well as after welding is completed.

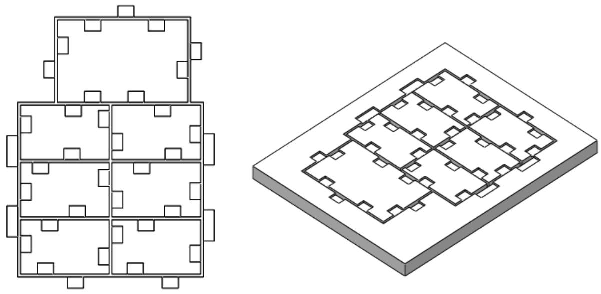

Fig -1: Accumulator Container fixture

4. STEERING MOUNT FIXTURE

Another such part that needed to be welded with accuracy was the steering mount. The mount shape was as shown in Fig -2. The steering mount guides the steering column, which then connects to the continuous velocity joint. The angle of the guide is an important factor for deciding whether to choose a double UV or a single UV joint, further this angle is found from a kinematic iteration of the steering geometry around the suspension of the vehicle. So, if this angle changes there is a good chance of the steering geometry changing. Further ergonomics data is used to make sure that the location of the mount is suitable for the driver. These factors make it necessary that welding of the steering mount to the chassis member be precise.

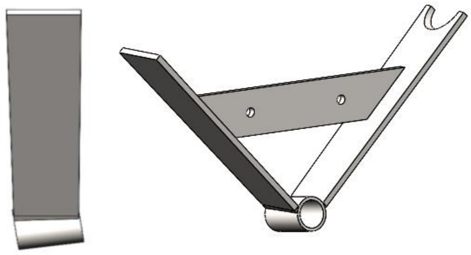

Fig -2: Steering mount

To meet the requirements of the design model it was decided to design a fixture in such a manner that it had a slope along with those different locating points, with this it was necessary to make sure that the parts to be welded are properly held together in the correct position. For this purpose, the fixture had locating holes that also acted as holding points. In addition, to make sure the hollow cylindrical part does not deform during welding a small MDF bush was also used to prevent it from distorting.

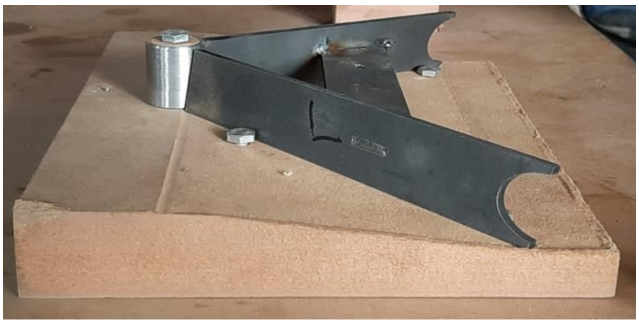

Fig -3: Fixture holding parts in place for welding

5. SPACE FRAME FIXTURES

5.1 Design Constraints and Considerations

1. The design of the fixtures was constrained by the manufacturing machines and tools available to us. As the machine available was a 3-axis CNC machine, it was necessary to have a separate plane for drawing each fixture as per the orientation of the tube supported. To do this, we had to design a unique fixture for each chassis member such that when observed in the top view, the fixture and the chassis member are at the same angle with the x-axis, shown in Fig -6 and Fig -7.

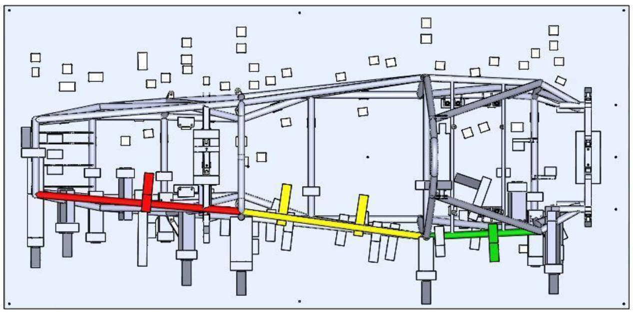

Fig -4: Top view of chassis and fixtures

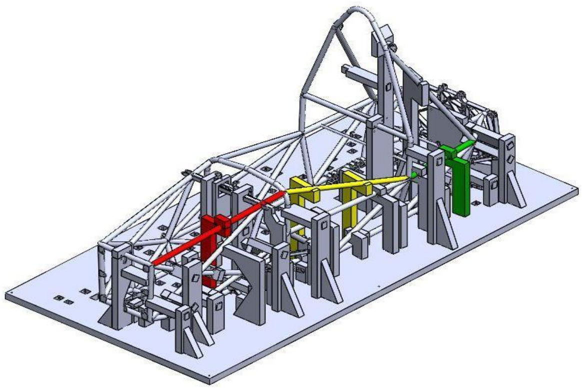

Fig -5: Isometric view of chassis and fixtures

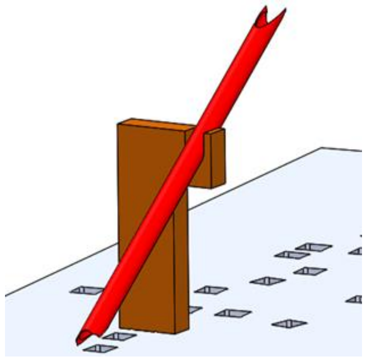

Fig -6: Example of fixture supporting a tube

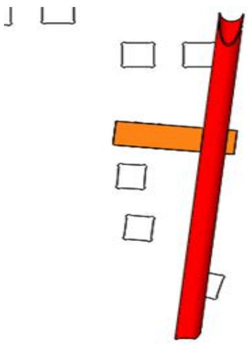

Fig -7: Fixture plane parallel to tube's axis

2. The next constraint we had was for near-vertical tubes. Manufacturing a single piece fixture for some tubes was not possible on a 3-axis machine unlike the case shown in Fig -9. Hence, such fixtures had to be made in multiple parts as shown in Fig -8.

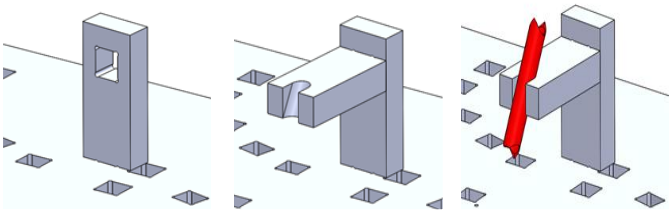

Fig -8: Tube supported by two fixture

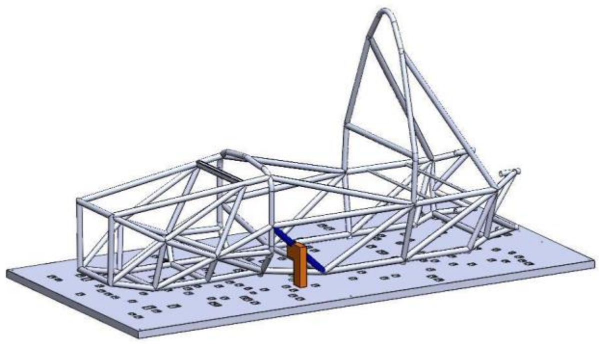

Fig -9: Fixture supporting near vertical tube

3. The cutting tool used for machining had a diameter of 6mm so we had to design the base plate according to it. The design also had to be done ensuring ease of assembly and minimum machining time. In order to do this, a special butterfly-like shape was made at each female part. Additionally, each male part was given a fillet such that the edges of the fillet on the male part are coincident to the butterfly made on the female part.

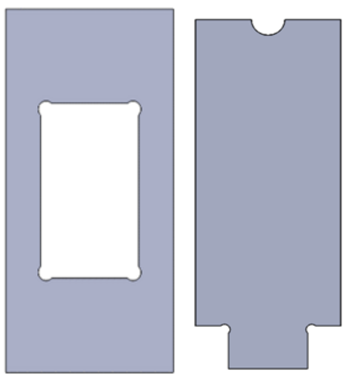

Fig -10: Female part with Butterfly at corners and male part with Butterfly at part comes in contact with base plate

5.2 Easy Assembly and Removal of fixtures

- The fixtures were designed in such a way that they could be assembled very easily.
- The 'Male' part of the fixtures held individual chassis members, while the 'Female' part was the base plate. The base plate had holes cut in it wherever the male part was supposed to be fitted.
- Due to this, the fixture assembly was like a giant "Jig-Saw" puzzle and could be assembled in just over 2 hours.
- In the case of metal fixtures, we had to cut each fixture to release the chassis, but the MDF fixtures were designed in such a way that we were able to remove the fixtures easily without much hassle.
- Additionally, an origin was marked on the base plate, to make it easy to locate the origin in case any further holes need to be drilled on the base plate again.

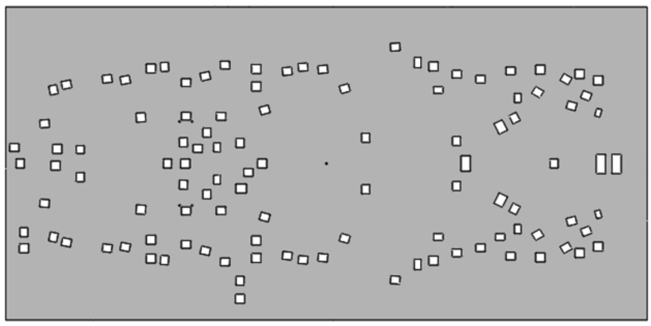

Fig -11: Base Plate

5.3 Key Considerations and Features

1. Use of caps:

We realized that while welding, some of the tubes (specifically the uppermost ones) would not stay inside the walls of the fixtures. To solve this problem, we designed "caps" that would constrain the tubes from the top as well.

These caps were attached to the main fixtures using steel plates and bolts of diameter 6mm.

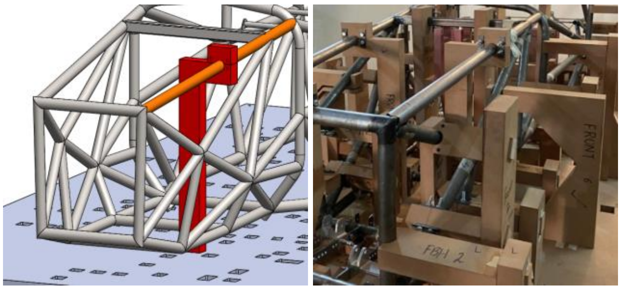

Fig -12: Caps show in CAD and actual

2. Use of Wedges:

During design, it was observed that some of the fixtures were longer than 500mm, while some were even longer than 1000mm. These fixtures would bend under their own weight and the deflection at the top would result in loss of accuracy.

To overcome this, two methods were developed:

a. In fixtures longer than 1000mm, such as the fixture for the main hoop, using a rectangular wedge between symmetrical fixtures like in Fig -13.

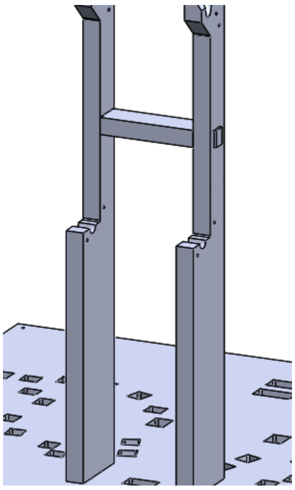

Fig -13: Use of rectangular wedge

b. Triangular wedges attached to the base plate behind long fixtures to prevent deflection as in Fig -14.

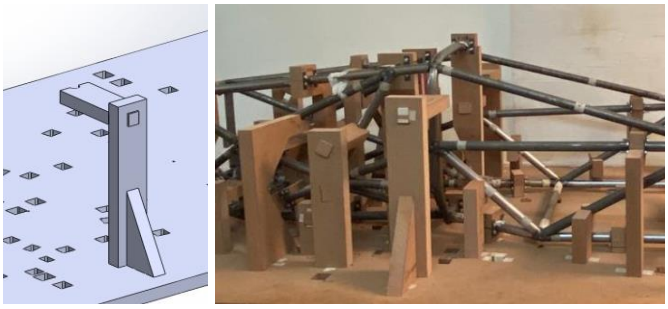

Fig -14: Use of triangular wedge

5.4 Designing for Important Mounting Points

- Suspension mounts being one of the most important parts of the vehicle, very high accuracy is required [3, 5]. For this, special fixtures were designed and these fixtures were used along with a “Suspension Fork”.
- A suspension Fork is a part milled from mild steel, it acts as a locator and spacer to weld the suspension mounts. The fork is bolted to the MDF fixture taking reference directly from the origin (i.e. Base Plate) this ensures high accuracy.
- For the aerodynamic body mounts, reference was taken directly from the chassis, as it was not possible to have separate fixtures for them.
  - As the Rear Bulkhead is flat, it was constrained easily using two big fixtures- making a sandwich-like assembly.

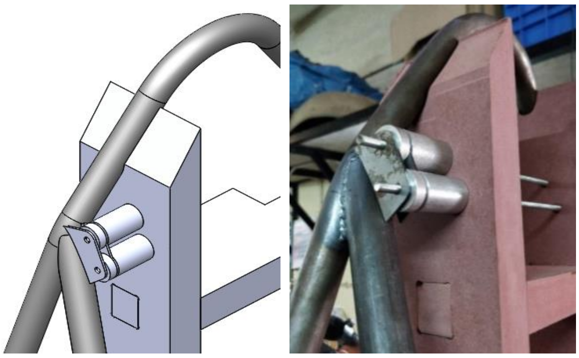

Fig -15: Fixture for aerodynamic body mounts

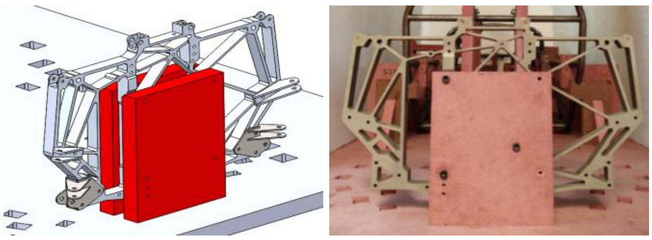

Fig -16: Fixture for rear bulkhead

5.5 Fixture for Holding Bent Tubes

In a Formula Student car, the chassis requires two roll hoops i.e. the Front Hoop and the Main Hoop, which is to be made out of a single metal tube as stated in the competition rulebook [1]. So according to our design, these roll hoops were made from a single tube and bent into a particular shape. After they are bent, to maintain these shapes of the roll hoops in previous years it was observed that due to residual stresses after bending, the tubes would spring back leading to the deformation from the required bent shape. This deformation meant that the roll hoops would not fit into the fixtures, which would lead to inaccuracies in the chassis [1, 11].

To prevent this, we used MDF to make fixtures to hold these tubes into place [11]. The fixtures were made using 3-axis CNC machining and sticking small blocks of wood on the upper surface of the tubes. Additionally, clamps and screws were used to hold the tubes into the fixtures.

Fig -17: Fixture for holding bent Main Hoop into place

6. MANUFACTURING OF FIXTURES

Manufacturing of fixtures was done using a 3-axis CNC Machine due to which we can only give a 2D cut or a 3D cut. The cut is done by giving a toolpath to the CNC machine using Autodesk® Fusion 360 software [12]. In this machine, there was a limitation of using a minimum of 6mm end mill cutter. Hence, we use a 6mm end mill cutter to avoid the wastage of MDF. Initially, the MDF sheet is placed on the bed with the base plate and aligned in such a way that the edges of the MDF sheet is parallel to the bed and then it is clamped. Thereafter an origin is set on the MDF sheet. Also while nesting fixtures in a sheet, a minimum gap of 12mm between two fixtures was provided.

6.1 2-D Cut

For a 2-D cut, a CAD is imported and then the first step is to create a setup then define the stock size and orientation. Next, an origin is selected and placed on a stock. Then a particular tool was selected from a tool library i.e. for 2-D cut we only need a 6mm end mill cutter, after that a cutting depth is given [13]. The drilling tool path was assigned by defining start and final depth.

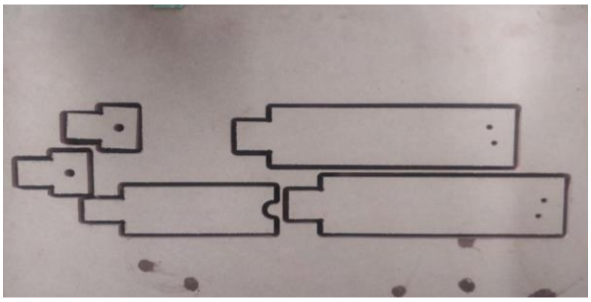

Fig -18: Fixtures after 2-D cut

1. First, a tool path is given to create the holes or slots in a fixture.

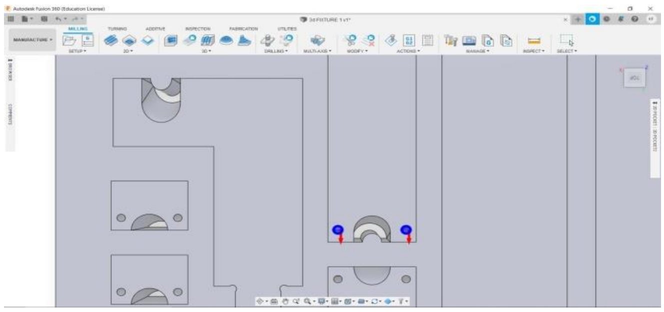

Fig -19: Hole Cut

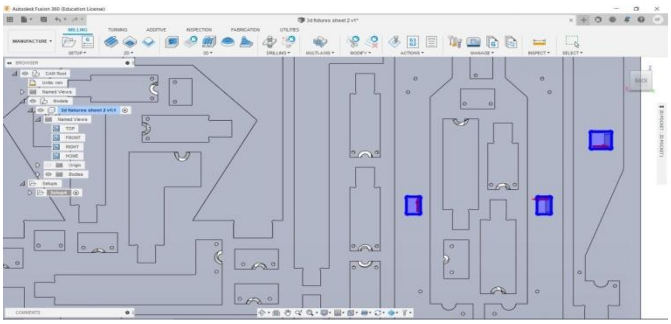

Fig -20: Slot Cut

Then, a tool path is given to the outer edge of a fixture as shown in Fig -21.

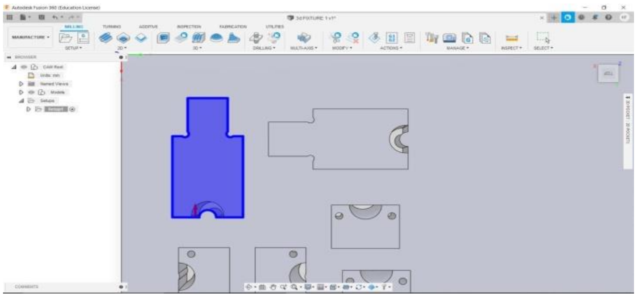

Fig -21: Boundary Cut

6.2 3-D Cut

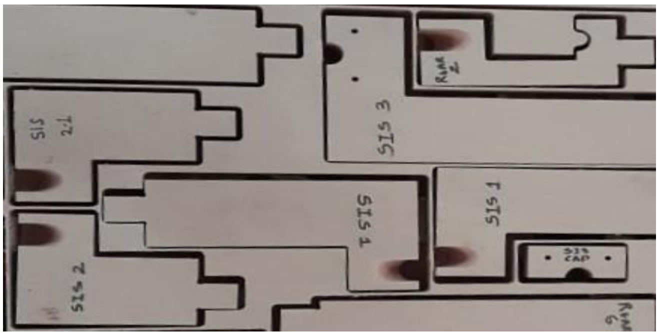

Fig -22: Fixture after 3-D cut

For a 3-D cut, a CAD file is imported. The first step was to create a setup then define the stock size and orientation. Then, an origin was selected and placed on a stock the same procedure as for a 2-D cut. Next, the first rough cut was given using a 6 mm flat end mill cutter from the tool library. After removal of the major stock, a tool path for the smooth cut is given using a 6 mm ball nose cutter for a good surface finish. Then these G-codes are copied and pasted in the .mmg file and imported to the 3-axis CNC machine.

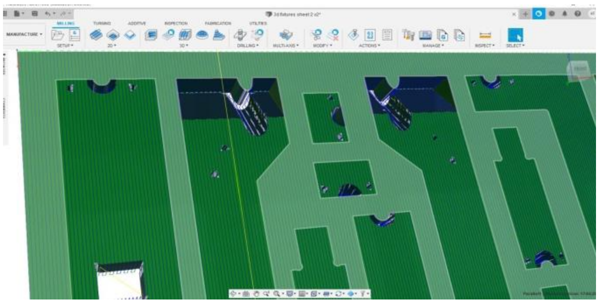

Fig -25: 3-D cut

7. RESULTS

The validation part of the fixtures and the overall welding process using the Coordinate Measuring Machine (CMM) is a bit expensive hence; we decided to validate the welding of the chassis over the other components. In addition, from the CMM results, we deduced that the maximum inaccuracies of the points were not more than 2mm, which is a very good result in contrast to metal fixtures. To improve better we tried to find out the possibilities due to which these inaccuracies would have led to and came up with the best possible solutions for it.

Fig -24: Setting up the coordinate system before scanning

Fig -25: 3-D scanning of the chassis

8. PROBLEMS FACED

The problems were faced mainly during the machining and the assembly processes. Design issues were understood later during the assembly and welding processes. During machining, the major problem faced was that the material being used was MDF, which is available in the form of sheets of a certain thickness. Therefore, as per the machine available for milling and design considerations, a certain thickness was decided and the CAD was designed considering it.

1. The material received by the manufacturer was not of the exact thickness and was not uniform. Although these deviations were in millimeters, still problems were faced. Due to excess thickness at places, it was necessary to give a couple of more cutting cycles to remove this excess material from the fixture. Holes drilled at such locations had to be reamed to get the full depth.

2. During assembly, the fit that was decided for the fixtures was not achieved at every place due to the material and machining errors. This problem was overcome by applying masking tape around the opening for tight fit and manufacturing some fixtures again as per the available spacing.

3. Design errors were also encountered during tube fitting and welding mainly at places where the welding torch could not reach for a complete full weld, so welding was done at such places after removing it from the fixture assembly.

4. Also at some places, there were too many fixtures that proved useless during welding.

These kinds of design errors can be overcome by increasing the overall fixture assembly height and the spacing between fixtures to ensure that the welding torch can reach where required easily. The material must be thoroughly checked and larger deviations can be removed by overall surface milling to get a uniform sheet of MDF. Even with all these errors, the overall welding process was near precise and the results obtained were more than satisfactory.

9. CONCLUSIONS

There was a significant increase in accuracy using MDF fixtures compared to metal fixtures of previous years. The use of MDF as a fixture for welding not only provides stability and sturdiness during and after welding but it is very flexible in design as well. Other fixtures like steering mount and accumulator also provided results that we required. Similar was the case for fixtures used for holding the bend tubes. The manufacturing process that we implemented was for a single prototype model but MDF can be used for mass manufacturing processes as well as it can be reused again. In addition, if there are any last-minute changes in the design, necessary changes can be done with ease in the fixture assembly. Another benefit of working with MDF fixtures is that it can be used for the mass production of any component or part and the accuracy will not be compromised. These fixtures do not demand any caution or particular care while using them and hence provide a long-term life with multiple working cycles and do not need to be manufactured after short use. The errors caused in this process can be minimized and they did not affect our overall welding process as a whole. Thus, overall MDF has a great application in the field of fixtures used for welding and it can aid in other manufacturing processes that require any kind of fixtures or jigs.

ACKNOWLEDGEMENT

We would like to acknowledge Bhavik Shah, Kartik Gandhi, Nikit Bid, Saumil Kamdar, and Yagnesh Chothani for their contributions in the initial stages of ideation and prototyping of this concept. We are immensely grateful for their guidance and comments on our project and this manuscript.

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