Manufacturing of Bi-Polar Plates Using Hydroforming Process

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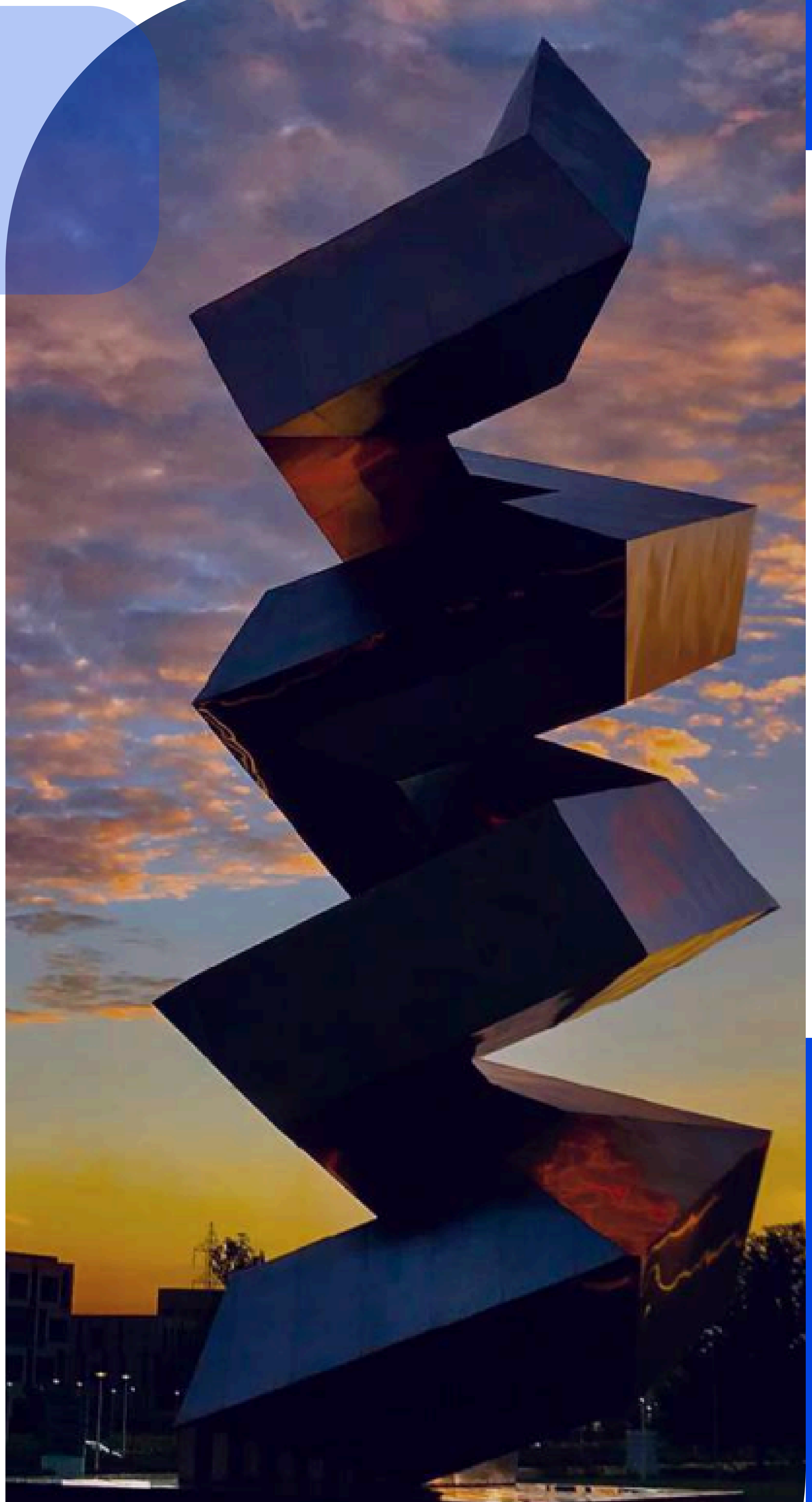

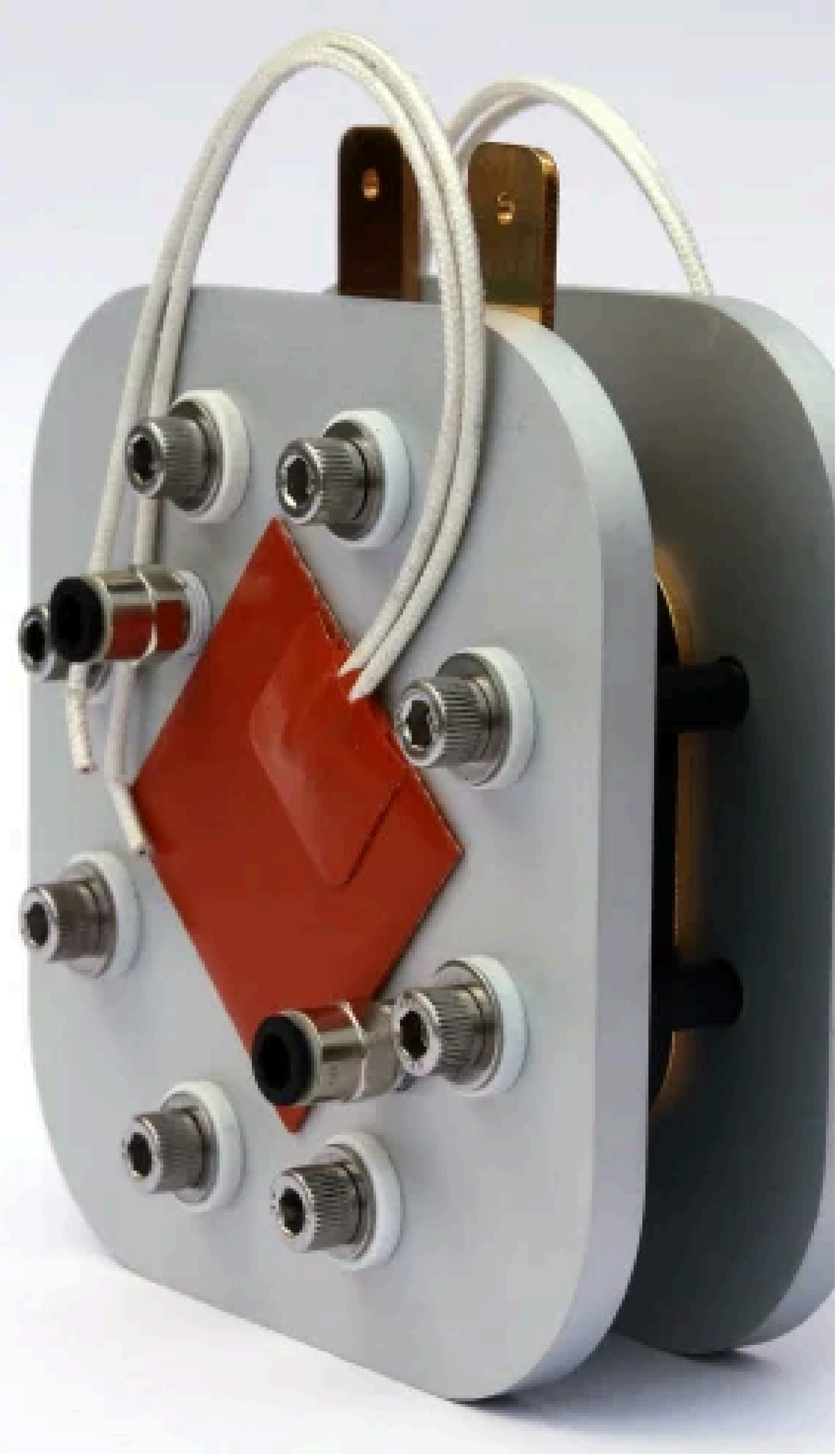

CONTENT

Introduction

In the quest for sustainable energy solutions, fuel cells have emerged as promising alternatives to traditional combustion-based power generation methods. Among the critical components of a fuel cell system are the bipolar plates (BPP), which facilitate the efficient distribution of reactants and the collection of electrical current within the cell. As the demand for fuel cell technology continues to grow, the need for advanced manufacturing techniques for more compact and efficient bipolar plates becomes increasingly apparent.

Problem Description

When making PEM bipolar plates for fuel cells using traditional methods like drawing, the plates can warp and become uneven in thickness. This causes issues with fitting the plates in the fuel cell stack and affects overall performance due to inconsistent contact resistance.

Hydroforming, a new method using uniform water pressure, avoids these problems, producing flatter, more even plates. This results in better-performing fuel cells that are easier to assemble.

Objectives

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Understand the principles of fuel cells, bipolar plates, flow channels, and the hydroforming process.

Design and construct a hydroforming setup tailored specifically for producing PEM bipolar plates.

Investigate the advantages of hydroforming over traditional methods for manufacturing PEM bipolar plates.

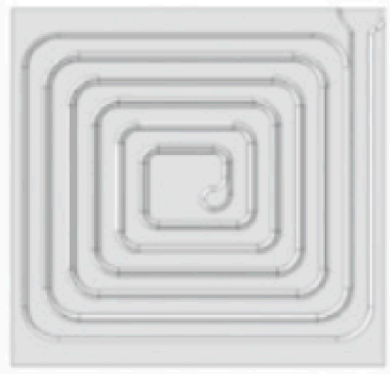
Review existing literature to gather insights into the latest developments in PEM bipolar plate manufacturing and simulation techniques.

Use computational simulations to model the hydroforming process and predict its outcomes accurately.

Existing Studies and Literature Review

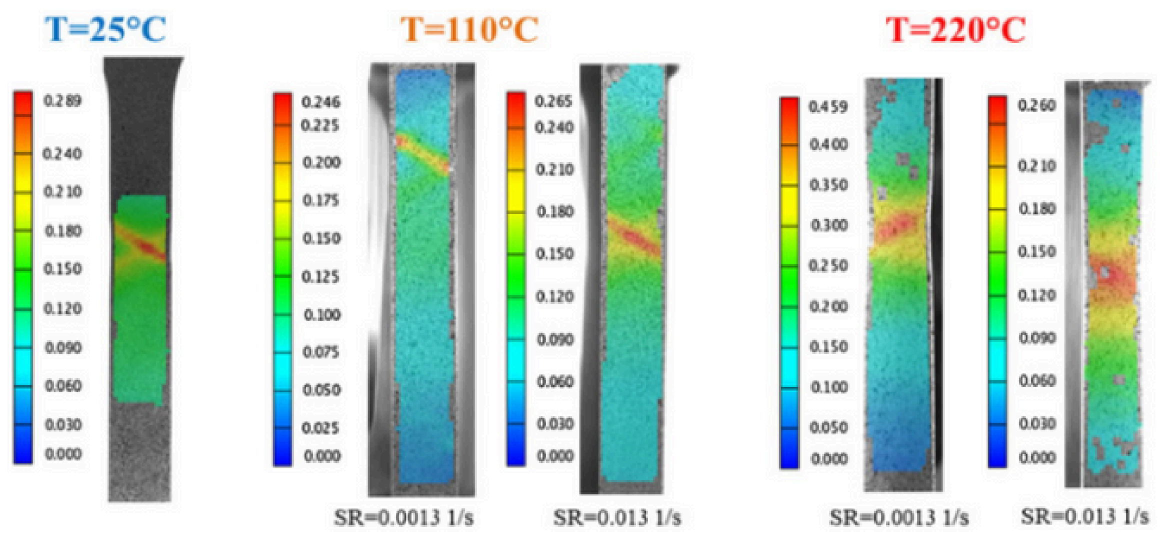
1. Numerical–experimental investigations on the manufacturing of an aluminum bipolar plate for proton exchange membrane fuel cells by warm hydroforming:

Giovannini et al. studied three BP geometries (SER, SP, MSER) using experimental tests and numerical simulations to optimize channel geometries for better fuel consumption and formability. They focused on channel width, depth, and die upper radius. The study found that higher temperatures improve material formability but pose challenges in achieving and maintaining these temperatures during the process.

Geometry	Serpentine	Spiral	Multiple Serpentine
Abbreviations	SER	SP	MSER
Plant view			

The research highlights a comprehensive approach to BP design, focusing on single-step channel forming and efficient separation of reagents and coolant. It finds that the SP geometry provides the best performance, with uniform strain distribution and the capacity to withstand higher forming pressures at all temperatures.

Giovannini et al.'s work underscores the importance of temperature control in HF processes, showing that while higher temperatures can improve formability, the benefits diminish beyond 110°C due to practical challenges.

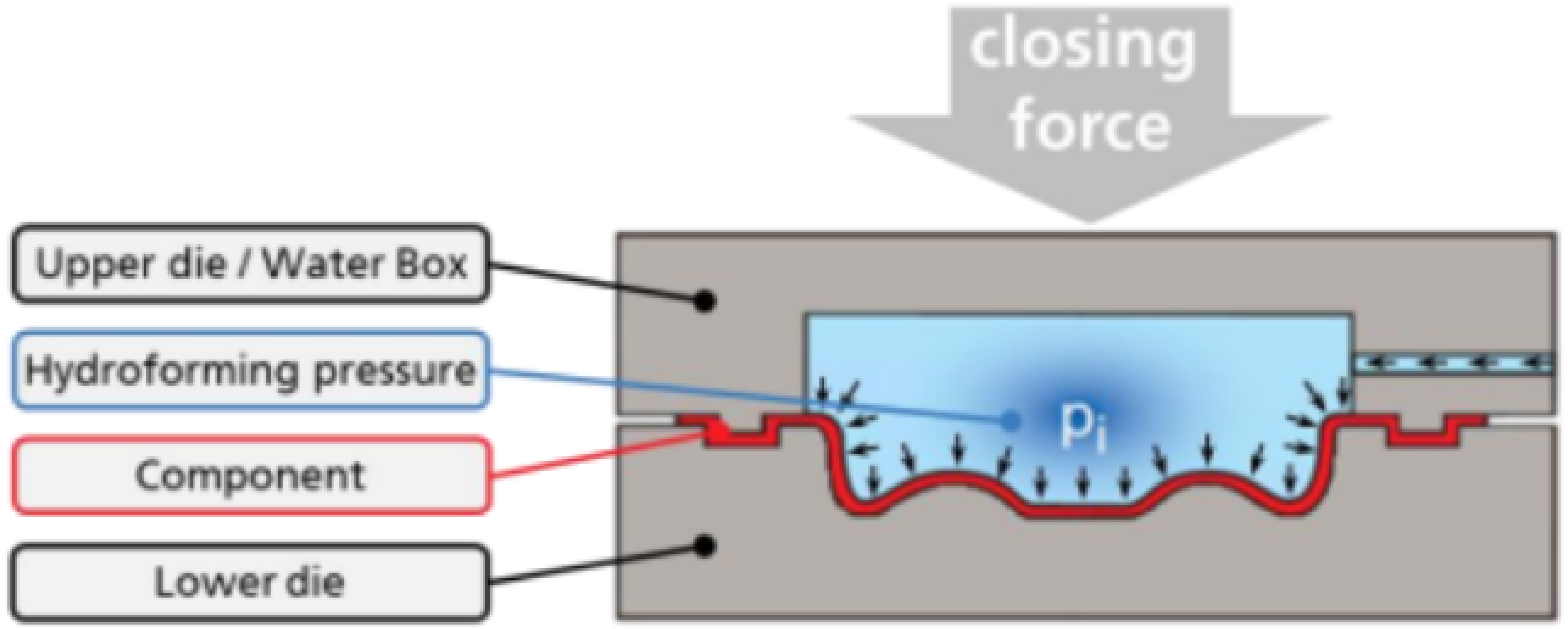


Their research provides valuable insights for optimizing BP design and HF processes for PEMFCs, with implications for enhancing energy efficiency and reducing weight in various applications, including compact electric vehicles.

2. Sealing Technologies for the Manufacturing of Bipolar Plates via Active and Passive Hydroforming:

Active Hydroforming Setup:

Pressure Application: In active hydroforming, a target-forming pressure, such as 200 MPa, is applied to the material using a hydraulic system. This pressure is crucial for shaping the material accurately.

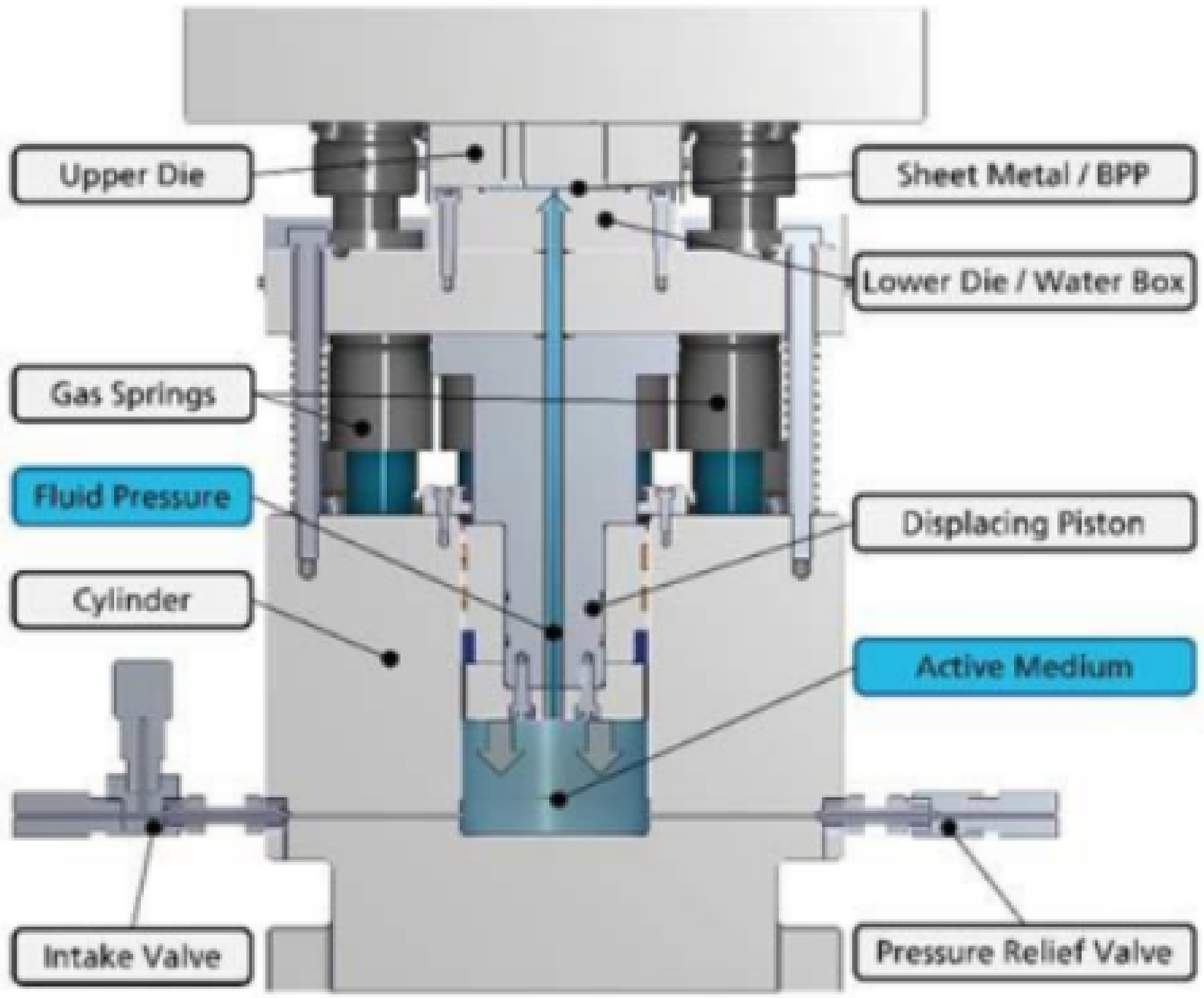


Benefits: Active hydroforming allows for precise control over the forming process, leading to accurate and complex shapes in the final product.

Passive Hydroforming Setup:

Initial Trials: In passive hydroforming, initial trials are conducted to test the process. These trials involve using a mold and achieving forming pressures exceeding 300 MPa.

Potential: The trials demonstrate the potential of passive hydroforming, showing that even at 200 MPa, components can be accurately formed, highlighting the process's capabilities.

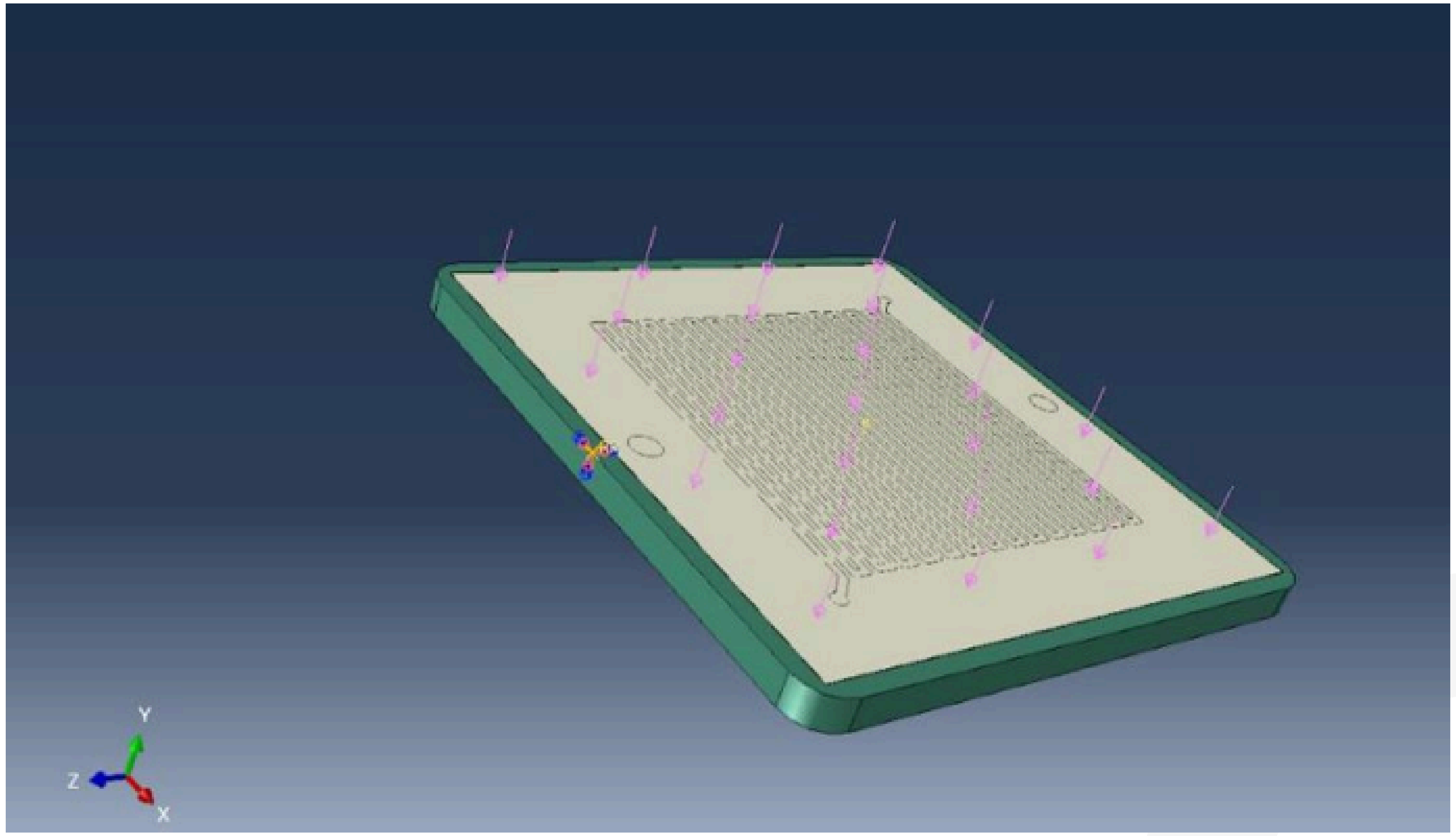


Future Plans: Further tests with the mold are planned to understand the relationship between the ram stroke, internal pressure, and to develop process control fundamentals.

Methodology and Results

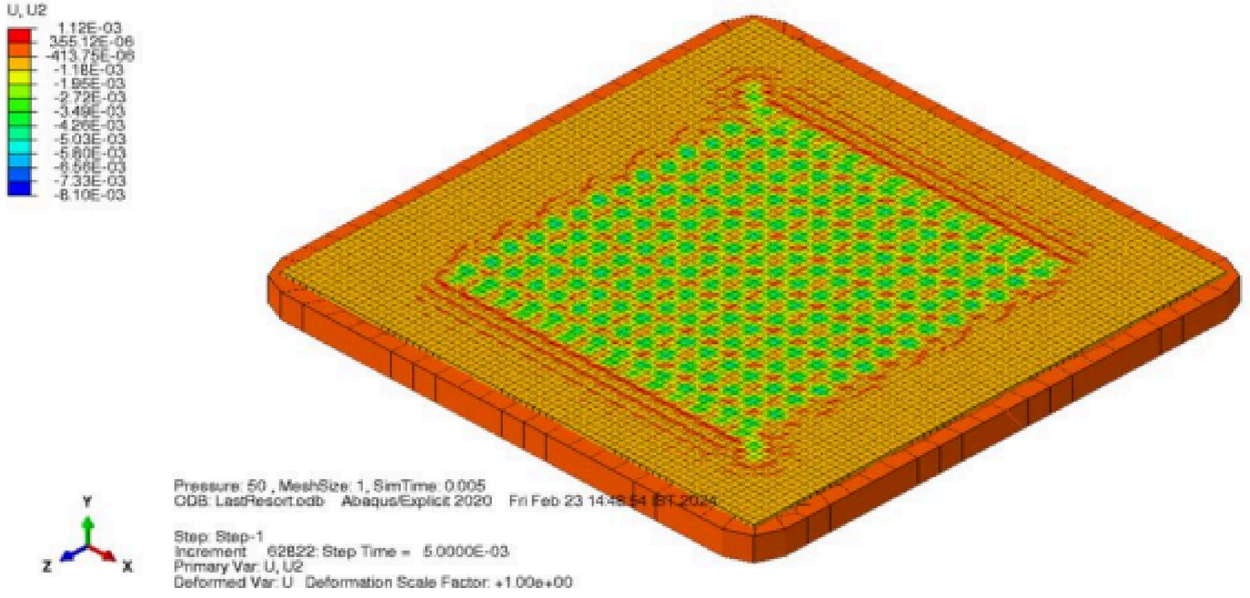
1. Abaqus simulations of the setup were run to achieve an idea of the experiment's result and attain the minimum pressure required to attain the desired sheet shape.

The Solidworks model of a serpentine channel die (discrete rigid) was imported into Abaqus and fixed w.r.t universal co-ordinate system and the sheet (3D deformable) was pressed against the die with a uniform pressure of 50 MPa, The sheet's material was chosen as steel and its end were kept free while simulating using various hexagonal mesh sizes to attain accurate sheet deformation values.



Results of the Simulations :

Mesh Size: 1mm.



Mesh Size: 0.5mm

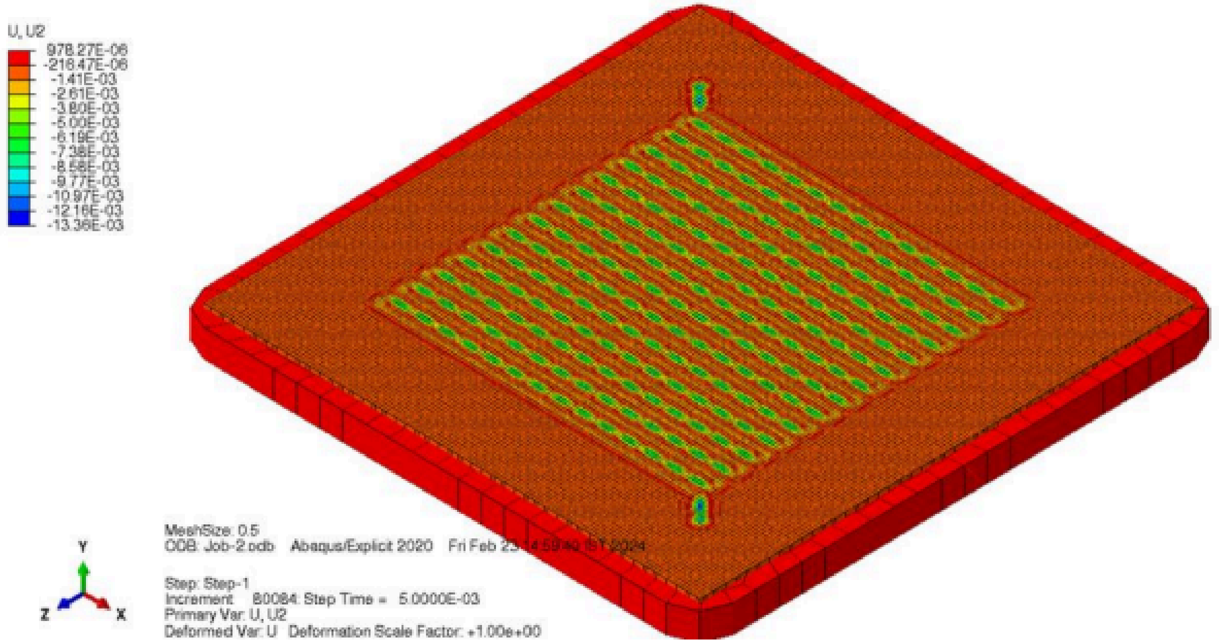


Figure 12: Simulation Results - Mesh Size: 0.5mm

Mesh Size: 0.1mm

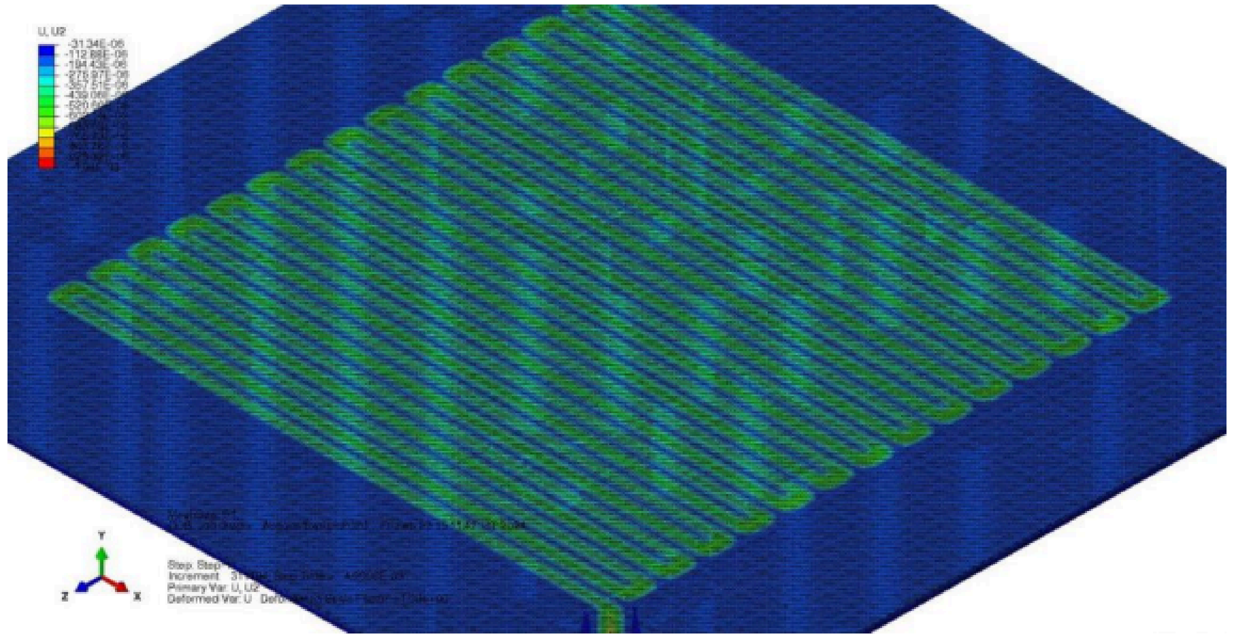


Figure 13: Simulation Result - Mesh Size: 0.5mm

The maximum deformation in every case is in the order of micrometers upon applying the load of 50 MPa. Also, no convergence in Maximum Y-displacement was observed when the Mesh size was reduced. Thus, it is concluded that the material used should be much softer and thinner than the used material to reach the desired magnitude of deformation.

2. Manufacturing Process of the Passive Hydroforming Setup :

We began with a 10mm thick Mild Steel Sheet, cut pieces using slot milling, and welded them together to make the container. Seam welds made sure that the container remained waterproof.

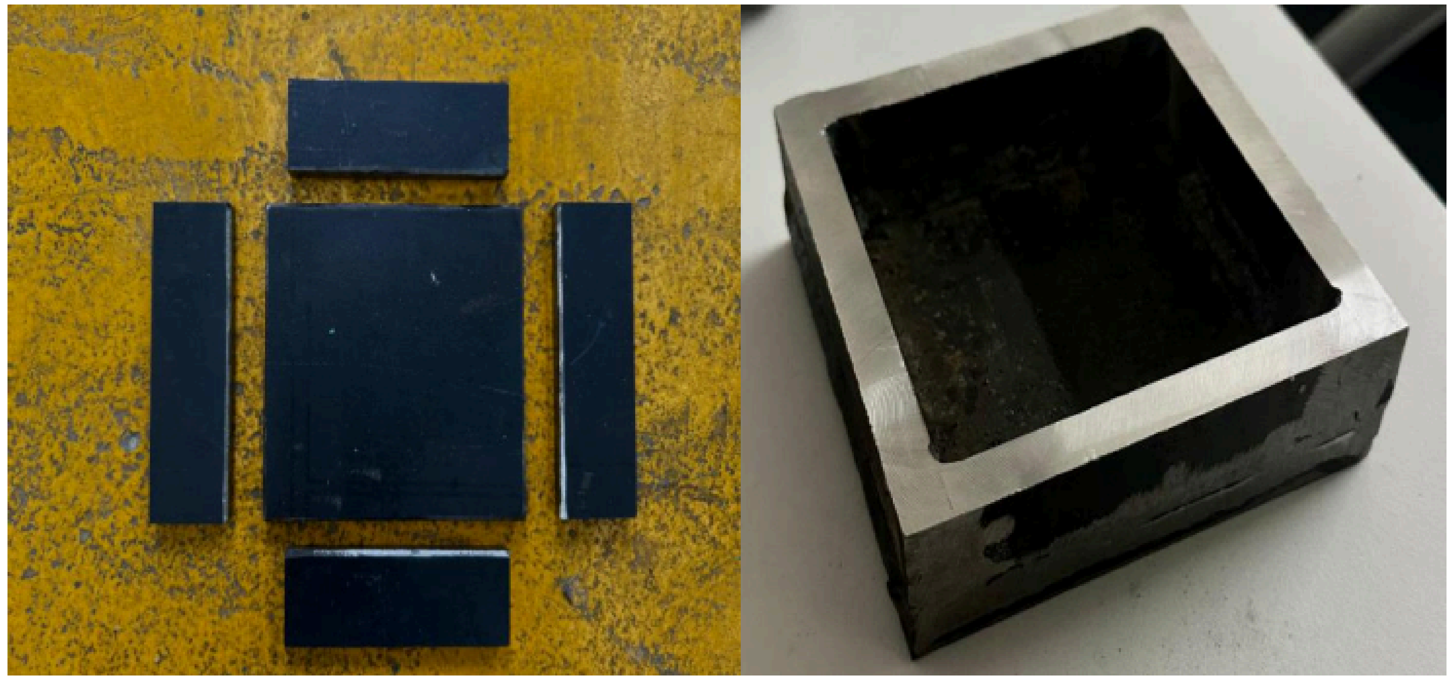


Fig 1 : Container

Fig 2 : Die

The main die block was made, similar to the fluid container. Pieces from 10mm Mild Steel were cut using slot milling. These were welded together to form the outer box of the Die. The second part was the block that contained the Channel Design, which was the central part of the die. Firstly, the tool path and the CNC program were made for the profile. The intricate channel design required by the setup posed difficulty regarding the fragility of the cutting tool of that size. Thus, a low depth of cut had to be given while the CNC traversed the path, which made the job very time-consuming. Finally, the block and the bounding box were welded to complete the Die piece.

3. Testing the Setup :

This is an ongoing phase as we test the setup on stainless steel sheets of thickness 10,50 and 100 microns. We recently made headway by solving the problem of leakage due to tearing of sheets at the corners by getting the edges of the die rounded. This helped us attain a better pressure, but the setup started leaking from the clay type gasket that we were using. So to reach the required pressure we are now experimenting on different gaskets primarily tape type gaskets that wouldn't get displaced due to pressure in contrast to the previous gasket to serve our purpose.

Conclusion

Design

The project journey, from exploring fuel cell principles to designing and testing a hydroforming setup for PEM Bipolar Plates (BPP), represents a significant step forward in sustainable energy solutions. Our focus on addressing challenges like warping and thickness inconsistencies in traditional BPP fabrication through hydroforming has yielded valuable insights from existing studies and simulations.

Efficiency

Key findings from the literature review, including numerical-experimental investigations and feasibility studies of hydroforming processes, have guided our approach in optimizing BPP designs and manufacturing techniques. The exploration of active and passive hydroforming setups underscored the precision and efficiency achievable through controlled pressure application.

Material Properties

Simulation results using Abaqus software provided critical data on material deformation behavior under hydroforming conditions. While challenges such as simulation convergence with finer mesh sizes were encountered, the outcomes emphasized the crucial role of material properties and process parameters in achieving desired deformations.

Future Scope

Fluid Heating : Introducing fluid heating mechanisms into the hydroforming setup can enhance the process's efficiency and precision. Heating the fluid to specific temperatures can optimize material properties, improve formability, and reduce energy consumption during the hydroforming process. Future iterations of the project could explore integrating heating elements or circulating heated fluid within the system to achieve optimal forming conditions.

Optimizing Channel Design : Continual optimization of channel designs for PEM Bipolar Plates (BPP) is crucial for maximizing fuel cell performance. Future research could focus on advanced computational modeling techniques, such as computational fluid dynamics (CFD) simulations, to fine-tune channel geometries for improved reactant distribution, reduced pressure drop, and enhanced overall fuel cell efficiency.

Automation : Implementing automation technologies within the hydroforming setup can streamline production processes, increase productivity, and ensure consistent quality in BPP manufacturing. Future developments may involve integrating robotic systems for loading and unloading sheets, automated pressure control mechanisms, and real-time monitoring and feedback systems for process optimization. Automation not only improves efficiency but also reduces manual labor requirements and minimizes human error, leading to more reliable and cost-effective production.

THANK YOU

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