MULTIDISCIPLINARY PARAMETRIC OPTIMIZATION OF COOLING CHANNEL CROSS-SECTION FOR BATTERY THERMAL MANAGEMENT.

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Abstract

In electric vehicles, the battery thermal management system (BTMS) plays an important role in driving the battery performance. Most of BTMS have a liquid cooling system and the performance of the liquid cooling channel continues to be a challenge. This study focuses on parametric optimization of the cross-section of the cooling channel using computational fluid, thermal, and structural analyses. The objective of the study is to design optimal cross-section through multi-disciplinary optimization considering thermal and structural performance.

This study appreciates the use of seamless CAD-CAE integration for the optimization process. Four shapes of the cross section of the cooling fluid channel are considered and their effect on cooling performance of the battery cell is analyzed. Firstly, a computational fluid dynamic (CFD) simulation including the conjugate heat transfer effects is performed for thermal analysis of representative battery cells and fluid channel system. Following this, the steady state pressure values from the CFD analysis are mapped to the structural model of the same system in order to check the structural performance. Finally, this process is embedded in the optimization process to get the optimal cross-section design.

Keywords: battery thermal management system, cooling channel parametric optimization, CAD-CAE integration, electric vehicles,

Introduction

Li-ion battery is widely used in electric vehicle nowadays, but its performance is only guaranteed in certain temperature range. Therefore, precise temperature management is critical for electric vehicle performance and the battery thermal management system (BTMS) is a challenging topic for the automotive OEMs. Most of BTMS uses fluid cooling system and cooling channel design is one of the challenges nowadays.

Current study focuses on optimizing the cross-section of the coolant channel based on thermal and structural analyses. First, various cross section shapes are studied with the same simulation boundary condition. The study involves CFD simulation to assess temperature of the battery with changing cross-sections. The best cross-section was chosen by studying the cooling performance of the channel. Once the best shape of the cross section was chosen, the cross-section geometry was parameterized for the optimization process including CFD simulation as well as structural simulation of the channel. The CFD and structural simulations are performed sequentially by varying cross-section parameters to obtain the best cooling performance of the system.

Numerical models for fluid cooling analysis

The sequential CFD simulation including the conjugate heat transfer effects and structural analyses were performed using 3DEXPERIENCE platform. Four shapes of the channel cross-sections were considered: 1. Rectangular, 2. Elliptical, 3. Tilted parallelogram, and 4. Crescent shapes. The mode of the channel and battery cells is shown in Figure 1 and the different cross-sections are shown in Figure 2. The channel has the same dimension (460 mm by 40 mm by 5 mm) for different cross-section shape. The same number of identical 18650 cylindrical battery cell placed with equal distance (25 mm) on the top of the channel as shown in Figure 1. The cross section area is maintained as the same for all the shapes of the cross sections. The bottom of the battery cell is tied with the top surface of the channel. Table 1 provides the details of cross section areas and volumes. 3D Sweep meshing technique is used to mesh the fluid cavity and the solid channel. Mesh size 1 mm is used for cross-section surface for all four shapes of the channel cross-sections. The number of elements is around 2 million.

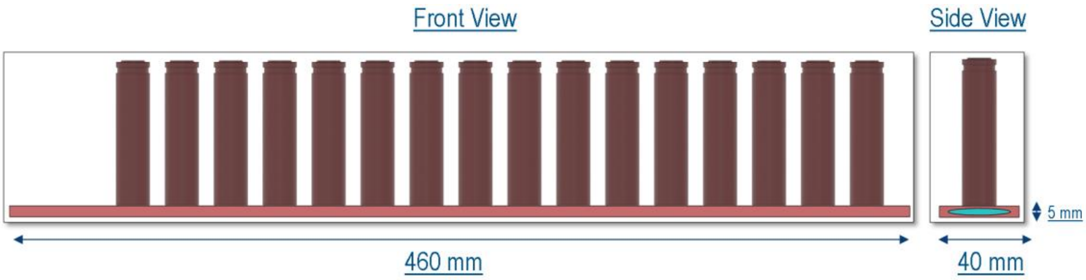

Figure 1. Fluid channel model with battery cell

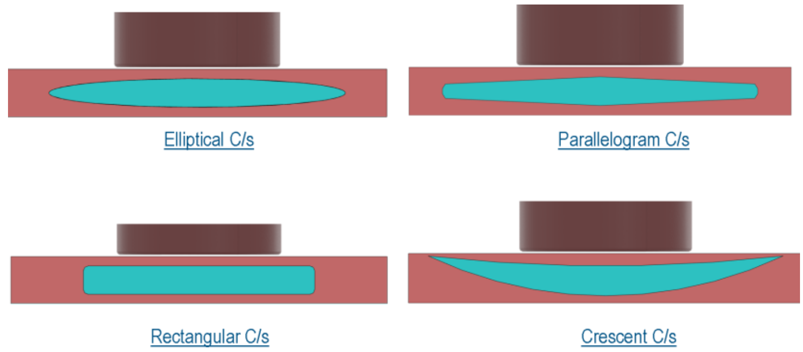

Figure 2. Cross Section Configurations

Table 1. Cross section area, perimeter and volume

Sr. No.	Cross-section name	Area	Perimeter
1.	Elliptical	73.63 mm2	63.43 mm
2.	Rectangular	73.59 mm2	54.342 mm
3.	Parallelogram	73.6 mm2	68.262 mm
4.	Crescent	73.57 mm2	73.263 mm

Glycol is used for the coolant and aluminum is used for the fluid channel in this study. A homogenized battery material is used to define overall heat transfer phenomenon. All the materials properties are shown in Table 2.

Table 2. Material definitions

Material	Phase	Conductivity (W/m.K)	Density (Kg/m3)	Heat capacity (J/(Kg.K))	Viscosity ((N.s)/m2)	Elasticity (N/m2)	Poisson's ratio
Battery	Solid	{1.01,1.01,30.22}	750	2690	-	1.8e+011	0.265
Aluminum	Solid	238	2710	903	-	7e+010	0.346
Coolant	Liquid	0.405	1078	3300	0.00429	-	-

For CFD analysis, a volume flow rate 1 liter/min is applied at the inlet and outlet pressure is set to zero and the initial temperature of coolant is set to 290 K while 300 K temperature is assign as initial temperature at all solid section (channel and battery cells). Assuming 1C discharge rate, a constant 13 kW/m3 heat generation rate [1] is applied to the battery cell. In CFD analysis, the conjugate heat transfer simulation provides the heat transfer through the fluids to the solids. Figure 3 shows schematic view of the CFD analysis.

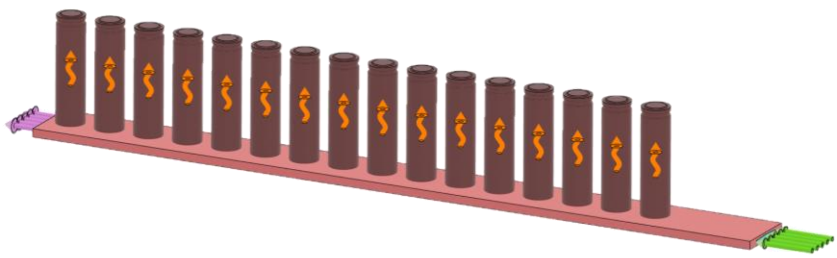

Figure 3. Fluid Simulation Setup

Comparison between different cross section designs

Figure 4 and Table 4 show the steady-state CFD results of different channel cross-section designs. The outlet fluid velocities and average temperatures at the top of the cells near the outlet are a little different between the cross-section designs. The turbulent effect is not significant in the current model as shown in Table 4. Therefore, the turbulent model is not considered in following optimization process.

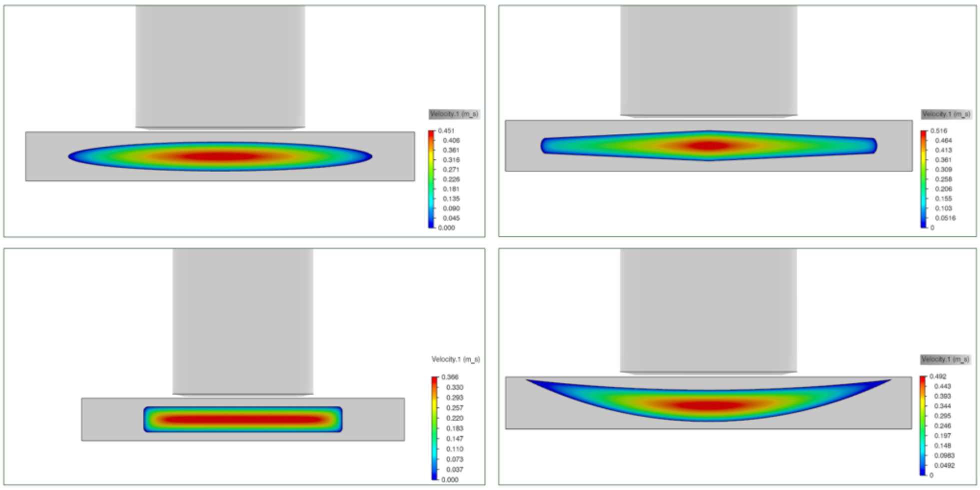

Figure 4. Velocity contours at outlet in different cross-section designs

Table 2 Comparison between turbulent and non-turbulent flow models

Cross-section	Maximum velocity at outlet (m/s)		Reynold's number	Average temperature on cell top near outlet (K)		
	Turbulent	Non-turbulent		Turbulent	Non-turbulent	%diff
Elliptical	0.491	0.491	0.531	308.743	308.750	0.0022
Rectangular	0.366	0.366	0.462	309.129	309.134	0.0016
Parallelogram	0.516	0.516	0.518	307.588	307.573	0.0048
Crescent	0.492	0.492	0.460	308.263	308.271	0.0025

Cooling performance of the cross section is also assessed by the temperature plot at the channel top surface versus channel length as shown in Figure 5. The top surface of the cooling channel is exposed to both temperature loads heating from one side and cooling from another side. In this case, there is positive heat transfer from the bottom surface of the cell to top surface of the cooling channel and then from top surface of the cooling channel to the coolant. Based on Figure 5, the parallelogram cross-section design is chosen for the following optimization model.

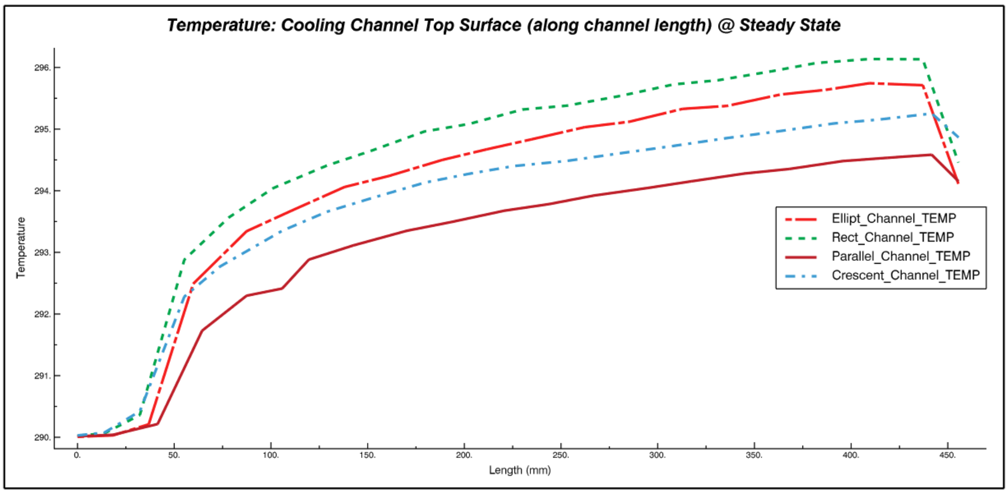

Figure 5. Channel top surface temperature comparison

Multi-disciplinary parametric optimization process

A parametric geometry for parallelogram cross-section is shown in Figure 6. There are two parametric design variables: short axis length and long axis length. The cross section is symmetric to the vertical axis. Minimum four layers of sweep elements were maintained in channel geometry for the heat transfer equation to converge between cell bottom and fluid. Once the geometry for each design parameters is created, the mesh is automatically updated in 3DEXPERIENCE platform.

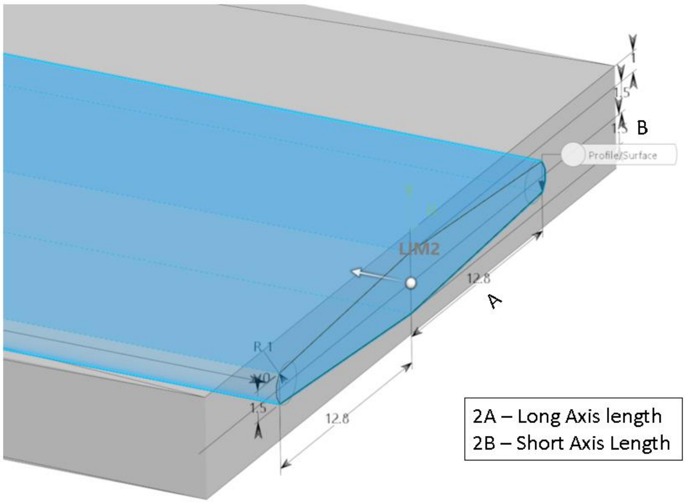

Figure 6. Parameterized channel cross-section for the fluid volume (blue)

The CFD simulation model is set as the same as the model in the previous section. For structural analysis, only the channel solid geometry was used. A first order tetrahedron mesh was used for convenience. The pressure loading from CFD analysis is also considered as well as the weight of each battery cell. The pressure from CFD is mapped to the structural model using the script and the pressure load which is equivalent to the weight on contact surface between battery cell and the channel surface is applied. As a boundary condition, two ends of the channels are constrained for all 6 degrees of freedom for convenience. And static procedure is performed to obtain deformation and stress as shown in Figure 7.

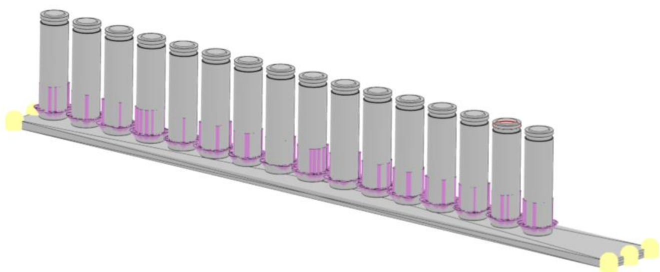

Figure 7. Structural simulation set-up

A sequential flow and structure analyses are integrated in process composer in 3DEXPERIENCE as shown in Figure 8 for an optimization process. The process allows result data values from fluid analysis being exported and maps to structural analysis. The pointer-2 method was used as the optimizer. The short and long axis length are selected as design variables for the optimization as described before. A design space for 200 iterations was chosen automatically by the algorithm. Temperature at the top surface of the cell in fluid analysis, maximum absolute deformation and maximum Von-Mises stress in the fluid channel from structural analysis are selected as the target variables. The objective of the optimization is to minimize all target variables. The long axis length can varies from 20mm to 35mm and the short axis length can varies from 2mm to 3.16mm respectively.

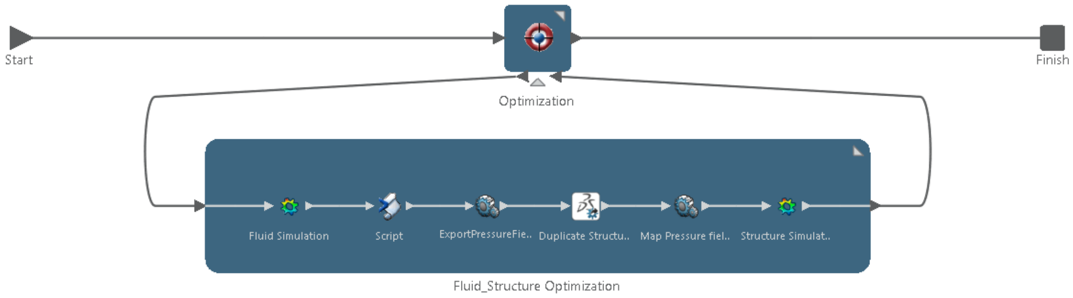

Figure 8. Optimization process set-up

Optimization results and discussions

The process runs 200 iterations and 25 iterations failed to execute since the mesh algorithm is not able to handle the geometry variations during meshing execution. Optimizer did traverse through whole design space and started converging in the range of 22mm to 28mm for long axis length and 2.4mm to 2.8mm for short axis length as shown in Figure 9. The final design parameter values are 24.52mm for the long axis length and 3mm for short axis length. As we get the optimum cross section by considering the thermal and structural analyses, we can always conclude to have the optimum mass for the considered cross section geometry keeping the material properties same. Table 5 shows the initial and final design variables and target variables.

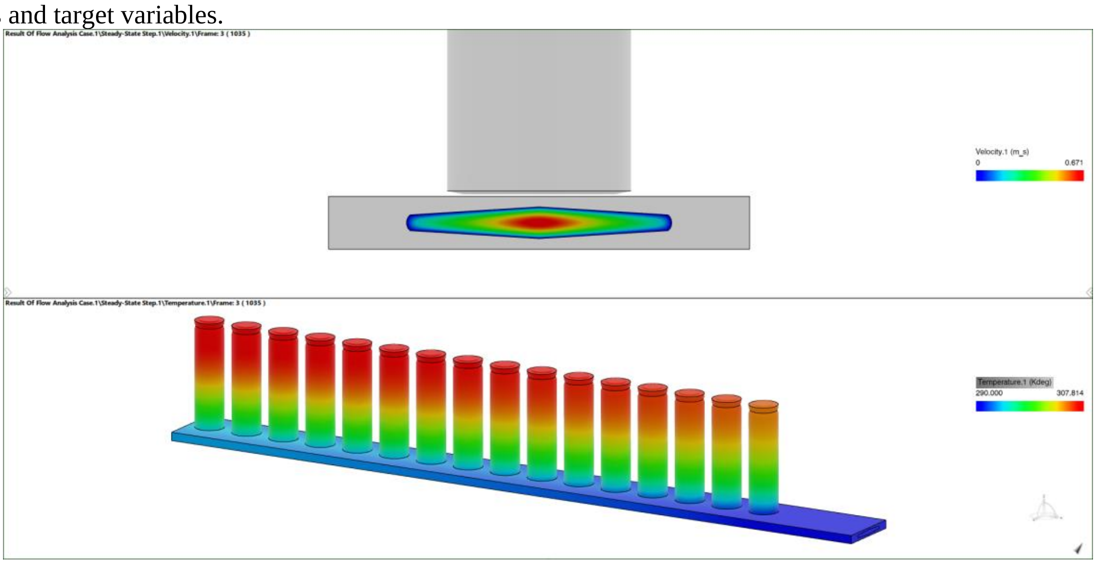

Figure 9. The optimized velocity and temperature contours

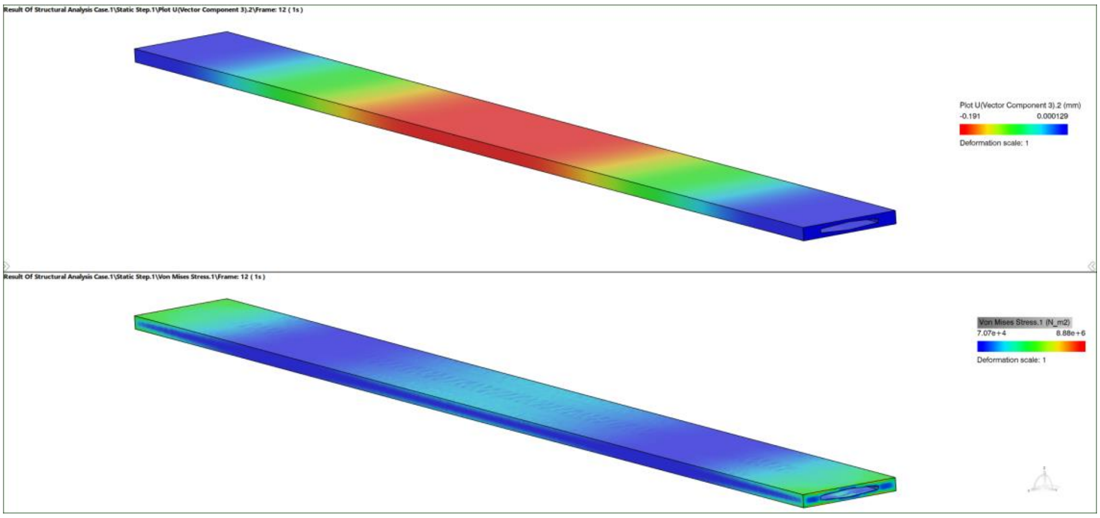

Figure 10. The optimized vertical deformation and von-mises stress contours

Table 5 Initial and final design/target variable

	Long axis length	Short axis length	Velocity at outlet (m/s)	Average temperature on cell top near outlet (K)	Maximum Von Mises (MPa)
Initial	20.2mm	3mm	0.803	308.112	9.5
Final	24.52mm	3mm	0.670517	307.814	9.42

Conclusions

This study shows the optimization process considering steady-state fluid cooling analysis and structural analysis for battery cooling channel cross-section design. Thanks to CAD-CAE integration in 3DEXPERIENCE, the CFD and structural mesh are automatically updated once the CAD geometry is changed. With given inlet flow rate, the turbulent model is not needed in the numerical simulation. The right cross-section shape can be easily selected by the numerical simulation. And the optimal design parameters can be decided through the optimization process including fluid cooling and structural analyses.

Acknowledgments

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