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# DESIGN OF COMPOSITE FIXTURE FOR MACHINING CERAMIC MATERIALS USING ABRASIVE WATER JET MACHINING (AWJM)

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**ABSTRACT**

The conventional machining of ceramic components is a hard task because of its brittle nature. Water jet machining is one among the non-conventional machining processes which is suitable for machining of ceramics. In this work, a fixture is developed to cut ceramics rods each of diameter varying from 9 to 7 mm and 30 mm length into two pieces. The fixture was developed to reduce the machining time, to hold the ceramic rods safely after machining and to eliminate the abrasion on the machine work table while cutting rods. The proposed design has to adhere less fabrication cost without compromising the strength of the fixture. Since the clamping device requires numerous machining operations for holding 22 pieces of varying diameter, it was proposed to select wooden material as the clamping device. Mild steel rod was selected to support the clamping device. Finite element simulation was carried out to simulate the force acting on the fixture during machining. Further, the ceramic rods were machined in the water jet machine using the fabricated fixture. The machining cost is reduced to approximately Rs 1000 per hour.

**Keywords:** abrasive water jet machining (AWJM), ceramics, finite element simulation, machining cost.

## INTRODUCTION

AWJM has no thermal distortion on the machined work piece, high machining versatility to cut any material, high flexibility to cut in any direction, and small cutting forces which are some of the distinct advantages over other non-conventional machining process [1, 2]. Ceramics materials which are known to be brittle can be machined using AWJM. A proper design of fixtures is essential for the development of a new product. Fixture design for abrasive water jet machine (AWJM) for cutting ceramic rods using high pressure water and abrasive slurry trough erosion process is an interesting task.

Many investigations have been carried out to study the various profile cutting performance on an alumina ceramic by AWJM over a wide range of process parameters [3]. The cost involved in the machining of materials by AWJM is high. So design of fixture to reduce the machining cost can be the solution. The Basic fixture design consists of two main aspects such as location and clamping of work piece to be machined. In general, fixtures are classified as manufacturing fixtures, repair fixtures, inspection fixtures [4]. Among these, manufacturing fixtures requires high clamping forces and precise location of work piece. The fixture has to be designed by considering the application of the fixture, number of part to be held by the fixture, level of accuracy, criticality of the part, standardization of fixtures, replaceable, reusable and discard ability of the fixture [5]. The graphical theme of the fixture is created by computer-aided engineering (CAE) tools such as PRO/E [6]. Then, finite element analysis software such as ANSYS is used to evaluate the deformation and stress acting on component while acted upon by forces [7, 8].

### Design objective of the fixture design

The main objective of the work is to bring down the AWJM cost for cutting the ceramic rods approximately Rs. 5000 for an hour. The rods were cut in “MICRO STEP water jet machine”. To reduce the machining cost our first task is to increase the cutting rate. This becomes the design objective of the fixture which is to improve the machining speed of the ceramics and also to reduce the wear of the machine table. These in turn will reduce the machining cost of the AWJM. Since the fixture will be used for a few number of cycles, higher investments is not advisable. Also by using wood as a work clamping device and steel as the supporting device the fabrication cost of fixture can be reduced. The fixture has to hold the ceramic pieces in place after the cutting process is finished. Initially a fixture was used to hold up to 22 ceramic rods for cutting. From Figure-1 it is clear that the machining takes place perpendicular to the direction of working table and erosion of working table. The Figure-2 shows the extent to which the table is eroded. By placing the model as given in Figure-3 the machining will be done parallel to the direction of working table the erosion can be avoided. The fixture has to be designed to hold the rod after cutting it to avoid the jobs lost in the water jet pool where it is hard to recover. This is due to that the pool sieve size (2 cm x 2 cm) is larger than the size of the ceramic rods.

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**Figure-1**. Fixture found perpendicular to the working table.

**Figure-2.** Magnified view of the corroded part.

**Figure-3.** Fixture found parallel to the working table.

**Synthesis of fixture design**

The prime function of composite fixture is to locate and to hold the job without deflection while machining. The main concern of the work clamping part is to maintain the job without any injuries while machining is carried out at extreme forces. Initially a fixture was modeled to hold only 22 pieces alone with wood D1 as the clamping and supporting device as in Figure-4. One FEM analysis it was found that the stress values were high. To counteract the problem a small mild steel rod was placed beneath the clamping device D2 as in Figure-5.

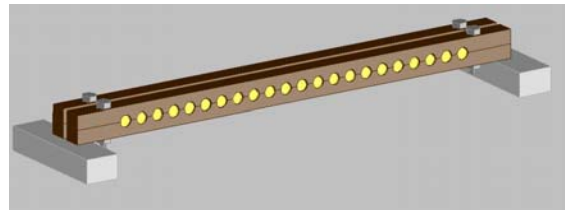

**Figure-4.** Wood used for both clamping and supporting device (D1).

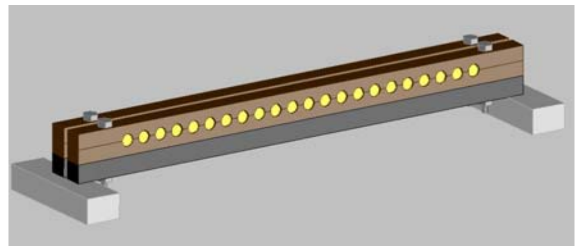

**Figure-5.** Mild steel rod used as supporting device (D2).

Selection of material is based on the strength, life and repeated usage. These factors play a major role which will affect the cost accordingly. Since the clamping device requires numerous drilling operations to provide holes for clamping many pieces of varying diameter, it was proposed to select a wooden material. Teak Wood is selected for its resistance to distortion while exposed to water and also does not compromise the strength. Wood as a clamping material is softer than ceramics which will reduces the risk of injuries to the ceramic rods during clamping and machining. This will avoid the need of bushes. Mild steel rod was selected to support the clamping device. The fixture is designed to hold rods of varying diameter from 7 to 9.8 mm and length of 40 mm. It has an upper part and lower part which can be spilt in to two halves each of 15 x 15 mm square cross section and length of 520 mm. And two bolts are used to hold the two halves in place to retain the ceramic rod till the end of cutting process. A 5 mm semi circular holes are drilled at an offset of 2 mm from the axis of the hole to the surface of wooden flank is shown in Figure-6. Two such components are placed at a distance of 7 mm to allow the nozzle to reach the ceramic rod as near as possible (Figure-7).

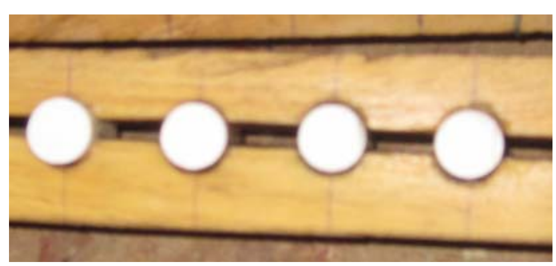

**Figure-6.** Offset holes to hold pieces of varying diameter.

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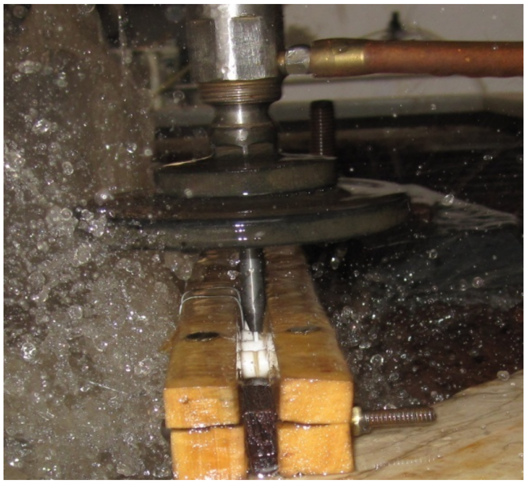

**Figure-7.** Gap between fixtures while machining to allow nozzle to reach the ceramic rods as near as possible.

**Analysis of proposed fixture design using FEA**

The five different fixture models as per the design along with work pieces (ceramic rods) were created in Pro/ENGINEER solid modeling software. It is imported to ANSYS-WORKBENCH module in IGES format with solid model. IGES is a neutral standard format used to exchange 3 dimensional models between any standard CAD/CAM/CAE systems. The flow chart in Figure-8 gives the methodology to design a fixture based on FEM approach.

**Material properties**

The fixture, work piece material in this finite element study is assumed to behave as homogenous, isotropic, linear elastic and ductile material. The material used in the material used as the supports and bolt is mild steel while teak is the material selected to hold the alumina ceramic rods. The material properties of the wooden part of fixture, ceramic rods and support rod are listed in the Table-1.

**Table-1.** Material properties of the work pieces and fixture.

| Name of the parts | Young's modulus (MPa) | Poisson ratio |
|---|---|---|
| Wooden fixture [5] | 9100 | 0.3 |
| Steel fixture [9] | 200000 | 0.3 |
| Ceramic rods ($Al_2O_3$) [10] | 35000 | 0.208 |

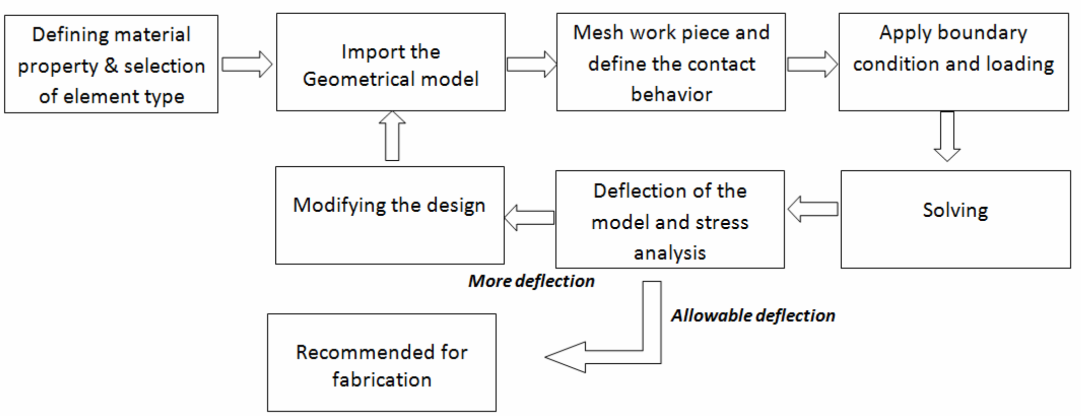


**Figure-8.** Flow chart for design of fixture using FEA.

**CONTACT**

The interaction between the small ceramic rod, upper part of the wooden fixture, lower part of the wooden fixture and metal support has to be defined. This is done by defining contact and the target surfaces of the parts. The Figures-9(a), (b) and (c) shows the interactions between the wooden parts and the steel supports. Also the interaction between the upper and lower wooden parts with the ceramic rods are shown in Figures-9 (d and e).

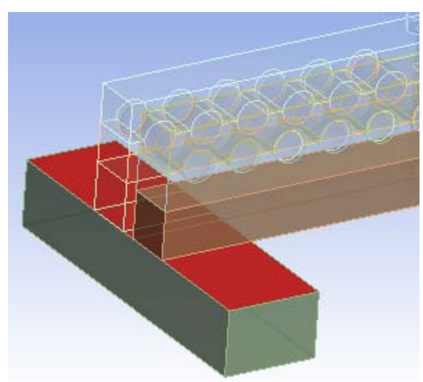

**Figure-9(a).** Interaction between support and steel fixture part.

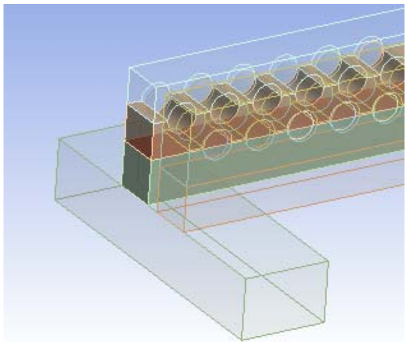

**Figure-9(b).** Interaction between steel fixture and lower wooden part.

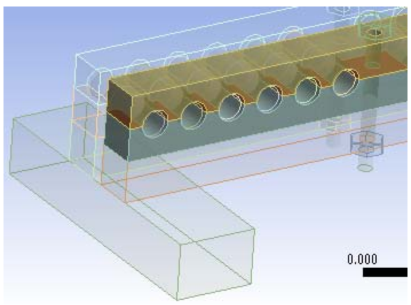


**Figure-9(c).** Interaction between upper and lower wooden part.

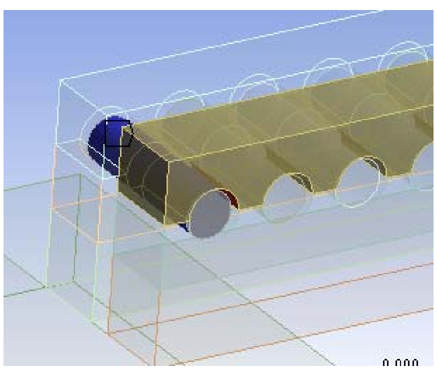

**Figure-9(d).** Interaction between ceramics and upper part of the wooden part.

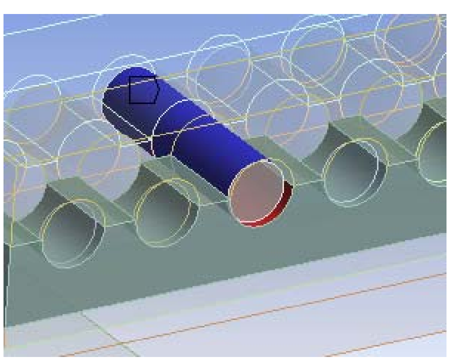

**Figure-9(e).** Interaction between ceramics and lower part of the wooden part.

**MESHING**

An 8-noded hexahedral element with three degrees of freedom at each node i.e. translations in the nodal X, Y, and Z directions is selected to mesh the work piece Figure-10. The element has the ability to degenerates to a 4-node tetrahedral configuration with three degrees of freedom per node Figure-11. The tetrahedral configuration is known to be more suitable for meshing non-prismatic geometry, but the results predicated is less accurate than the hex-configuration. ANSYS recommends that no more than 90% of the mesh must be comprised of elements in the hexahedral configuration [11]. The meshed model D1 and D2 is and is shown in Figures 12 and 13, respectively.

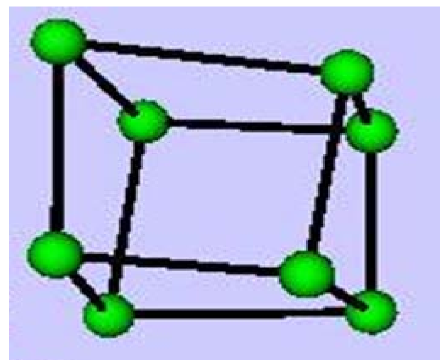

**Figure-10.** 1 8-node hexahedral element with 3 DOF.

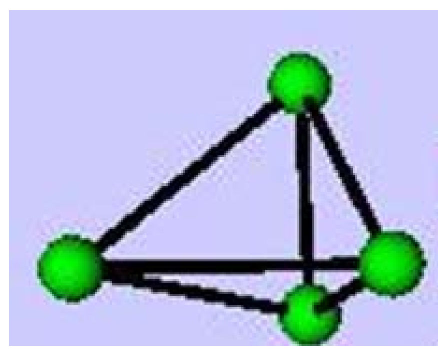

**Figure-11.** 4-node tetrahedral element with 3 DOF.

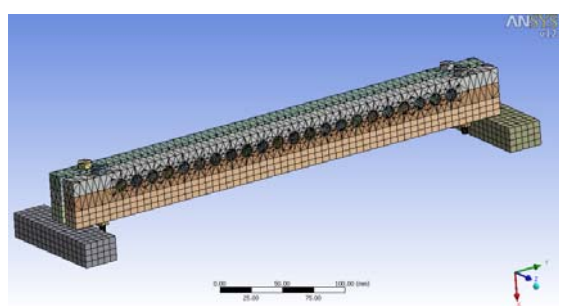

**Figure-12.** Meshed view of the model D.1.

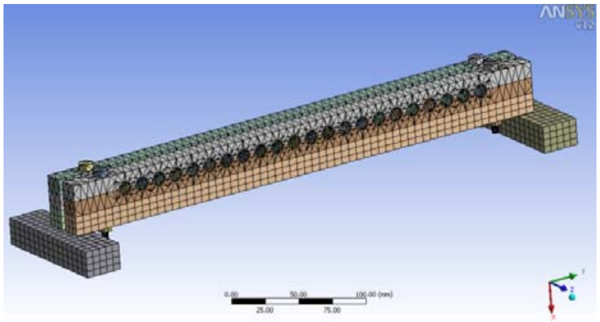

**Figure-13.** Meshed view of the model D2.

## LOADING AND BOUNDARY CONDITION

By applying the exact loading and boundary conditions the actual behavior of the fixture with the work piece can be obtained. The Figure-14 gives the orientation of the nozzle and work piece. Also Figure-15 shows that the cutting force acts vertically downwards on the ceramic rods. It can be concluded that the loading of the AWJM is similar to apply a force vertically downward over the ceramic rods. This loading is defined in ANSYS by a force of 355 N applied vertically downward on the rods Figure-16. The supports are modeled exactly same as in Figure-17 and downward movement is arrested as found in the actual case. In this work, the loads are given in the central work piece which gives more deflection in the same fixture. The analysis is carried out for the two design and results were obtained.

**Figure-14.** Orientation of nozzle to the work piece.

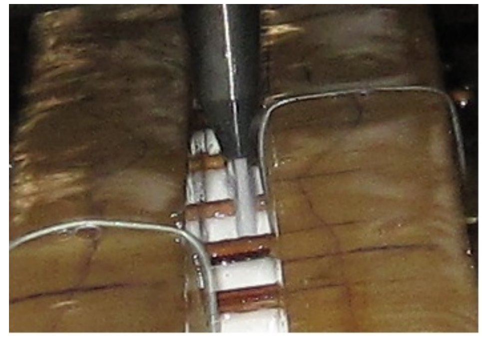

**Figure-15.** Cutting of rods by AWJM.

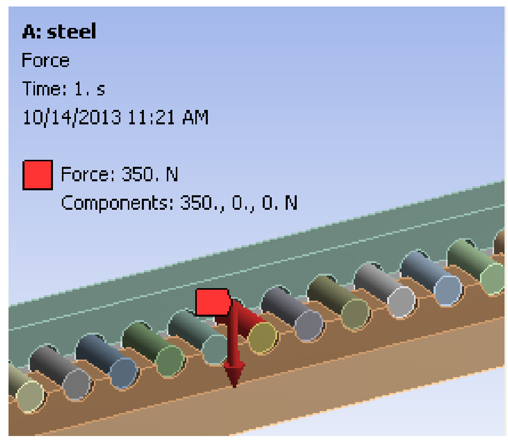


**Figure-16.** Application of loads on the ceramic rod in FEA.

**Figure-17.** support to the fixture.

## RESULT AND DISCUSSIONS

The analysis of the deformation and stress acting on the fixture is carried out and is given in Table-2. The fixture D1 deflects 0.32553 mm as given in Figure-18 and von mises stress is found to be 28.865 mm (Figure-19). This deflection will affect the cutting performance which leads to increase cutting time. The fixture D2 with Steel support placed beneath the wooden part reduces the deflection to 0.035148 mm (Figure-20). Also it can be found that the stress acting in the material is found to be (Figure-21) 34.235 N/mm2. But the deflection in D2 low compared to D1.

**Table-2.** The deflection and the stress values of different fixtures.

| Name of the fixture | Max deformation (mm) | Von-mises Stress (MPa) |
|---|---|---|
| D1 | 0.32553 | 28.865 |
| D2 | 0.035148 | 34.235 |

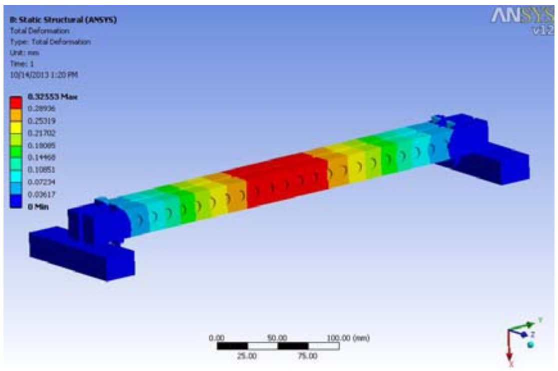

**Figure-18.** Deflection of the fixture design D1.

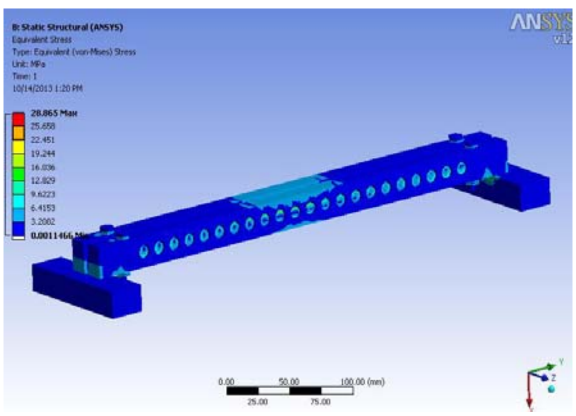

**Figure-19.** Von mises stress of the fixture design D1.

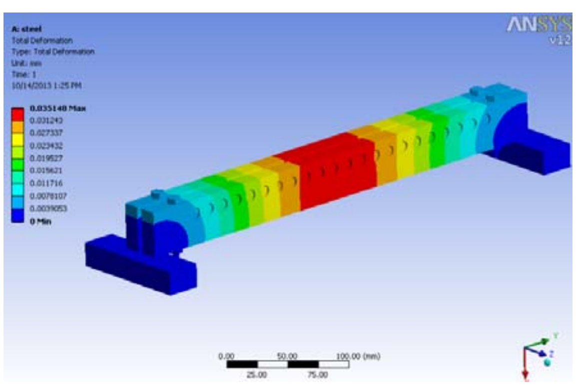

**Figure-20.** Deflection of the fixture design D2.

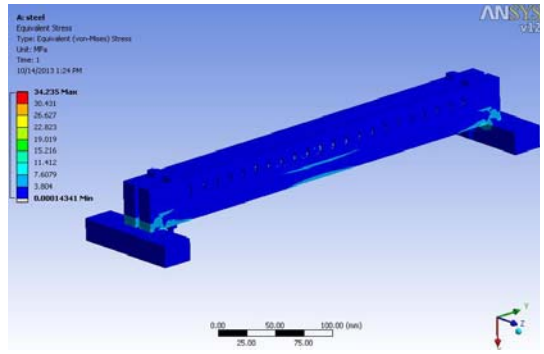

**Figure-21.** Von mises stress of the fixture design D2.

Also the factor of safety for the two designs D1 and D2 is found based on the yield strength of structural steel 250 MPa [9] and ultimate strength of teak wood 40 MPa [5]. The factor of safety of teak wood in D1 is found to be 0.9914 as shown in Figure-22.

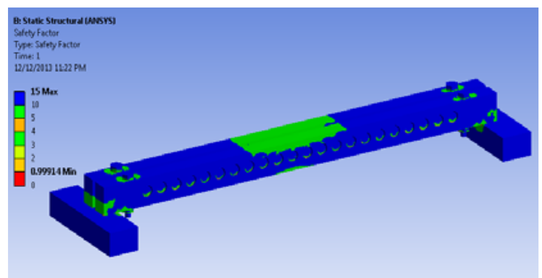

**Figure-22.** Safety factor for teak in fixture D1.

In Figures 23 and 24 the factor of safety of wood in D2 is found to be 1.1684 for wood and 7.3025 for support.

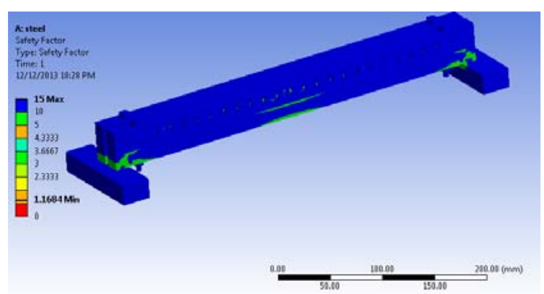

**Figure-23.** Safety factor for teak in fixture D2.

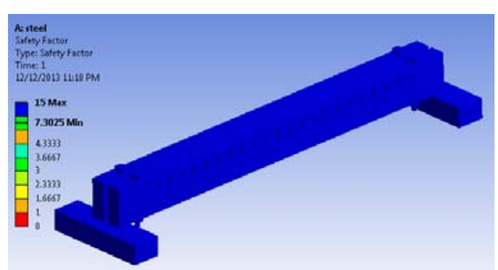

**Figure-24.** Safety factor for support in fixture D2.

The factor of safety for teak in fixture D2 is greater than fixture D1for the same load. This also proves that the fixture D2 is a better design.

The D2 fixture was recommended as the suitable design and was fabricated. The machining process was then carried out using the fixture as shown in Figure-25. The machining time was reduced approximately to 15 minutes compared to the previous run (machining perpendicular to the machine table) for the same number of 22 pieces while. Also the machine table corrosion is eliminated. The cost of cutting is reduced approximately Rs 1000 by using this fabricated fixture. The cost of the fabricated fixture is low as compared to the saved machining cost.

**Figure-25.** Cut alumina ceramic rod using AWJM.

**CONCLUSIONS**

The fixture was designed based on the objectives and a model was developed using PRO E. Then, Finite element analysis was carried out on the five proposed model. The model which exhibited least deflection and stress value was selected for fixture fabrication. The fabricated fixture was used for cutting the ceramic rods. The cutting task was found much easier and it also reduced the machining cost. The fabrication cost of the fixture was covered effectively by the saving done in cutting costs.

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