ICEST-2K24 [International Conference on Engineering, Science and Technology]
In Association with
International Journal of Scientific Research in Science, Engineering and Technology
Print ISSN - 2395-1990 | Online ISSN : 2394-4099 (www.ijsrset.com)

Design and Development of Micromixers on Acrylic Sheet Using Co2 Laser Machining and Their Numerical Analysis Using Comsol

Mr. Aditya S. Jadhav[1], Mr. Vaibhav T. Zadkar[2], Mr. Abhay D. Ronge[3], Mr. Swapnil D. Lamkane[4] Mr. Shubham D. Todkari[5], Mr. Uttam L. Anuse[6]
*[1,2,3,4,5]Student, Mechanical Engineering Department, SVERI's College of Engineering, Pandharpur. Maharashtra
[6]Assistant Professor, Mechanical Engineering Department, SVERI's College of Engineering, Pandharpur. Maharashtra

ABSTRACT

This study presents the design and development of micromixers fabricated on acrylic sheets through CO2 laser machining, coupled with numerical analysis performed using COMSOL Multiphysics. Micromixers are critical components in microfluidic systems, offering efficient mixing of fluids at the microscale, which is essential for numerous applications in chemical, biological, and medical fields. The choice of acrylic as the substrate material is motivated by its favorable properties, including optical transparency, chemical resistance, and ease of machining. Various design configurations of micromixers were developed, optimizing parameters such as channel width, depth, and geometry to enhance mixing performance. The laser machining process parameters, including power, speed, and frequency, were systematically varied to achieve the desired channel dimensions and surface quality.. The numerical simulations for Square shaped chamber with T-Inlet and Zig-Zag shaped chamber with Y-Inlet were performed using COMSOL Multiphysics to model the fluid flow and mixing behavior within the micromixers. The Y-Inlet with Zig-zag shaped mixer gives higher mixing Index ie.0.97 at 0.1 m/s. The simulations provided insights into the velocity fields, pressure distributions, and concentration profiles, enabling a detailed understanding of the mixing mechanisms and performance optimization.

Keywords: Micro mixers, Acrylic Sheet, CO2 Laser Machining, COMSOL Multiphysics, Microfluidics, Numerical Analysis, Fluid Mixing, Microchannel Fabrication

I. INTRODUCTION

Micromixers are essential components in the field of microfluidics, playing a crucial role in ensuring efficient mixing of fluids at the microscale. Their applications span across various domains, including chemical synthesis, biological assays, medical diagnostics, and drug delivery systems. The efficiency and performance of micromixers are pivotal in enhancing reaction rates and improving the homogeneity of solutions, which directly impacts the reliability and accuracy of microfluidic devices.

Traditionally, micromixers have been fabricated using techniques such as photolithography and soft lithography. While effective, these methods can be time-consuming, costly, and limited in the flexibility of design modifications. In contrast, CO2 laser machining offers a rapid, cost-effective, and versatile alternative for the fabrication of micromixers, particularly on acrylic substrates. Acrylic sheets are chosen for their advantageous properties, including optical clarity, chemical resistance, and ease of processing, making them an ideal material for microfluidic device fabrication.

This study focuses on the design and development of micromixers on acrylic sheets using CO2 laser machining. The primary objective is to explore the precision and capabilities of CO2 laser machining in creating intricate microchannel geometries and to assess the performance of the fabricated micromixers through both experimental and numerical approaches.

The CO2 laser machining process involves directing a focused laser beam onto the acrylic surface, which ablates the material to form microchannels with high precision. By adjusting laser parameters such as power, speed, and frequency, it is possible to control the channel dimensions and surface quality. This method allows for rapid prototyping and iteration of micromixer designs, enabling optimization of their mixing efficiency.

In parallel, numerical simulations are performed using COMSOL Multiphysics to model the fluid dynamics within the micromixers. These simulations provide detailed insights into the velocity fields, pressure distributions, and concentration gradients, facilitating a comprehensive understanding of the mixing mechanisms. The numerical analysis also serves as a tool for predicting and optimizing the performance of micromixer designs before fabrication.

This integrated approach of combining CO2 laser machining with numerical analysis aims to demonstrate the feasibility and effectiveness of this fabrication technique for developing high-performance micromixers. The findings from this study have significant implications for advancing the design and manufacturing of microfluidic devices, offering a scalable and efficient solution for various applications in science and engineering.

A. Need for Micro-Mixing

Active development and improvement of micro-fluidic devices have allowed making significant progress in biomedical diagnostics study, development of miniaturized micro- fluidic and nano -fluidic biosensors, in DNA analysis, chemical synthesis and genomics study, etc. The channel dimensions in micro-fluidic systems are measured in micrometres and in nano- fluidics they go down to nanometers. This allowed to noticeably reduce surface to volume ratios and thus, to decrease samples/reagents consumption and obtain compact devices. However, sample flows in such miniaturized channels are extremely laminar and not turbulent, which corresponds to small Reynolds number values. Consequently, in such laminar flows, traditional turbulent mixing between two liquids cannot occur. However, controllable and fast mixing is critical for subsequent practical development of micro-fluidic and lab-on-chip devices often used for assays involving many reagents and samples. That's why different mixing techniques were developed and studied by various research groups.

B. Applications

Application of micromixer technologies, which have driven a number of critical research trends over the past few decades, particularly for chemical and biological fields.

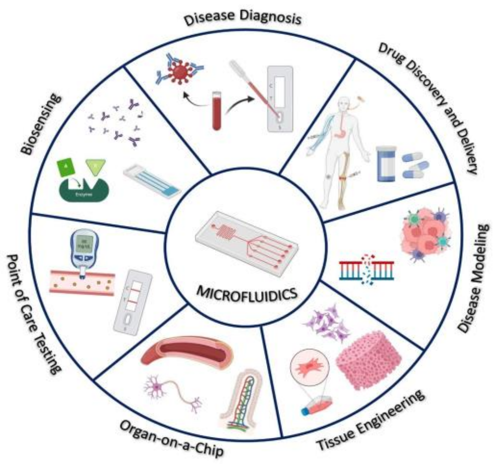

Figure 1: Applications

II. OBJECTIVES

- Design different Micromixer configurations for mixing applications in microfluidics.
- Carryout computational analysis for designed micromixers.
- Fabricate Micromixers using CO2 laser facility.
- Characterization of fabricated micromixers

III. METHODOLOGY

- Design of Micro-mixers for different configurations using Auto-CAD software: We are going to design the micro-mixers using Auto-CAD or CATIA software for different configurations. While designing we will add some obstacles for fluid disturbance while flowing through the mixer.
- Numerical analysis of micro mixers using COMSOL: After selection and fabrication of the micromixer its mixing length & other configurations, we are going to test it on simulation software i.e., COMSOL for comparing the difference between the actual readings and simulation results.
- Fabrication of Micro-mixers using CO2 LASER Machining: After designing micro-mixers we are going to manufacture it on a LASER machine using Laser engraving operation. All those channels will be fabricated on PMMA/Acrylic Sheet using the same manufacturing process. Also required bonding layers or plates will also be prepared by laser marching only.
- Characterization of fabricated micromixers is done by using Rapid I Vision.

A. Problem Statement

Design and Simulation of Square shaped chamber with T-Inlet and Zigzag shaped chamber with Y-Inlet were performed using COMSOL Multiphysics. From this simulation mixing index, Pressure Drop have been calculated by statical Technique.

1) Micromixer Designs: Design-1

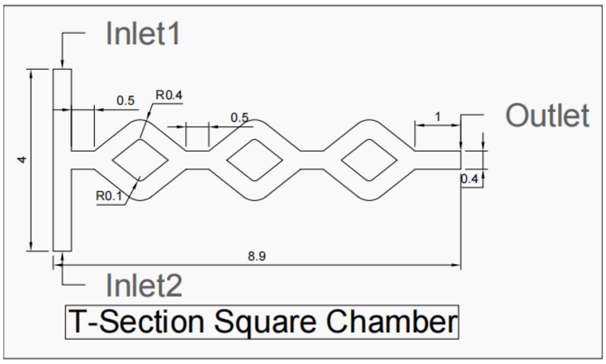

Figure 2: T-Shaped Inlet with Square shped Chamber

Design: II

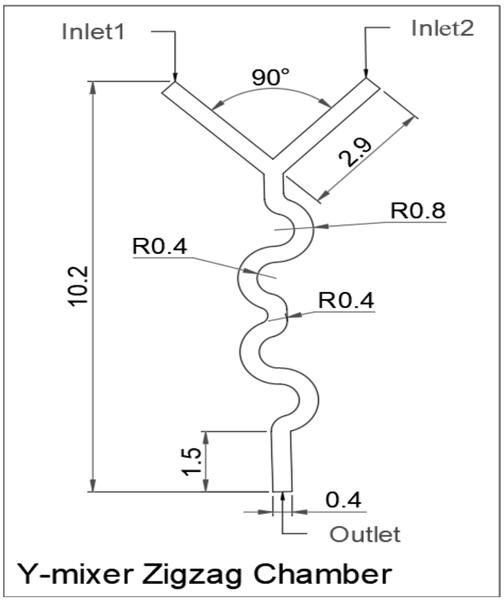

Figure 3:

2) Boundary Conditions & Fluid Properties: Boundry Conditions:

Inlet-1: Pure water with concentration of 0 mol/m3

Inlet-2: Ethanol with concentration of 1 mol/m3

Above conditions are used to simulate the fluid flow. Properties of fluids :

- Temperature of 20 °C.
- Densities of water = 9.998 × 102 kg/m3
- Density of =7.890 × 102 kg/m3
- Viscosity of water = 0.9 × 10–3 Pa.s
- Viscosity of ethanol = 1.2 × 10–3 Pa.s

- At the flow outlet zero static pressure is specified
- At all the channel walls no-slip boundary conditions are used.

IV. RESULTS AND OBSERVATIONS

A. Mesh Independent Test for Square chamber shaped T-Inlet Micromixer

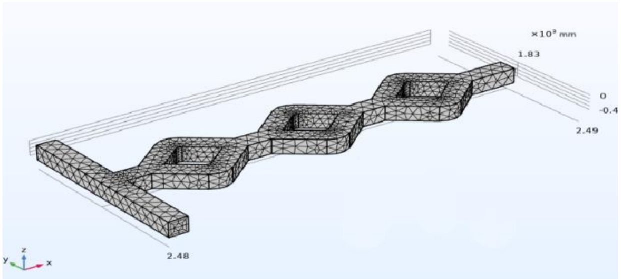

Figure 4: Extre-mely Coarse

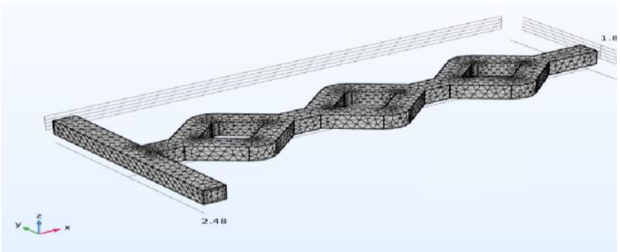

Figure 5: Extra Coarse

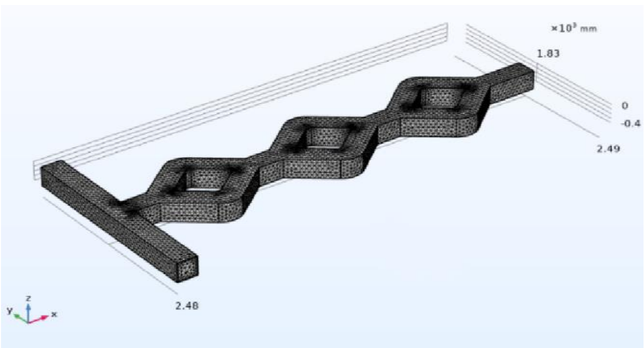

Figure 6: Coarse

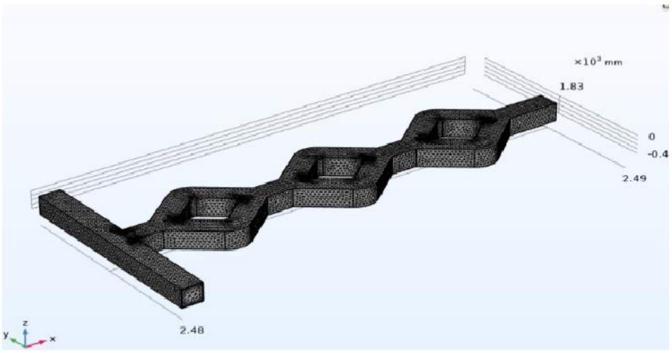

Figure 7: Normal

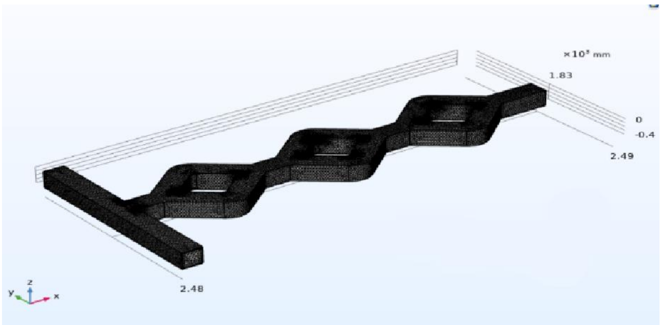

Figure 8: Fine

TABLE I

TABLE OF MESH INDEPEND TEST-1

Sr.No.	Mesh	No. Of Element	Pressure drop (Pa)
1	Extremely Coarse	9321	306.6594
2	Extra Coarse	17033	322.3878
3	Coarse	58990	335.1548
4	Normal	201410	339.6237
5	Fine	282363	342.00

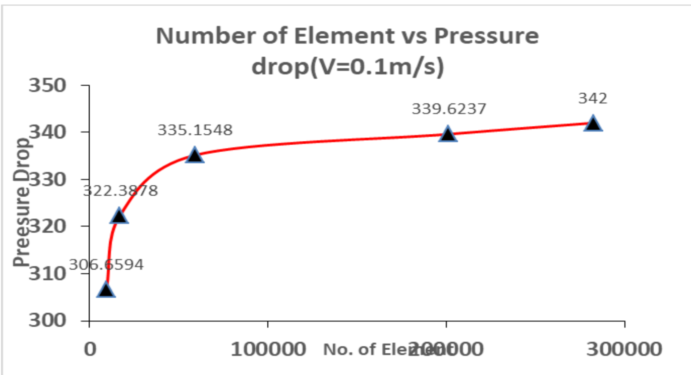

Figure 9:

From the mesh Independent test, it is clear that less variation is occurred in pressure drop calculation, hence Fine mesh selected for simulation of further component.

B. Computational Results for Y shaped inlet with Zig-Zag shaped chamber

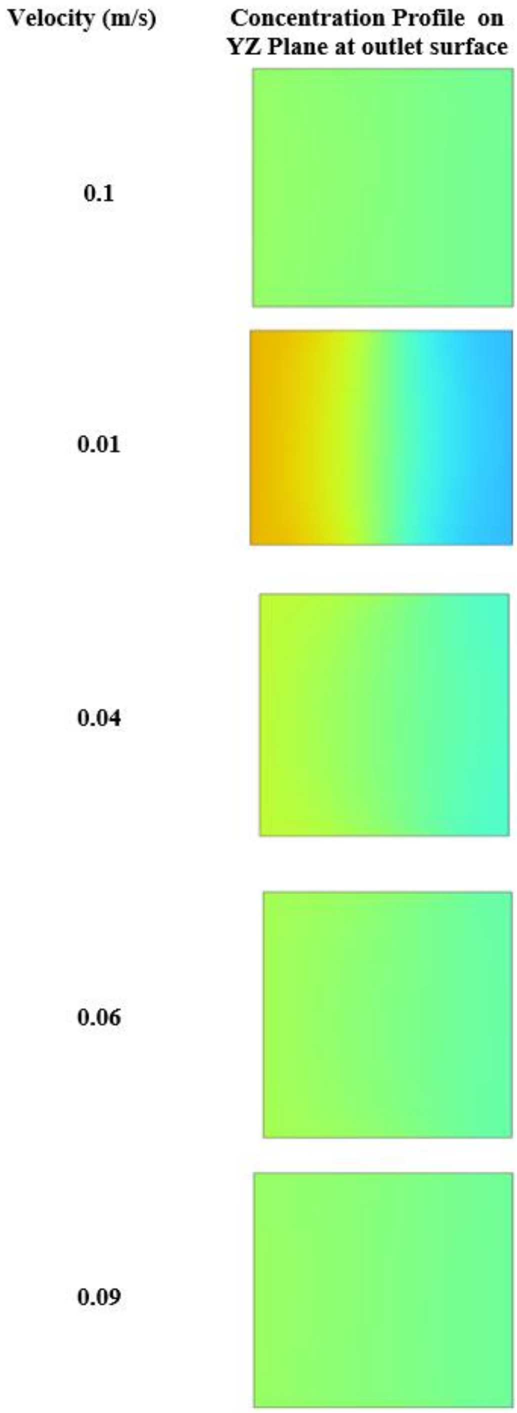

Figure 10:

C. Computational Results for T- Shaped Inlet with Square shaped chamber

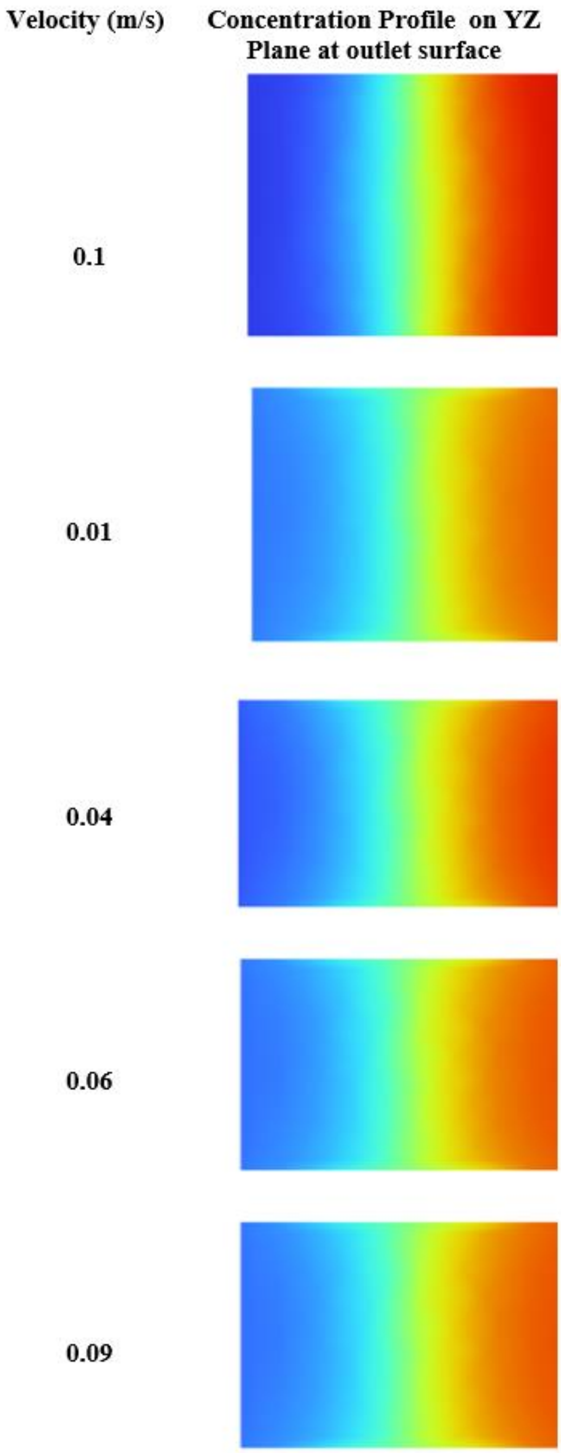

Figure 11:

From this concentration profile, it is clear that Mixing Index is 0.97 in Y shaped inlet with Zig-Zag shaped chamber & Mixing Index is 0.85 in Square shaped chamber with with T-Inlet.

TABLE III

MIXING INDEX IS CALCULATED FOR THE DIFFERENT VELOCITIES IS MENTIONED IN TABLE

Sr. No.	Velocity (m/s)	Mixing Index
1	0.02	0.963511834
2	0.04	0.974710889
3	0.06	0.978132023
4	0.09	0.978327676
5	0.1	0.978323419

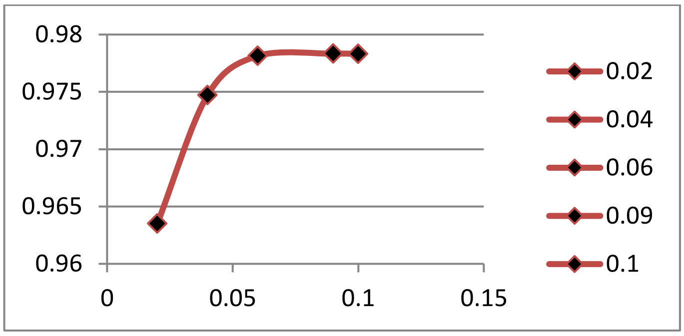

Figure 12: Graph: Velocity Vs Mixing Index

V. FABRICATION OF MICROMIXER MOLD BY CO2 LASER MACHINING

The component is fabricated by using Co2 laser machining on Acrylic sheet.

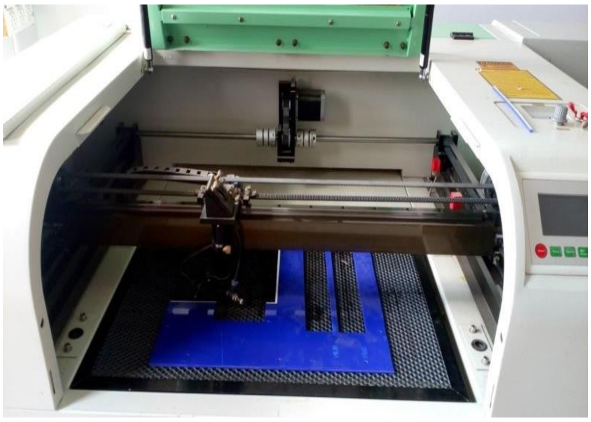

Figure 13: CO2 Machining Setup

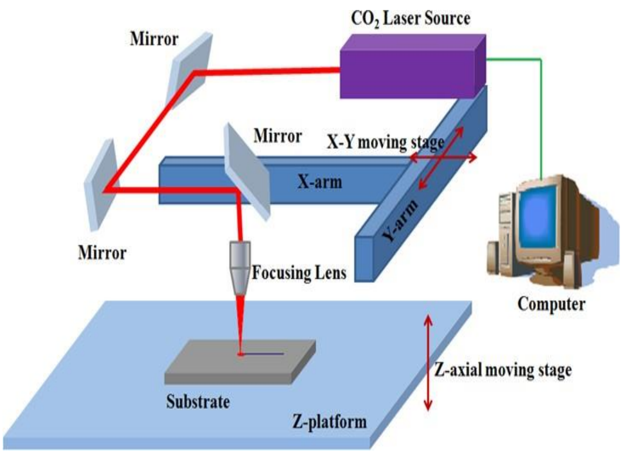

Figure 14: Block diagram of CO2 Laser Machining

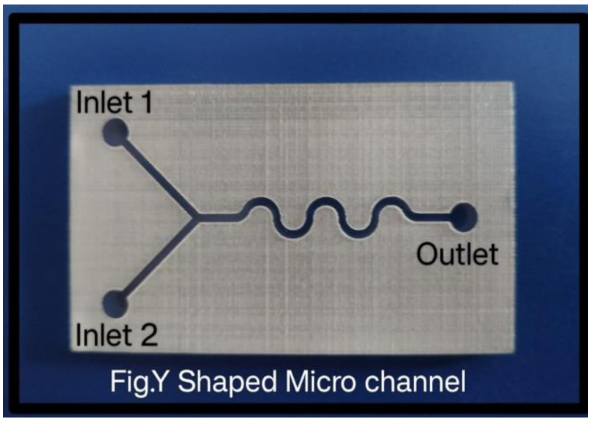

Figure 15: Fabricated Micromixers using CO2 Laser Facility

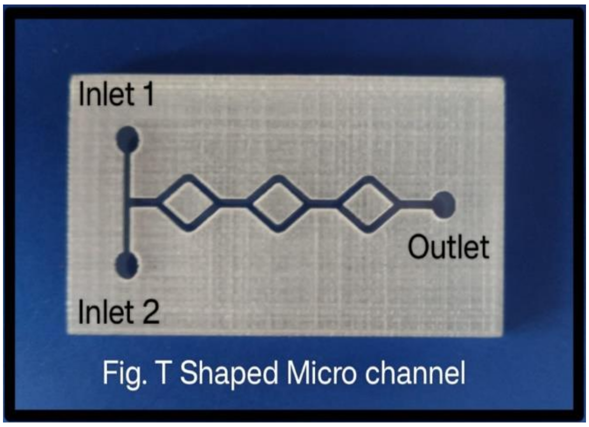

Figure 16: Fabricated Micromixers using CO2 Laser Facility

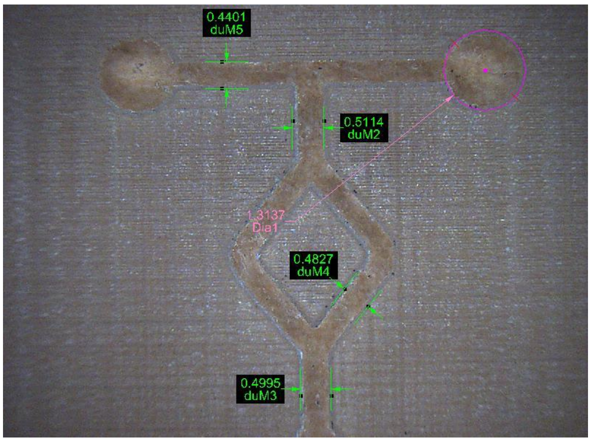

Figure 17: Characterization of fabricated microchannel by using Rapid-I Vision Machine

VI. CONCLUSION

The study successfully demonstrates that CO2 laser machining is an effective method for fabricating micromixers on acrylic sheets, offering high precision and flexibility in design. After doing computational analysis it noted that Mixing Index for Y-shaped Inlet Micromixer gives higher mixing Index ie.0.97 at Velocity 0.1 m/s.

VII. REFERENCES

[1] M.Reyhanian,C.Croizet, R.Gatignol, “Mixing Length in a Micro Channel”, 27th International Symposium on Rarefied Gas Dynamics Volume: 1333.

[2] Zonghuan Lu, Jay McMahon, Hlisham Mohamed, David Barnard, Tanvir R Shaikh, Carmen A. Mannella, Tercnce Wagenknecht and Toh-Ming Lu, "Passive microfluidic device for submilli second mixing", Sensors and Actuators B 144 (2010) 301-309.

[3] Gerlach A, Knebel G, Guber A E, Heckele M, Herrmann D, Muslija A and Schaller “Microfabrication of single-use plastic microfluidic devices for high- throughput screening and DNA analysis” Microsyst Technol. 7 265–8.

[4] Tsung-Han Tsai, Dar-Sun Liou, Long-Sheng Kuo and Ping-Hei Chen, "Rapid mixing between ferro-nanofluid and water in a semi-active Y-type micromixer", Sensors and Actuators A 153 (20 09) 267-273.

[5] Jojomon Joseph, Danish Rehman, Michel Delanaye, “Numerical and Experimental Study of Microchannel Performance on Flow Maldistribution”, Micromachines 2020, 11, 323; doi:10.3390/mi11030323

[6] Das, S.S., Tilekar, S.D., Wangikar, S.S. and Patowari, P.K, “Numerical and experimental study of passive fluids mixing in micro-channels of different configurations”, Microsystem Technologies, 23(12), pp.5977-5988,(2017)

[7] Seck Hoe Wong, Patrick Bryant, Michael Ward and Christopher Whartor, "Investigation of mixing in a cross-shaped micromixer with static mixing elements for reaction kinetics studies", Sensors and Actuators B 95, 414-424,(2013)

[8] Wangikar, S.S., Patowari, P.K. and Misra, R.D., “Numerical and experimental investigations on the performance of a serpentine microchannel with semicircular obstacles”, Microsystem Technologies, pp.1-14

[9] Gianni Orsi, Mina Roudgar, Elisabetta Brunazzi, Chiara Galletti and Roberto Mauri, "Water-ethanol mixing in T-shaped microdevices". Chemical Engineering Science 95 (2013) 174-183.

[10] Gidde, R.R., Pawar, P.M., Ronge, B.P., Misal, N.D., Kapurkar, R.B. and Parkhe, A.K., " Evaluation of the mixing performance in a planar passive micromixer with circular and square mixing chambers", Microsystem Technologies, pp.1-12

[11] Tsung-Han Tsai, Dar-Sun Liou, Long-Sheng Kuo and Ping-Hei Chen, "Rapid mixing between ferro-nanofluid and water in a semi-active Y-type micromixer", Sensors and Actuators A 153 (20 09) 267-273.