PROCEEDINGS OF SCIENCE

Development of CMS silicon strip detector module mechanics for Phase-II upgrade

Prafulla Kumar Behera[*] [1], **Ngangkham Peter Singh**[2], **Sivasrinivasu Devadula**[2], **Muhammad Alibordi**[1] [†]

[1] *Department of Physics, Indian Institute of Technology Madras*
Chennai-600 036, India
[2]*Department of Mechanical Engineering, Indian Institute of Technology Madras*
Chennai-600 036, India

The CMS experiment will change it's silicon tracker completely during phase-II upgrade. There is need to develop light and high precision and durable mechanical structure for silicon modules. The prime purpose of this should also be reducing material in the silicon tracker detector. The group at IIT Madras is involved in R&D of production of this structures. We have produced high precision bridge made of AL-CF material and carbon fiber stiffener.

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[*]Speaker.

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Communication:prafulla.behera@cern.ch

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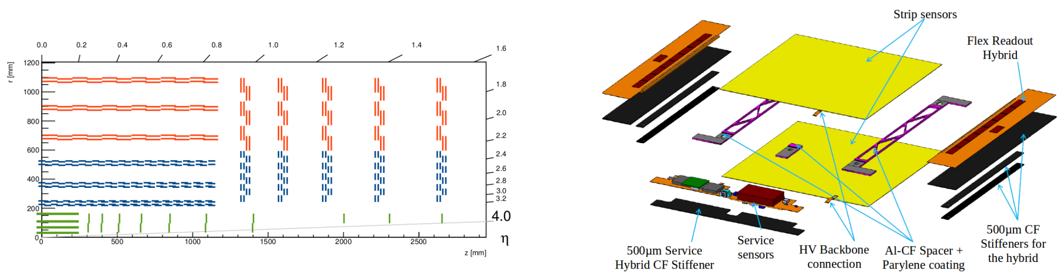
1. Introduction

The Compact Muon Solenoid (CMS) experiment is going to be upgraded to phase-II for better sensitivity and resolution. Our group is involved in tracker subdetector. The pertinent component under consideration is strip-strip (2S) modules and its physics consequences can be found in technical design report of tracker for phase-II upgrade [1].



(a) (b)

Figure 1: (a) Red bars are position of Strip-Strip (2S) modules within one quarter of outer tracker layout, (b) assembly of 2S module.

We are producing support parts of 2S modules as shown in fig. 1. The Carbon fiber reinforced Aluminum matrix composite or Aluminum-Carbon Fiber (Al-CF) and Carbon-fiber (CF) composite has been chosen as construction material for different geometrical parts of the whole structure. Al-CF composites has been used for bridge and stump while CF composite for fabricating different geometries of stiffeners. Macro abrasive waterjet (Macro- AWJ), micro abrasive waterjet (Micro-AWJ), milling, wire-electric discharge machining (EDM) processes has employed for fabricating these structures [2, 9]. In the following three sections, we are going to describe the fabrication of Al-CF composite stumps, Al-CF bridge and CF stiffeners respectively are shown in fig. 2.

1.1 Aluminum-Carbon fiber stump

The fabrication of Al-CF stump has performed in three stages. In the first attempt, AWJ was used for cutting the profile of the structure. The cutting experiment was conducted into two stages, first, slicing the profile from the bulk material and the second was drilling [10, 11] hole on the sliced section by using a sacrificial layer which has been considered as a support for the workpiece located at the base. This trial was important in order to understand the effect of AWJ interaction with the workpiece material (soft and brittle). Waterjet pressure employed was 300MPa and garnet abrasive of 80# (185μm) was employed for the cutting experiment. The jet was traversed for cutting the desired geometry at a speed of 75 mm/min with a stand off distance(SoD) of 1.5 mm. Orifice diameter of 0.35 mm and nozzle diameter of 0.76 mm were used for this cutting trials. In the second attempt, macro AWJ has used for slicing Al-CF from the bulk material by employing the same process parameters mentioned in the previous section. The sliced workpiece then milled with Jyoti KMill8 machine. Solid carbide endmill tool of 1.5 mm diameter with spindle speed between 3000 – 5000 rpm and feed rate of 50 – 100 mm/min has been used for machining the Al-CF structure. Depth of cut employed here 10% of tool diameter. For this fabrication process, a

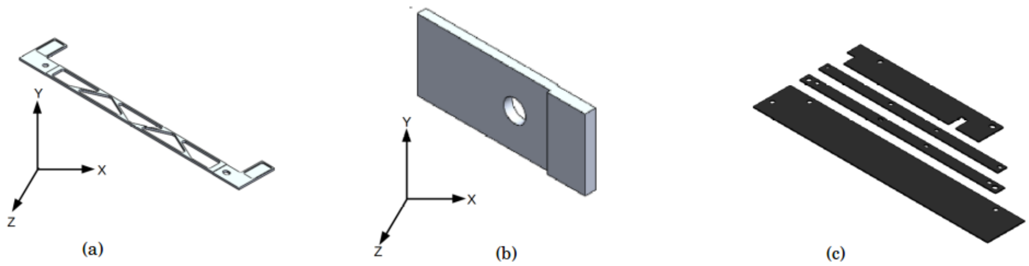


Figure 2: (a) and (b) Aluminum-Carbon fiber (Al-CF) part to be fabricated, (c) different geometries of carbon-fiber composite stiffener.

fixture was designed and fabricated in the same milling machine. It consists of different slots for holding the workpiece in all the multiple stages of machining. Micro-AWJ has been used for profile cutting from the slice made by wire EDM process. The profile of the Al-CF stump then successfully cut using macro-AWJ with a lesser control over the corner radius, however, the material failed in this stage due to the stagnation pressure coming from bottom layer.

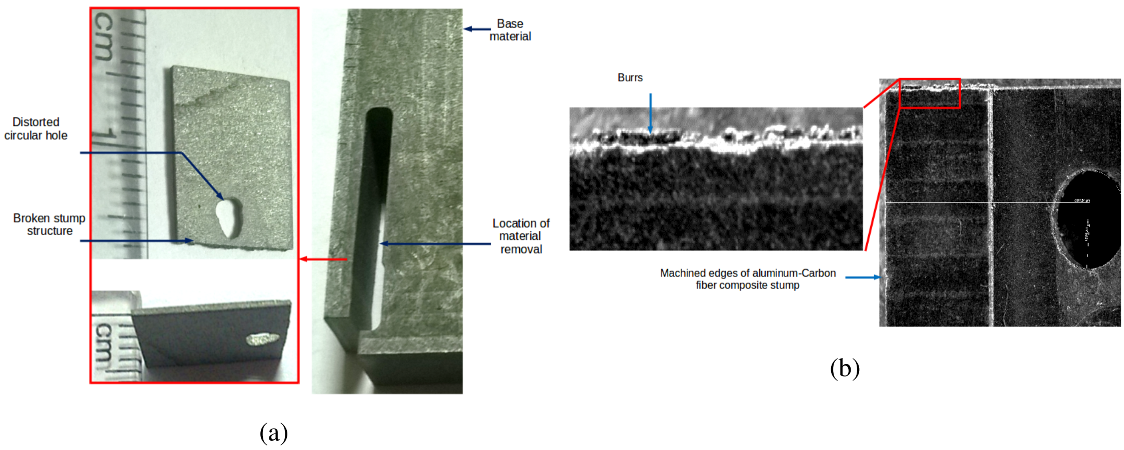


Figure 3: (a) Micro abrasive waterjet cutting of carbon fiber composite with sacrificial layers, (b) Aluminum-carbon fiber composite stump structure fabricated by milling operation on macro abrasive waterjet cut slice.

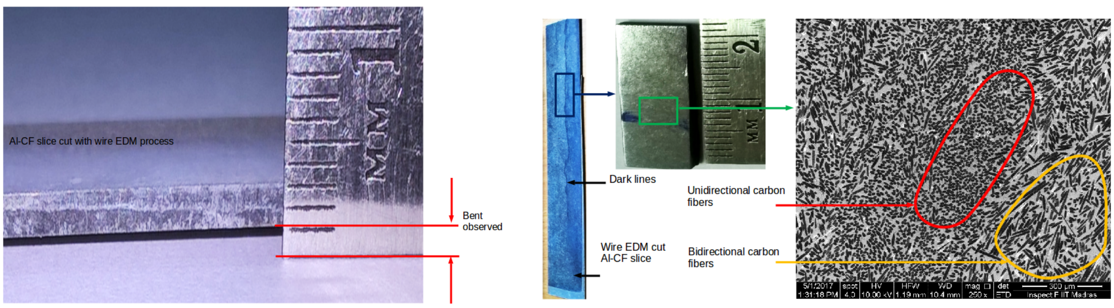
Furthermore, the geometry of the circular hole was distorted due to back flow of water and the inability to hold the workpiece firmly to the base as shown in fig. 3. In the second stage of milling of the slices cut with macro-AWJs, we have been producing the stumps within dimensional tolerance. Since the material was soft, burrs were observed along the edges of the profile and the measured dimensions are within tolerance given in Table 1. Micro-AWJ cut stump profile resulted in acceptable tolerances also given in Table 1. In addition to this, there were no visible damaged regions and de-lamination generated during the process.

Table 1: Desired and actual dimension obtained on Al-CF stump machined with micro-abrasive waterjet and in milling operation.

Location of measurement	Method of fabrication				
	Designed	Micro-AWJ		Milling	
Steps	Nominal (mm)	Actual (mm)	Deviation (mm)	Actual (mm)	Deviation (mm)
Diameter	3.00	3.00	+0.00	2.96	-0.04
Width	19.30	19.32	+0.02	19.29	-0.01
Width	8.00	8.02	+0.02	7.99	-0.01
Thickness	0.97	-	-	0.98	+0.01
Circularity	0.00	0.02	0.02	-	-

1.2 Aluminum-Carbon fiber bridge

For the fabrication of Al-CF composite bridge, Accutex AU-300iA CNC wire-cut EDM (WEDM) machine has been used for slicing Al-CF from the bulk material by employing brass wire of 25 μm. We first employed WEDM to cut 2.5 mm thick slices to avoid thermal effect which may cause bending. Later the produced pieces divided into 1.21 mm each. Dark lines on the slice surface were analyzed using scanning electron microscope (SEM) and has considered as manufacturing defects as shown in fig. 4.



(a) (b)

Figure 4: (a) Observed bent in discharged sliced aluminum-carbon fiber composite, (b) SEM analysis of discharged sliced aluminum-carbon fiber.

It was observed that the density of carbon fibers were perpendicular to the plane of cut is higher which makes the area darker than the rest and has assumed to be caused while pouring molten aluminum on compact carbon fibers. Results are shown in Table 2. Micro-AWJ was able to cut the profile on the Al-CF slice produced with wire EDM. A hole of diameter 300 μm has drilled as a trial to determine the process parameters to be used while cutting the profile. Milling operation was considered as a necessary and important step for reducing the thickness and pocketing operations.

Table 2: Desired and actual dimension obtained on Al-CF bridge machined with micro-abrasive waterjet and in milling operation.

Location of measurement	Method of fabrication				
	Designed	Micro-AWJ		Milling	
Steps	Nominal (mm)	Actual (mm)	Deviation (mm)	Actual (mm)	Deviation (mm)
Diameter	3.00	3.04	+0.04	2.98	-0.02
Width	3.00	3.01	+0.01	2.98	-0.02
Width	125.00	124.99	-0.01	125.03	+0.03
Width	8.00	7.99	-0.01	8.00	+0.00
Width	0.50	0.52	+0.02	0.52	+0.02
Width	0.50	0.50	+0.00	0.51	+0.01
Width	0.50	0.49	-0.01	0.54	+0.04
Width	0.50	0.51	+0.01	0.54	+0.04
Width	0.50	0.51	+0.01	0.52	+0.02

1.3 Carbon-Fiber stiffener of different geometries

Four different approaches have used in fabrication of different geometries of carbon fiber composite stiffeners (CFCS). Operating waterjet pressure of 100 MPa with a traverse rate of 75 mm/min and standoff distance of 3 mm have employed for the cutting experiment. In the second attempt, macro-AWJ has used for cutting the CFCS profile by employing abrasives (garnet) of 80# mesh at a flow rate of 309 g/min, while maintaining the same process parameters as in the previous case [11, 12]. Moving to third approach, the profile of the CFCS cut has been performed using CNC milling machine K8Mill by fixing the composite on a plate. Micro-AWJ machining process was employed for cutting the profile and considered as the fourth attempt. In order to contain the effect of stray particles on the kerf quality, a sacrificial layer has deployed on the top interacting face and the same procedure has maintained to support the structure. Fabricating CFCS structure with CNC milling operation using Jyoti KMill8 has performed with minor delamination along the narrow edges wherein, holes are located close to the edges. Dimensions of the geometry obtained agreed with the desired requirements and required minor adjustments on corner radius. The Table 3 shows the deviation obtained while fabricating the main circuit stiffener of CF composite with milling operation. Micro-AWJ machining of CF composite to fabricate the stiffener found that the material was soft, sensible and easily damaged. Significant damaged region were observed which is due to the jet divergence resulting in stray particles. Higher SoD leads to more damaged region, but avoids delamination. On the other hand, lesser SoDs increases the risk for delamination but decrease damaged region. Hence, selection of SoDs is a compromise between the two outcomes. The application of a top sacrificial layer at higher SoDs(>2.5mm) resulted significant improvement in controlling the damaged region without delamination. Additionally, application of low operating waterjet pressure leads to delamination on the top face while application of higher waterjet pressure leads to the delamination at the back face. Test coupon stiffener fabricated with micro-AWJ agrees

Table 3: Desired and actual dimension obtained for carbon-fiber composite machined in milling operation.

Location of measurement	Nominal (mm)	Actual (mm)	Deviation (mm)
Width	19.80	19.82	+0.02
Width	125.00	125.00	+0.00
Diameter	2.10	2.02	-0.08
Diameter	2.10	2.02	-0.08

with expected dimensions as shown in Table 4.

Table 4: Desired and actual dimension obtained for carbon-fiber composite machined with abrasive waterjet.

Location of measurement	Nominal (mm)	Actual (mm)	Deviation (mm)
Width	76.20	76.20	+0.00
Width	7.19	7.20	+0.01
Width	13.28	13.28	+0.00
Width	55.86	55.84	-0.02
Width	3.72	3.77	+0.05
Width	12.36	12.35	-0.01
Diameter	2.10	2.07	-0.03
Width	4.26	4.28	+0.02
Width	7.00	6.92	-0.08

2. Conclusion

Following conclusions have drawn from this experimental study for the fabrication of Al-CF stump, micro-abrasive waterjets produced parts with lesser deviations as compared to the parts fabricated with milling. Micro-abrasive waterjet fabricated Al-CF composite bridge structure had lesser deviations than the desired dimensions (profile) as compared to the milled structure. For the fabrication of CF stiffener of different geometries, micro-AWJ has found to be more flexible for cutting different geometries and was more productive. However, micro-AWJ induced certain delamination and fiber pull out along narrow edges and therefore, needs certain adjustment. On the other hand, milling operation resulted in lesser delamination and was also considered as one of the feasible fabrication process for the carbon fiber stiffeners.

References

[1] The Compact Muon Solenoid Phase II Upgrade, Technical Proposal, CERN-LHCC-2015-010, LHCC-P-008, CMS-TDR-15-02, 1June 2015.

[2] Y. Huang, Q. Ouyang, D. Zhang, J. Zhu, R. Li, and H. Yu, "Carbon materials reinforced aluminum composites: A review", Acta Metall. Sin. English Lett., vol. 27, no. 5, pp. 775-786, 2014.

[3] K. Asano, "Machinability of Short Alumina Fiber Reinforced Aluminum Alloy Composite," Mater. Trans., vol. 57, no. 8, pp. 1300-1304, 2016.

[4] D. F. Liu, Y. J. Tang, and W. L. Cong, "A review of mechanical drilling for composite laminates," Compos. Struct., vol. 94, no. 4, pp. 1265-1279, 2012.

[5] R. Teti, "Machining of Composite Materials," CIRP Ann. - Manuf. Technol., vol. 51, no. 2, pp. 611-634, 2002.

[6] M. Khoran, P. Ghabezi, M. Frahani, and M. K. Besharati, "Investigation of drilling composite sandwich structures," Int. J. Adv. Manuf. Technol., vol. 76, no. 9-12, pp. 1927-1936, 2014.

[7] R. Stone and K. Krishnamurthy, "A neural network thrust force controller to minimize delamination during drilling of graphite-epoxy laminates," Int. J. Mach. Tools Manuf., vol. 36, no. 9, pp. 985-1003, 1996.

[8] H. M. Ali, A. Iqbal, and M. Hashemipour, "Dimensional accuracy and strength comparison in hole making of GFRP composite using Co2 laser and abrasive water jet technologies," Indian J. Eng. Mater. Sci., vol. 21, no. 2, pp. 189-199, 2014.

[9] M. M. Islam, C. P. Li, S. J. Won, and T. J. Ko, "A deburring strategy in drilled hole of CFRP composites using EDM process," J. Alloys Compd., vol. 703, pp. 477-485, 2017.

[10] L. Dur*ão*, J. Tavares, V. de Albuquerque, J. Marques, and O. Andrade, "Drilling Damage in Composite Material," Materials (Basel)., vol. 7, no. 5, pp. 3802-3819, 2014.

[11] K. Phapale, R. Singh, S. Patil, and R. K. P. Singh, "Delamination Characterization and Comparative Assessment of Delamination Control Techniques in Abrasive Water Jet Drilling of CFRP," Procedia Manuf., vol. 5, no. 1985, pp. 521-535, 2016.

[12] D. S. Srinivasu and D. A. Axinte, "Mask-Less Pocket Milling of Composites by Abrasive Waterjets: An Experimental Investigation," J. Manuf. Sci. Eng., vol. 136, no. 4, p. 41005, 2014.

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