Frontal crash & Side Pole crash

배터리 패키징 구조최적화

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I. 연구배경

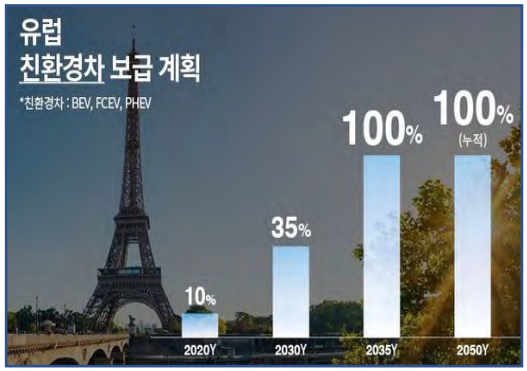
I. 연구 배경 _ 친환경 자동차 적용 배경

현재

- 환경 문제에 대한 관심이 높아짐에 따라 글로벌 완성차 업체들의 친환경 차량 보급 가속화
- 친환경 차량 시장에서 리튬이온 배터리를 주 동력원으로 사용하는 EV차량이 빠르게 발전 및 보급되고 있음
- 충돌 시 열폭주 현상과 같은 안정성에 대한 문제로 인해 내구성을 고려해야 하고 주행거리를 위한 경량화 또한 고려

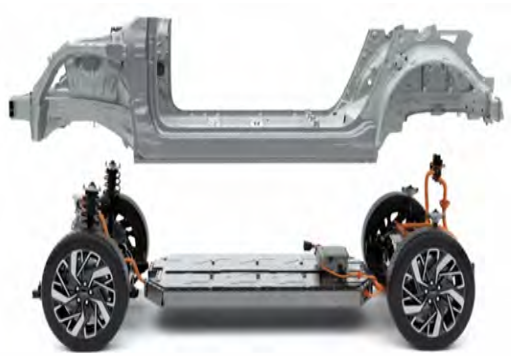
요구 항목

- 충돌 시 배터리 열폭주를 방지하기 위한 Battery pack & Module 내구성 확보
- EV 차량의 약 1/3 무게를 차지하는 배터리 팩의 경량화를 통한 EV 차량의 전비 및 에너지 효율, 가속성능 확보
- 경량화, 안전성 확보의 동시 만족을 목표로 연구를 진행



1) 출처 : 현대자동차

2) 출처 : 연합뉴스



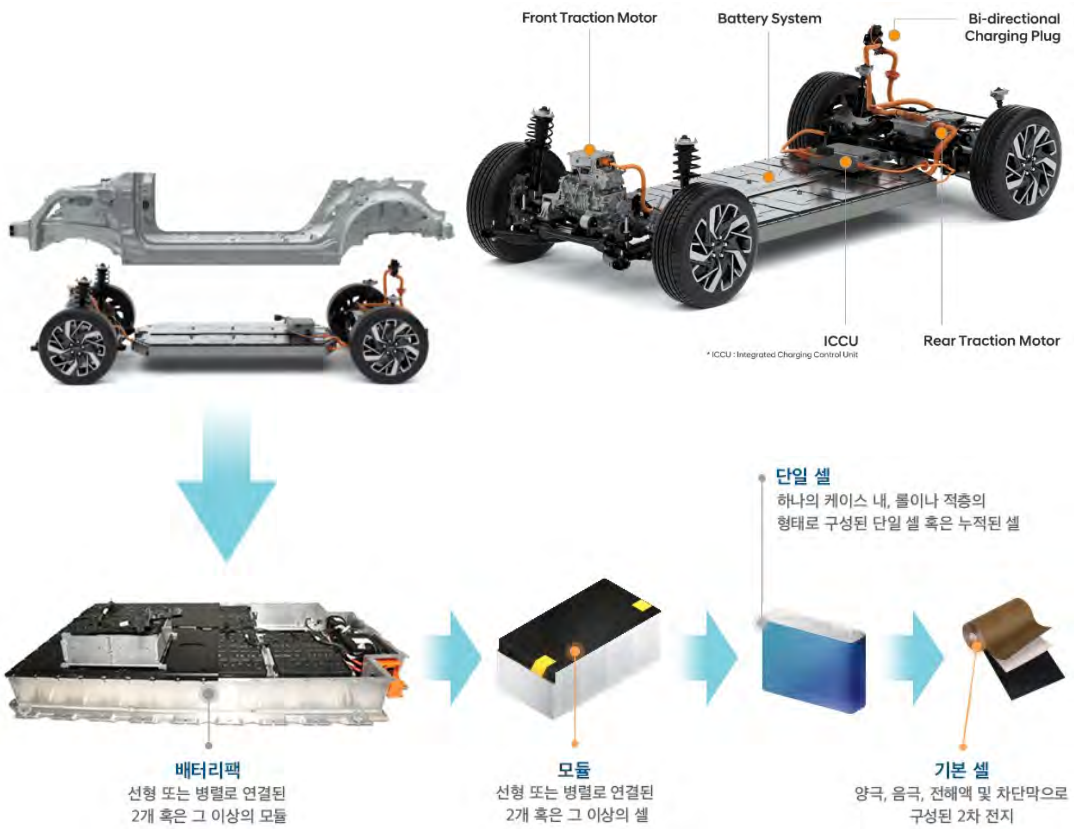
3) 출처 : 현대자동차(E-GMP)

목표

- 충돌 시 기존 Battery pack & Module에 비해 우수한 내구성 확보
- 기존 Battery pack & Module에 내구성을 확보하는 동시에 경량화
- 경량화 된 상태로 우수한 내구성을 확보할 수 있는 최적 설계 모델 도출

I. 연구 배경 _ 배터리 팩 구성

BATTERY PACK 구성



CELL 종류

원통형

파우치형

각형

1) 출처 : Li carco
2) 출처 : LG ENSOL

I. 연구 배경 _ 차량 시험 규정

Frontal Crash

시험 주최 기관 : IIHS [1]

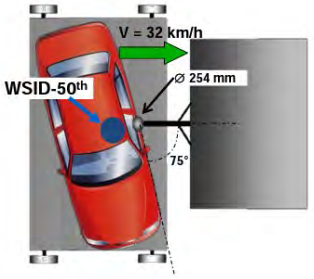
충돌 속도 : 40 mph (64 km/h)

1) IIHS : Insurance Institute for Highway Safety
미국 자동차 보험 협회

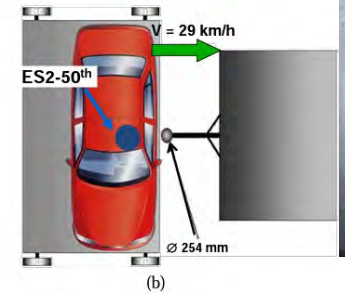
Side Pole Crash

시험 주최 기관 : EURO NCAP [2]

충돌 속도 : 18 mph (29 km/h)



(a)

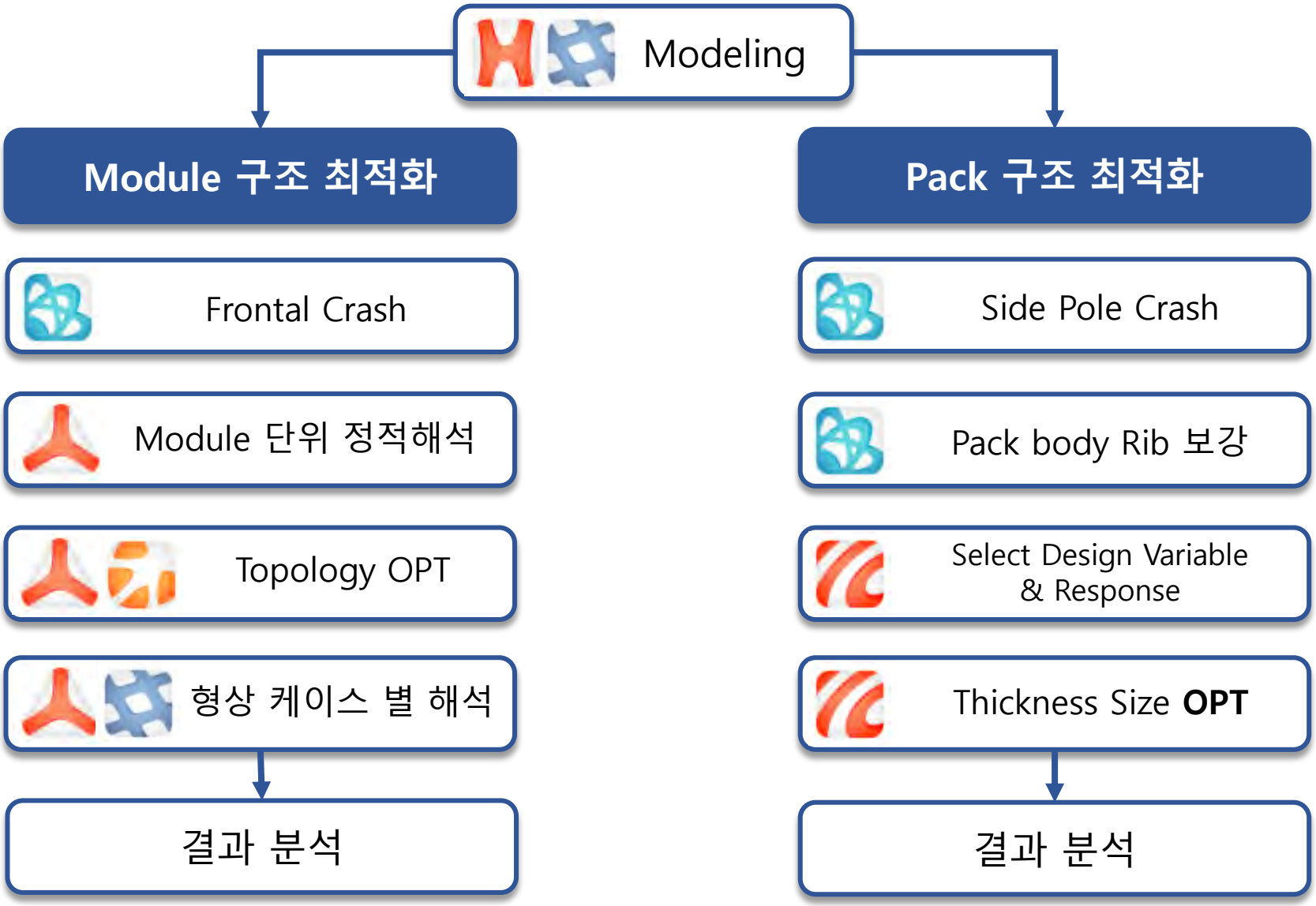


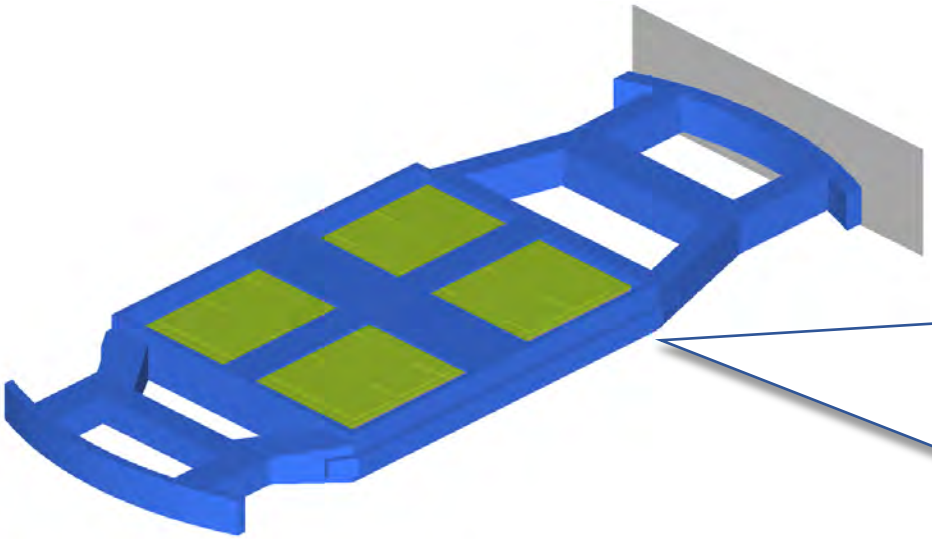
(b)

2) NCAP : New Car Assessment Program
신차평가제도

1) 출처 : frontal crash
2) 출처 : side pole

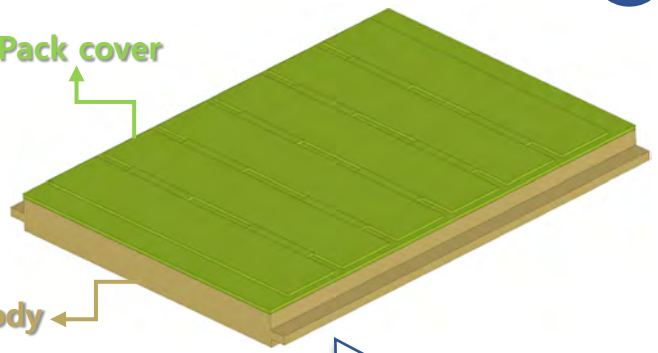
II. Process & Modeling


Modeling
Module 구조 최적화
Frontal Crash
Module 단위 정적해석
Topology OPT
형상 케이스 별 해석
결과 분석
Pack 구조 최적화
Side Pole Crash
Pack body Rib 보강
Select Design Variable & Response
Thickness Size OPT
결과 분석



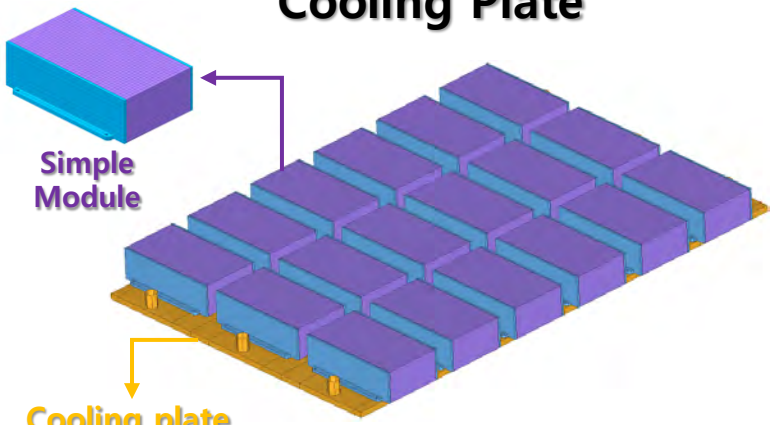
Battery PACK

1



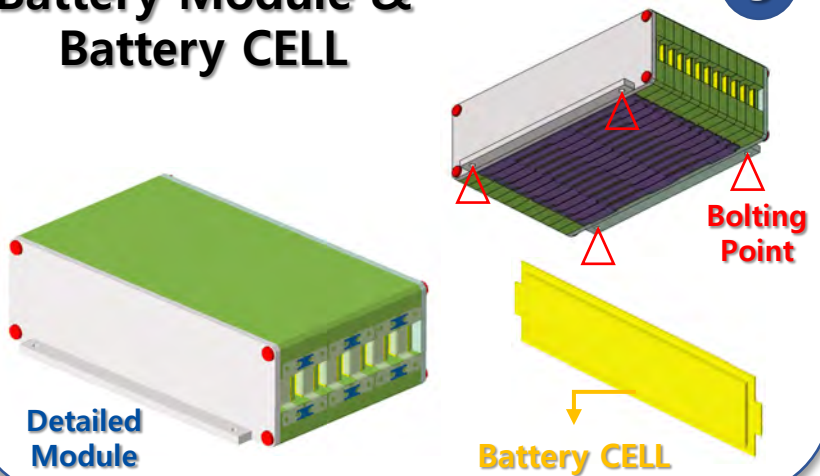
Battery Module& Cooling Plate

2



Battery Module & Battery CELL

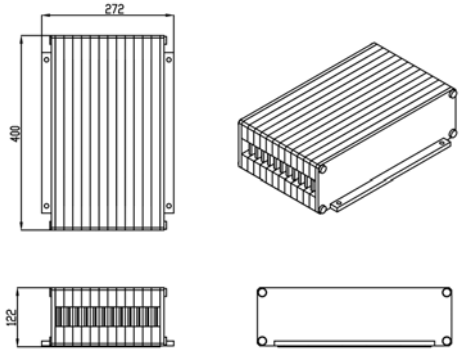
3



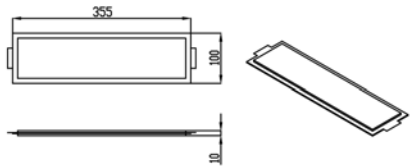
II. Process & Modeling _ Model Size

Crash body

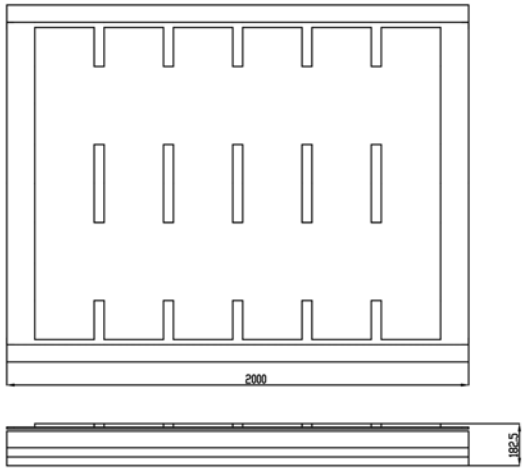
Battery module



Battery CELL



Battery Pack



Reference Model

모델명 : **all new GRANDEUR**

전폭 : 1,880 mm

전장 : 5,035 mm

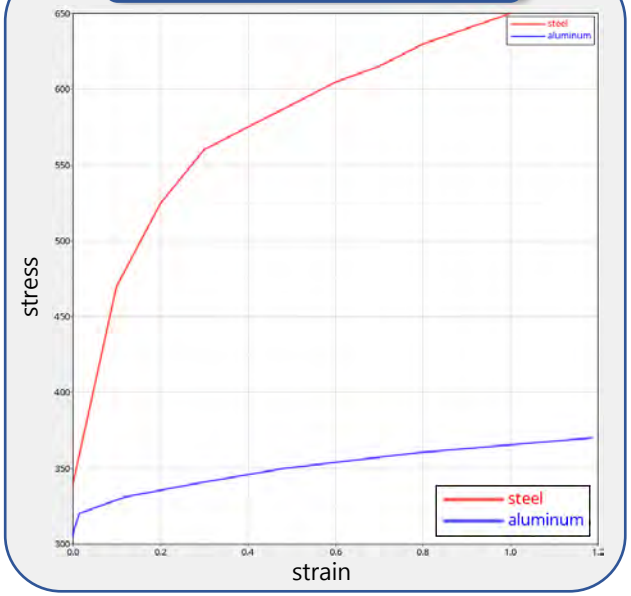
전고 : 1,460 mm

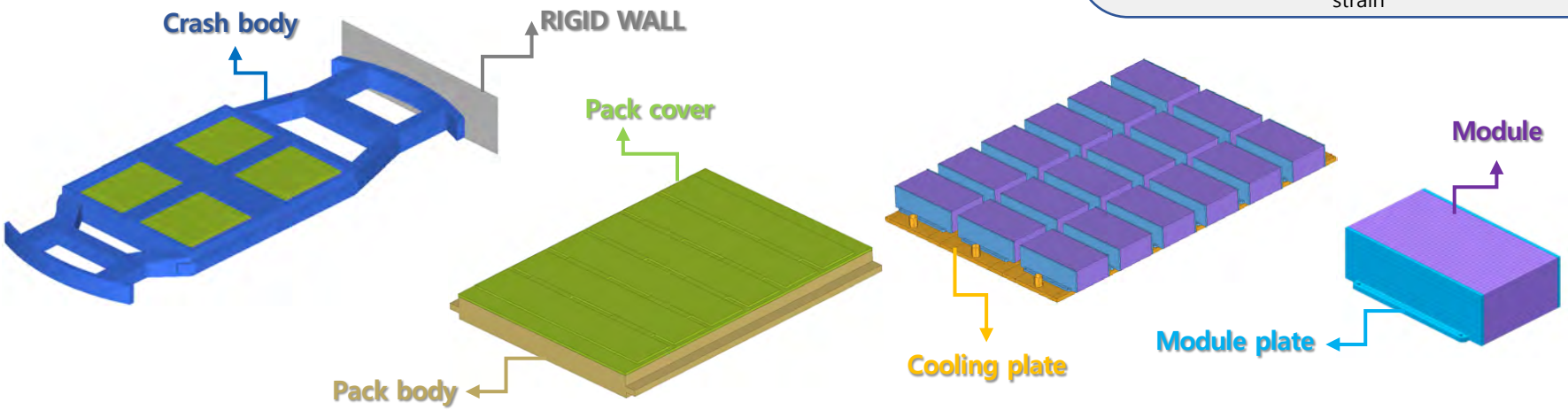
1) 출처 : 현대자동차

II. Process & Modeling _ Material information

DYNAMIC [Frontal & Side Pole Crash] → Material information					
Part name	Material	Density [t/mm³]	Modulus [MPa]	Poisson's ratio	Elastic / Plastic
RIGID WALL	RIGID	-	-	-	-
Crash body	Steel	7.89 E-9	210,000	0.3	Plastic
Pack body	Steel	7.89 E-9	210,000	0.3	Plastic
Pack cover	Aluminum 6061	2.7 E-9	68,000	0.33	Plastic
Cooling plate	Steel	7.89 E-9	210,000	0.3	Plastic
Module plate	Steel	7.89 E-9	210,000	0.3	Plastic
Module	Plastic (PA6)	1.12 E-9	2,600	0.35	Elastic

Plastic SS curve



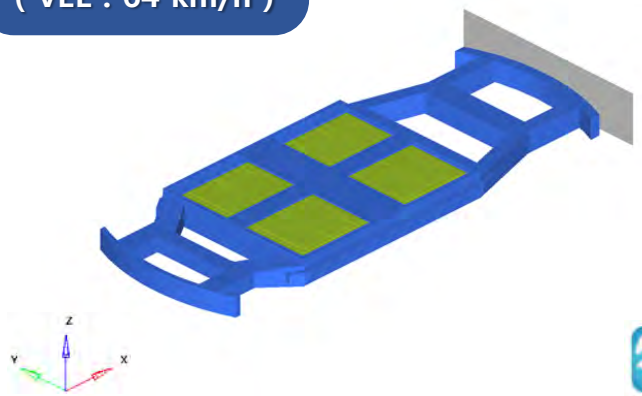


1) Reference : Fracture Toughness Measurement for Aluminum 6061-T6 using Notched Round Bars
2) Reference : Numerical Analysis for a Bicycle Frame made of Mild Steel and Composite
3) Reference : Altair Material Data Center 4MID 9B24100 (PA6)

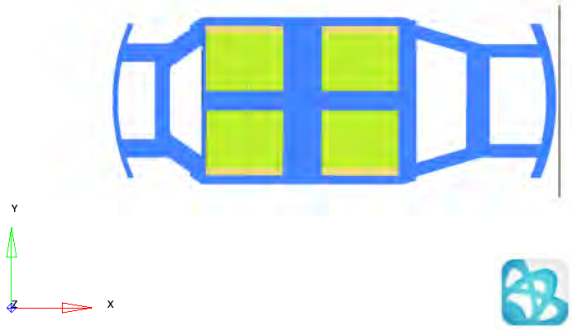
II. Process & Modeling _ Case of Crash

Frontal Crash
(VEL : 64 km/h)

Isometric view



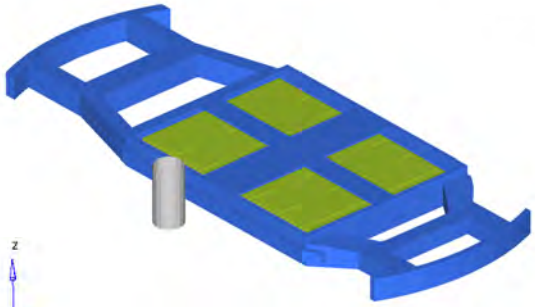
TOP view



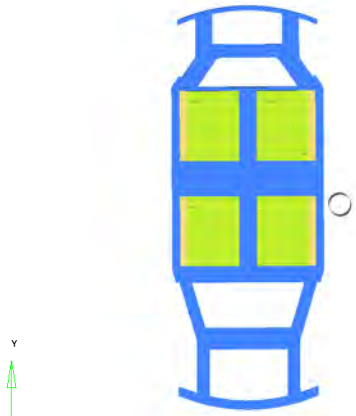
Real test

Side Pole
(VEL : 29 km/h)

Isometric view



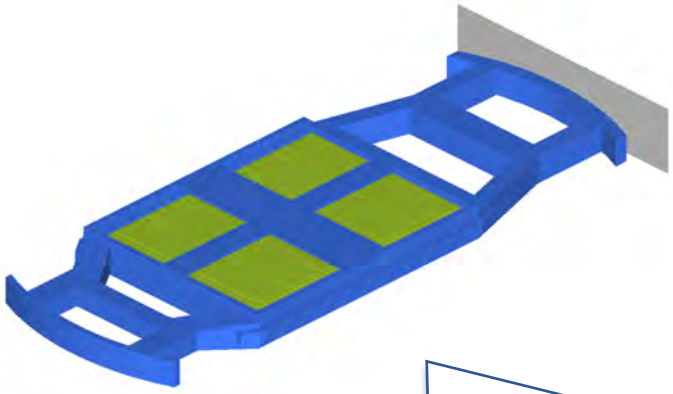
TOP view



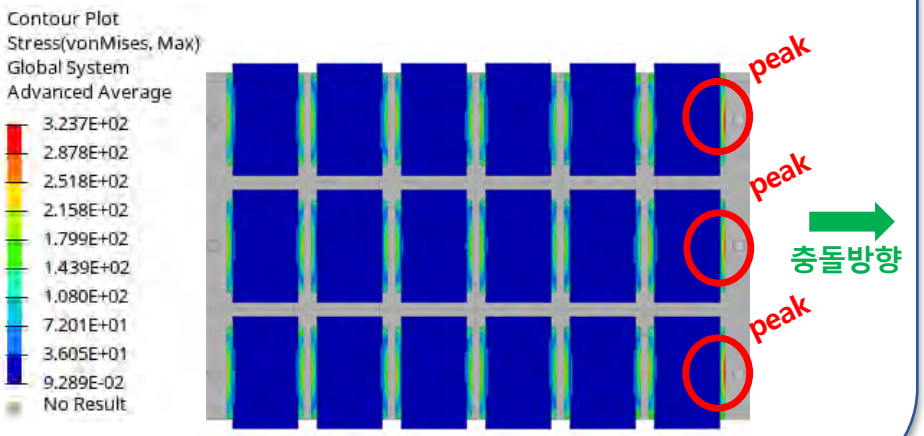
1) 영상 출처 : CN7 NHTSA frontal crash test
2) 영상 출처 : AVANTE side pole crash

II. Process & Modeling _ Case of Crash

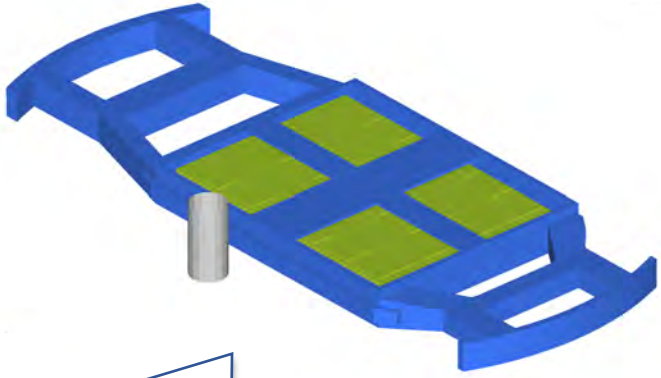
Frontal Crash (64 km/h)



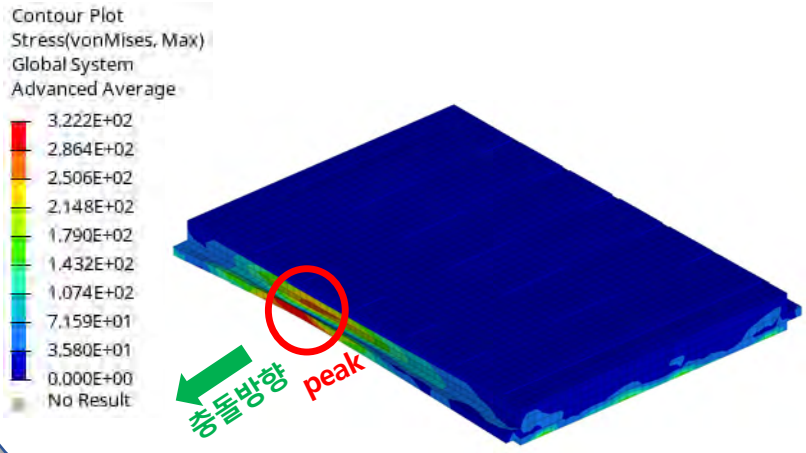
Module에서 충돌영향이 뚜렷하게 나타난다



Side Pole Crash (29 km/h)



PACK에서 충돌영향이 뚜렷하게 나타난다



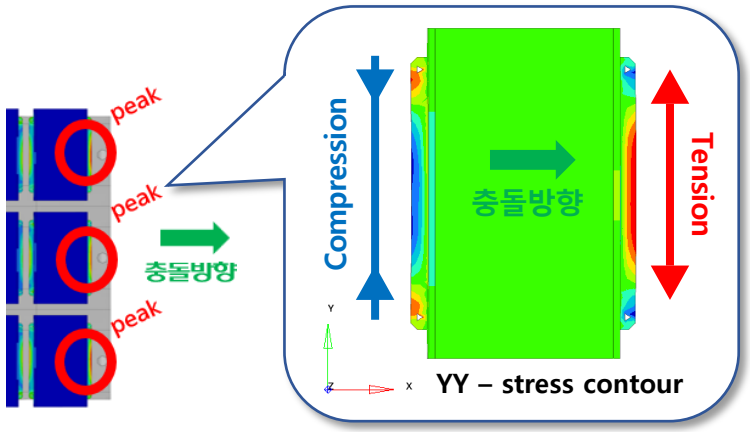
III. 모듈 구조 최적화

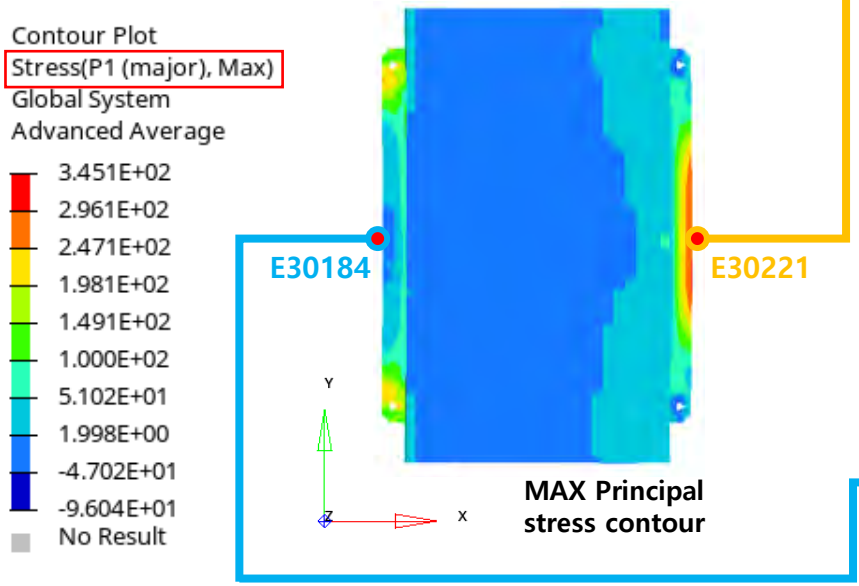
(Frontal Crash)

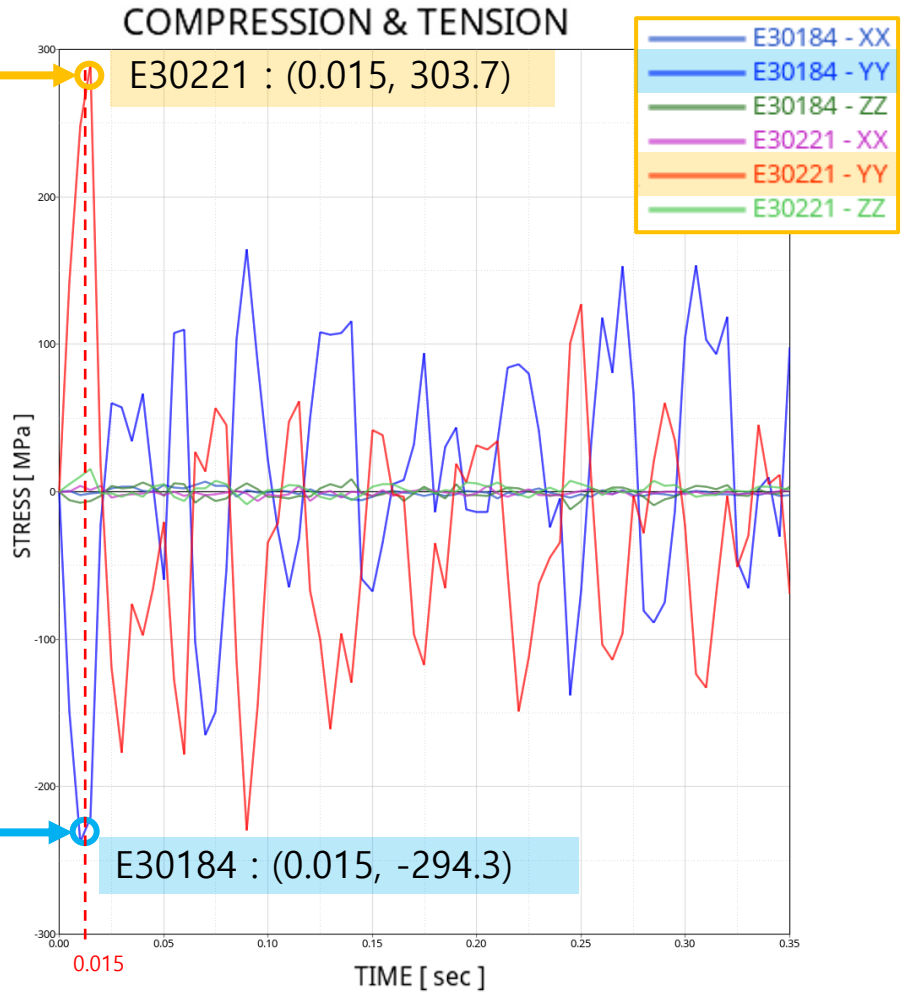
III. 모듈 구조 최적화 _ Stress Contour

Module 단위 정적해석

CHECK POINT :
- 충돌 접촉 발생시, 관성에 의한 특정 Stress Contour 발생 (64 km/h)
- MAX Principal stress 발생에는 YY- stress의 영향력이 높다

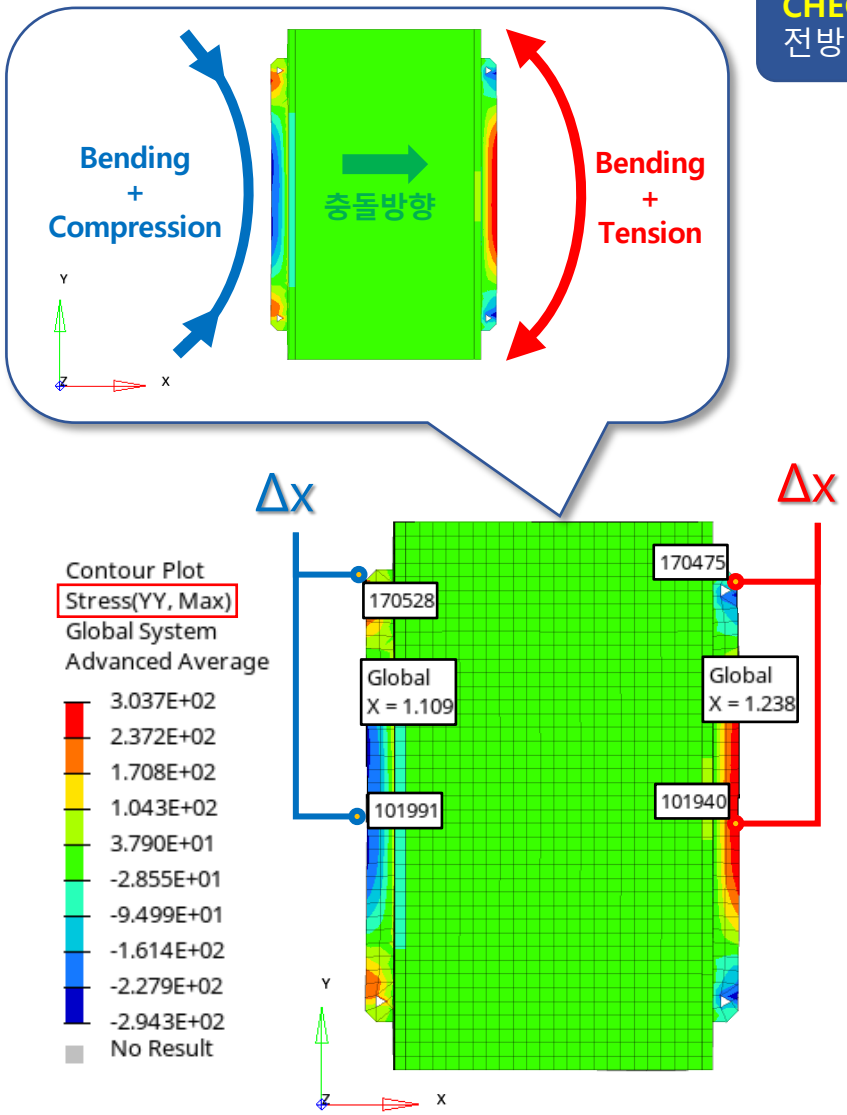


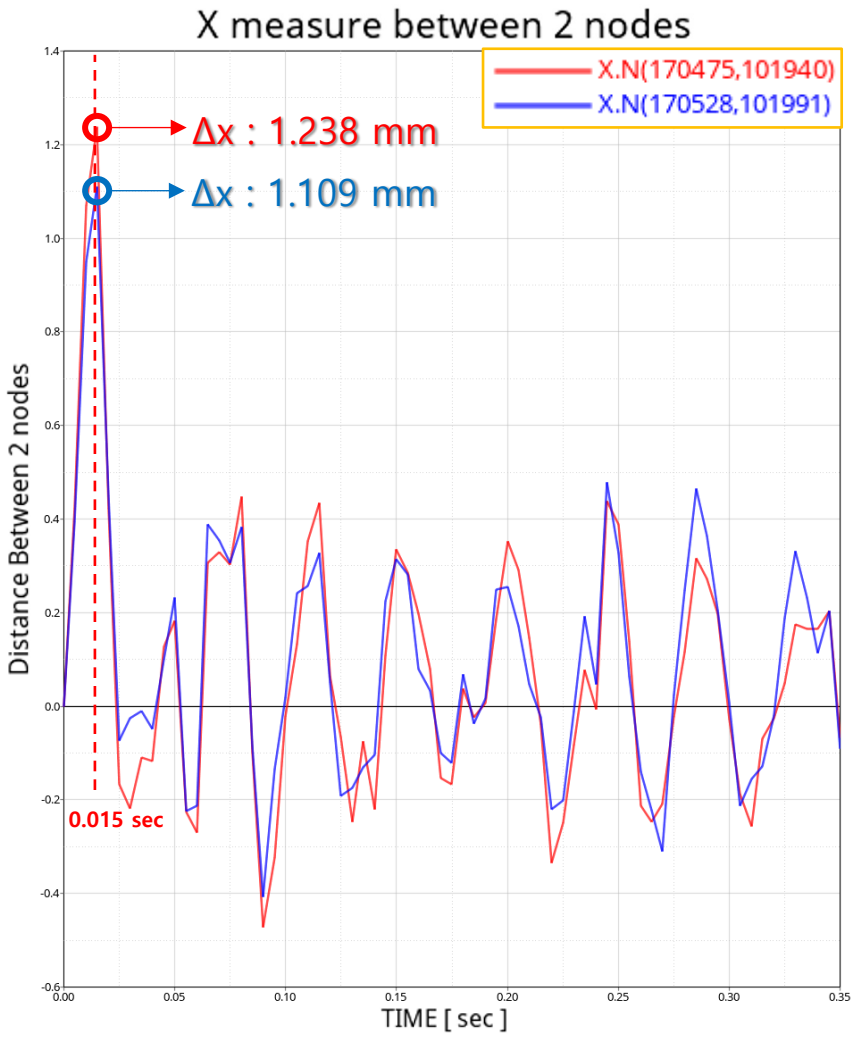




III. 모듈 구조 최적화 _ Deformation

CHECK POINT : 좌측 그림과 같이 발생하는 **Bending** 으로 인하여 전방은 Y 축 인장, 후방은 Y축 압축 응력이 작용하는 것을 분석 가능



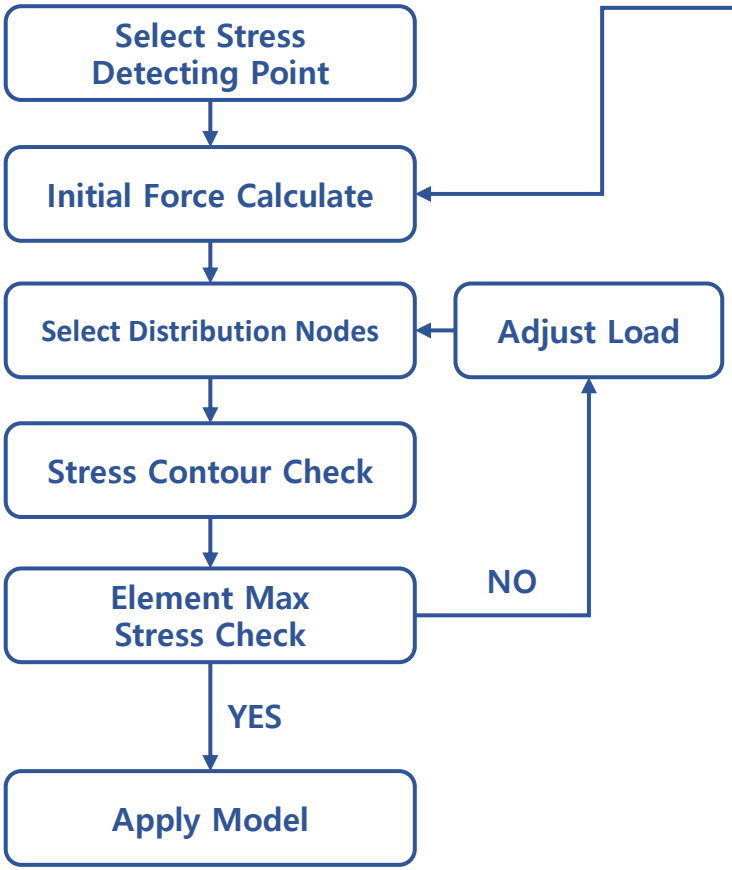


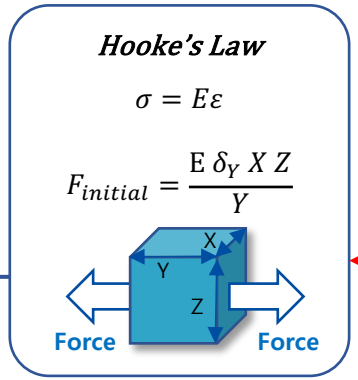
III. 모듈 구조 최적화 _ Equivalent Static Load

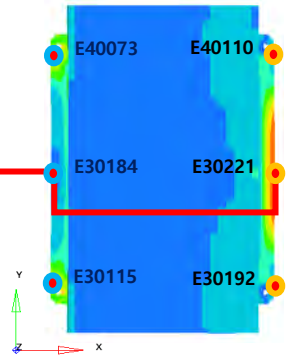
Module 단위 정적해석

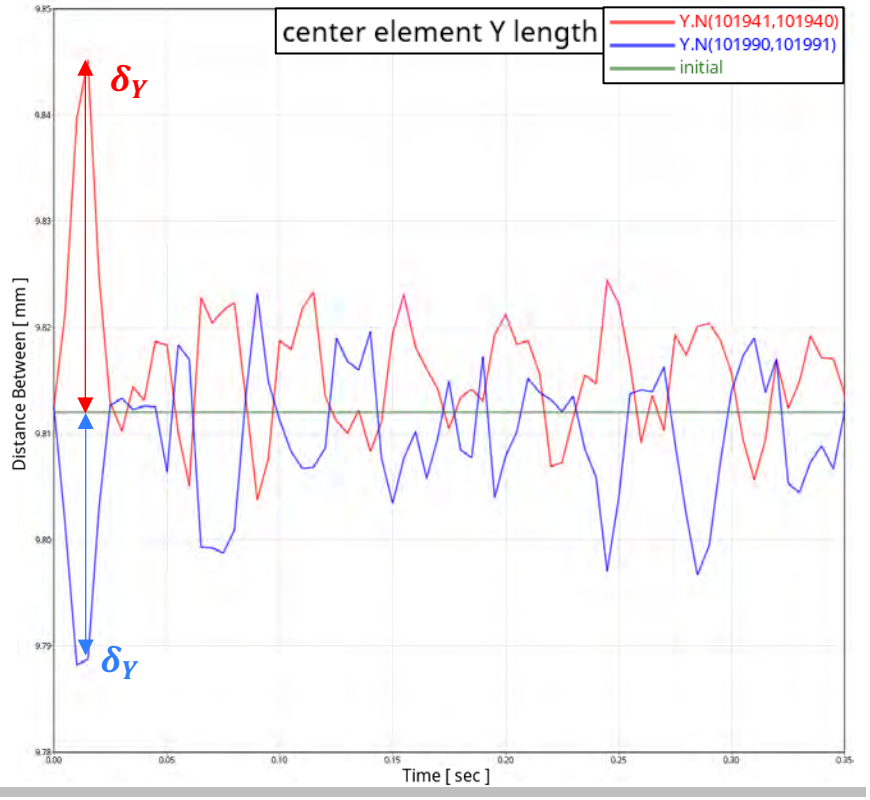
Explicit (dynamic) ⇨ **Implicit** (static)

Limitations : 모델의 해석 단순화를 위해 Y축의 stress 만을 고려하여 구현한다





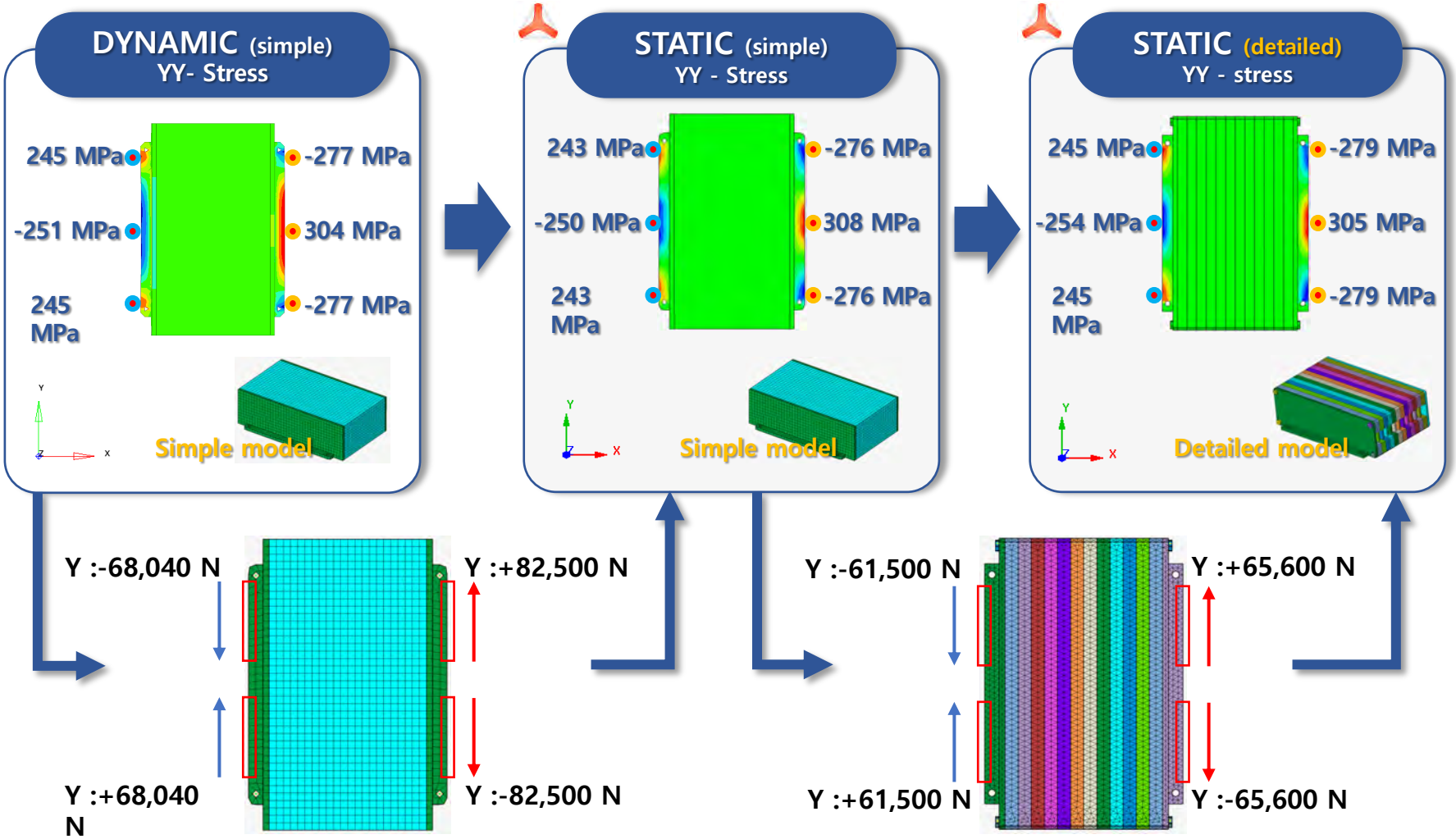




1) reference : converting dynamic impact events to equivalent static loads in vehicle chassis

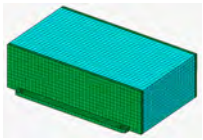
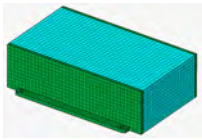
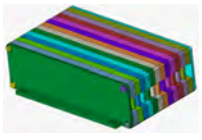
III. 모듈 구조 최적화 _ Equivalent Static Load

Module 단위 정적해석

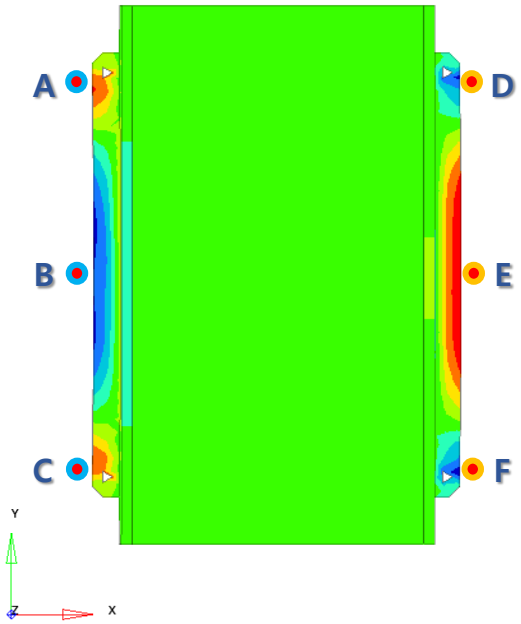


III. 모듈 구조 최적화 _ Equivalent Static Load

Module 단위 정적해석

Unit [MPa]		 Simple model	 Simple model		 Detailed model	
		DYNAMIC (reference)	STATIC (simple)	Error (%)	STATIC (detailed)	Error (%)
A C	Von-Mises Stress	**256**	203	20.7 %	273	6.2 %
	YY	245	243	0.82 %	245	0 %
B	Von-Mises Stress	**222**	210	5.4 %	267	16.9 %
	YY	-251	-250	0.4 %	-254	1.2 %
D F	Von-Mises Stress	**279**	244	12.5 %	272	2.5 %
	YY	-277	-276	0.4 %	-279	0.7 %
E	Von-Mises Stress	**284**	248	12.7 %	294	3.4 %
	YY	304	308	1.3 %	305	0.3 %

Stress Detect Point

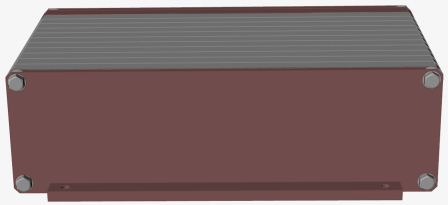


III. 모듈 구조 최적화 _ Topology

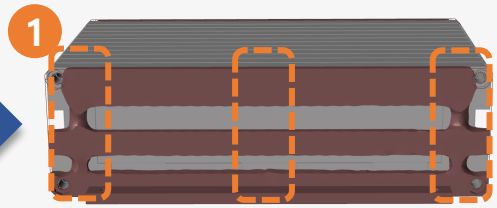
2차 최적화를 위한 디자인 요소

INSPIRE Topology

Optimization



Initial Shape



X 방향 밴딩을 고려한 중앙 부분 비드 추가

Optimization Shape

Current : YY-Stress 만을 고려한 설계

↓

초기 해석(Radioss)에서 x 방향으로 작용하는 Bending을 추가적으로 고려

↓

Inspire 모델을 기반으로 재설계 진행

↓

설계 케이스 스터디를 통한 2차 최적화 진행

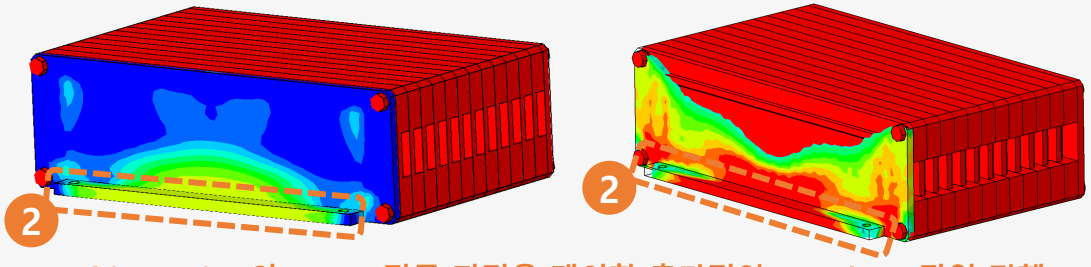
(레코드 기능으로 손쉽게 기존의 해석 조건을 세팅)

↓

최적화 모듈 적용 Frontal Crash 재해석(Radioss)을 진행

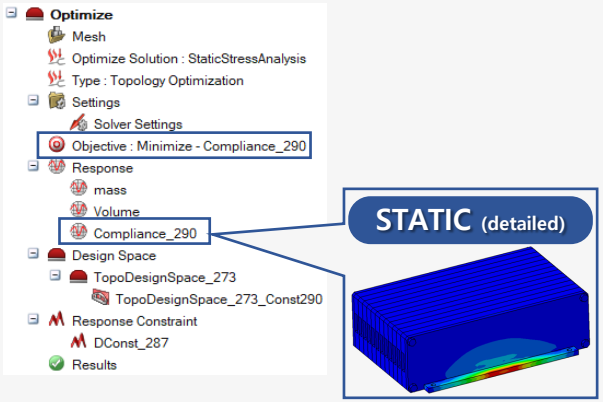
SIMLAB Topology

Optimization



Bolting point 와 Stress 집중 지점을 제외한 추가적인 Topology 작업 진행

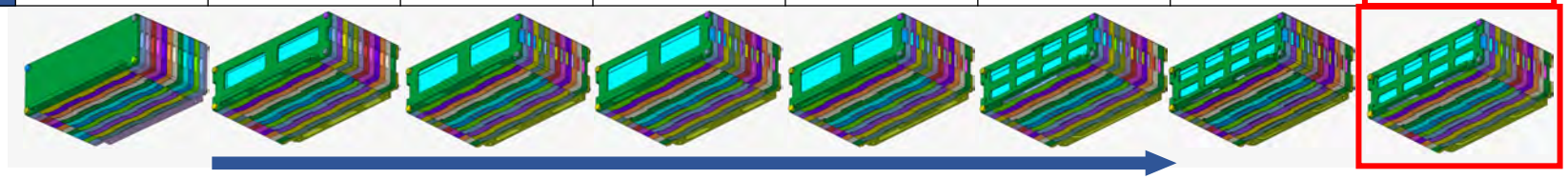
Optimization Shape



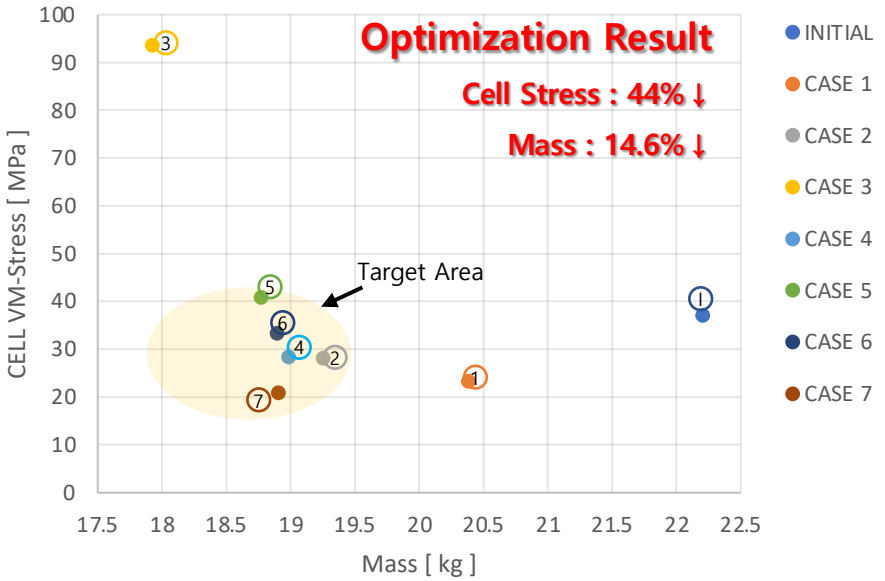
III. 모듈 구조 최적화 _ Optimization

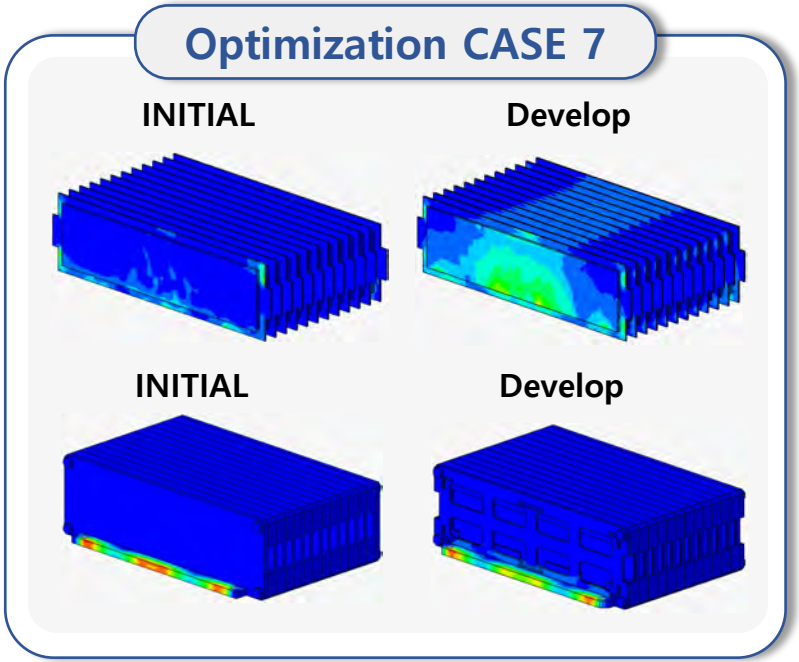
형상 케이스 별 해석

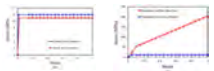
	INITIAL	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7
Plate stress [MPa]	249.3	551.2	435.7	409	560.7	426.5	370.3	387.8
Cell stress [MPa]	37.16	23.3	28.2	93.6	28.5	40.9	33.43	**20.97**
Mass [kg]	22.2	20.38	19.25	17.92	18.98	18.77	18.89	**18.96**



하중 영향을 Cell Case와 Plate로 집중, Cell Stress 가 감소하도록 반복적인 해석 피드백을 적용한 케이스 스터디를 진행





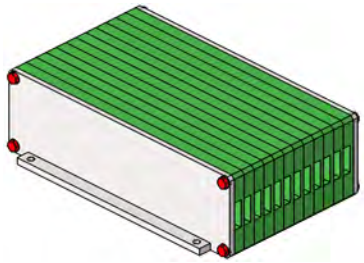


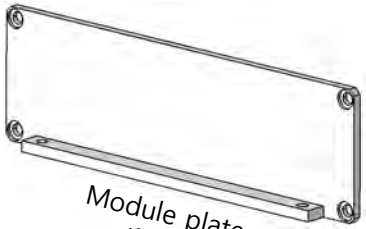
KOOKMIN UNIVERSITY

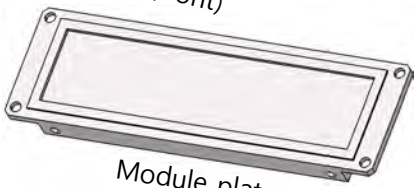
Active material Failure reference :
A representative-sandwich model for simultaneously coupled mechanical-electrical-thermal simulation of a lithium-ion cell under quasi-static indentation tests

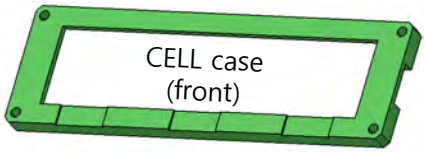
III. 모듈 구조 최적화 _ Result

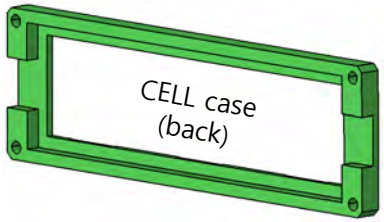
결과 분석











CELL VM- Stress

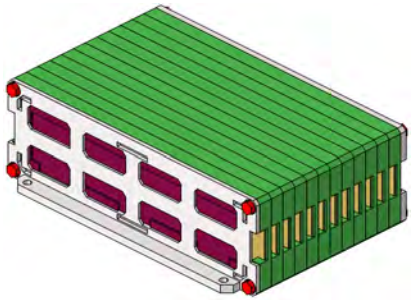
INITIAL	16.18 MPa ↓	Develop
37.159 MPa	43.57% ↓	20.976 MPa

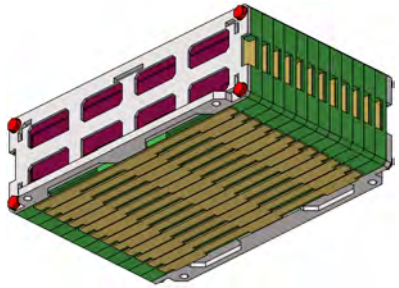
Module Mass (1EA)

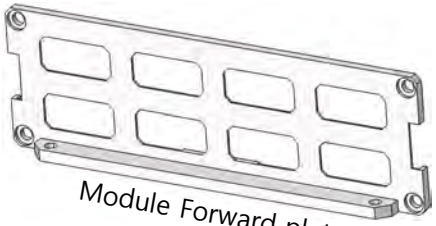
INITIAL	3.23 kg ↓	Develop
Mass: 22.1959 kg	14.57% ↓	Mass: 18.9613 kg

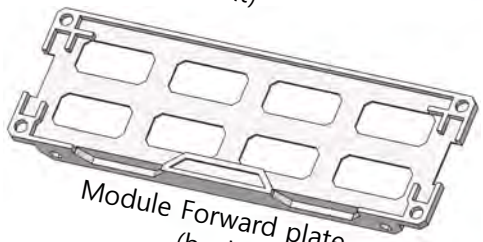
Initial Shape

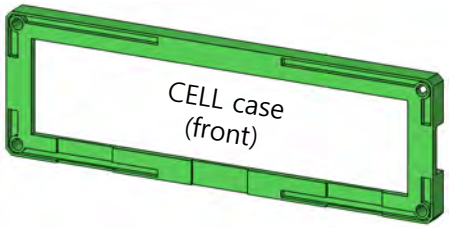
Optimization Shape

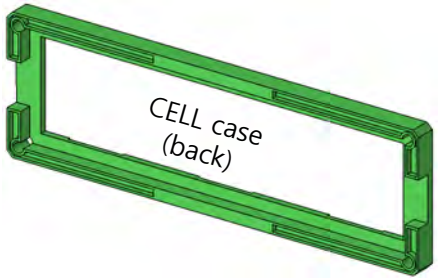


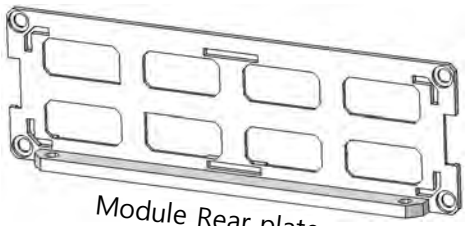


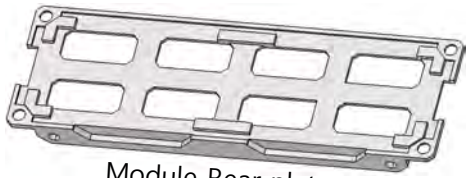












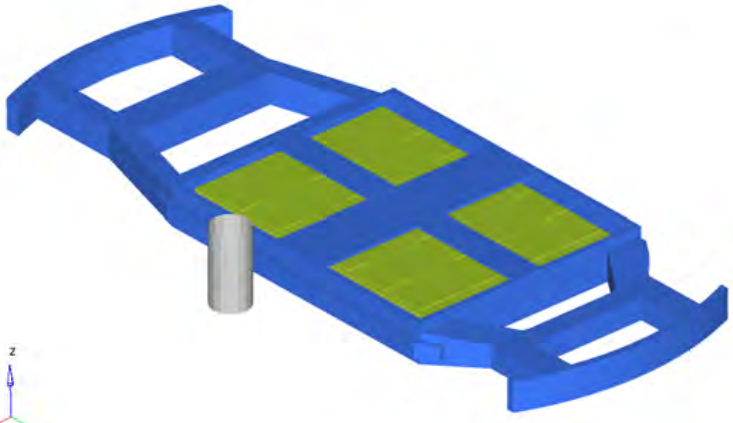
IV. 팩 구조 최적화

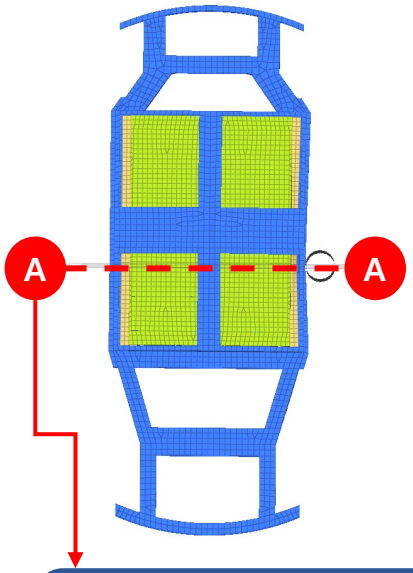
(Side Pole Crash)

IV. 팩 구조 최적화 _ Initial Model Information

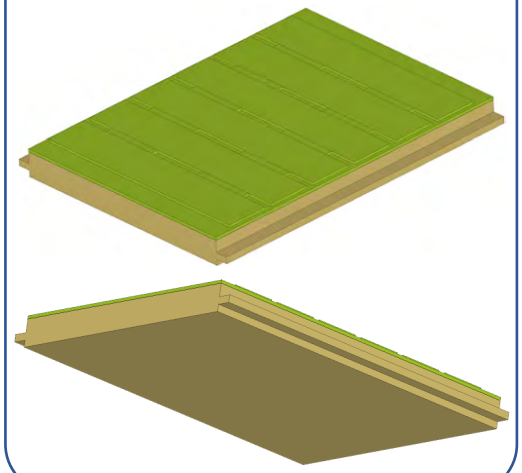
INITIAL (Non Rib Model)

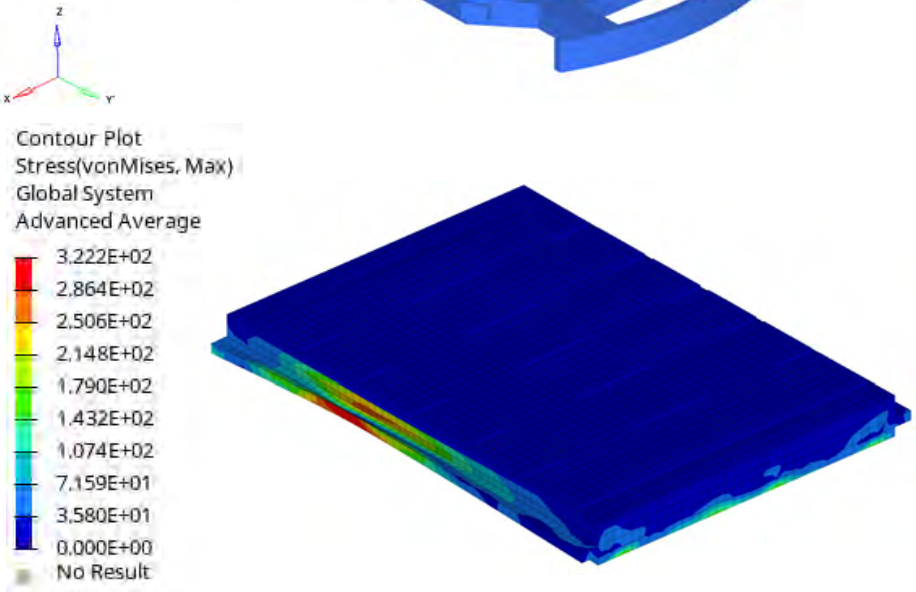
Crash Velocity : 14.5 km/h (시험 규정 속도의 50%)



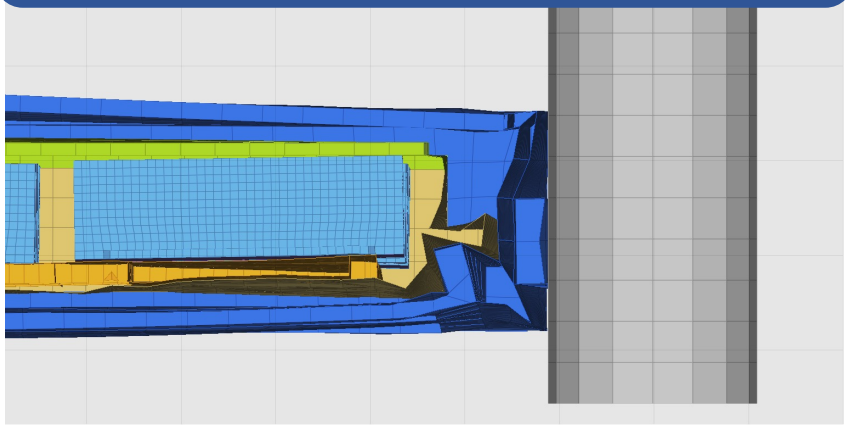


Non Rib Model





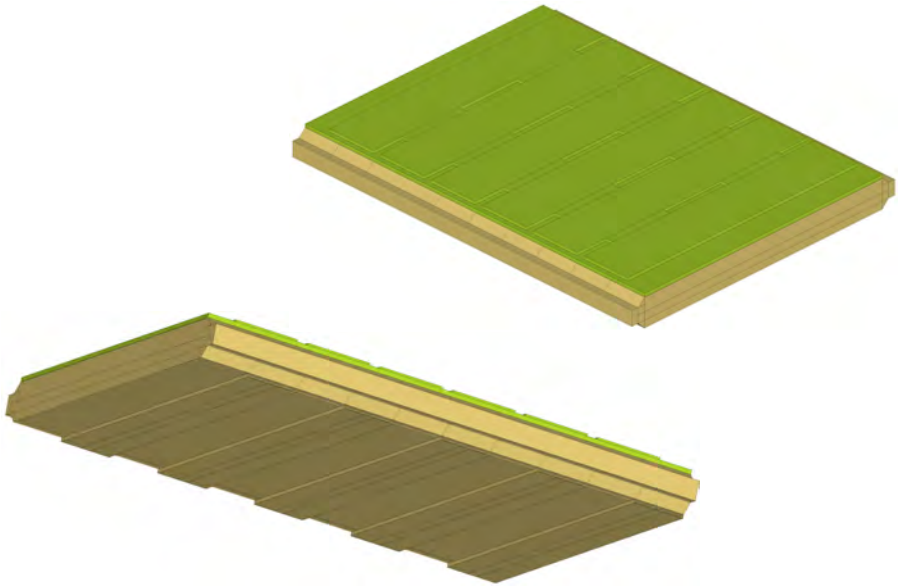
Section Cut View : A

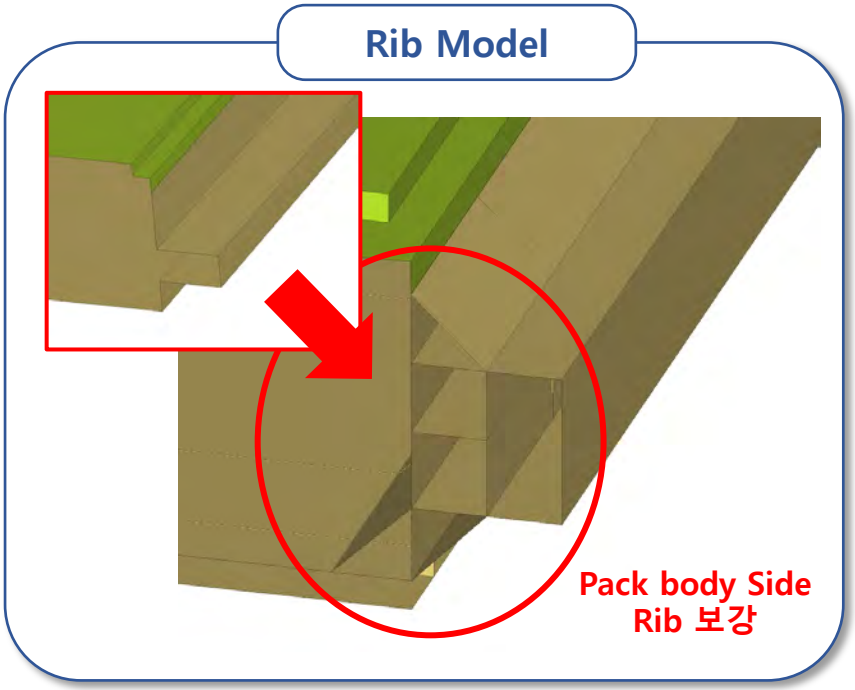


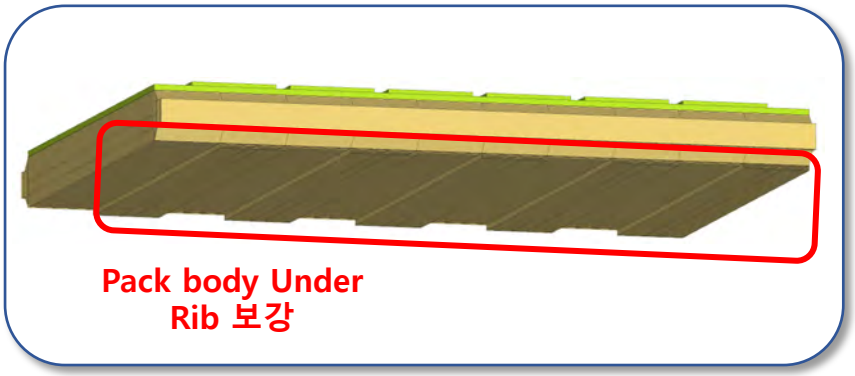
※ Pack body PART 구조적 보강 필요

DEVELOP (Rib Model)

	RIB Model Thickness		
	Pack body	Pack cover	Cooling plate
thickness [mm]	10	10	3
Mass [ton]	0.6348	0.0909	0.108
pack model mass : 1.17 ton			





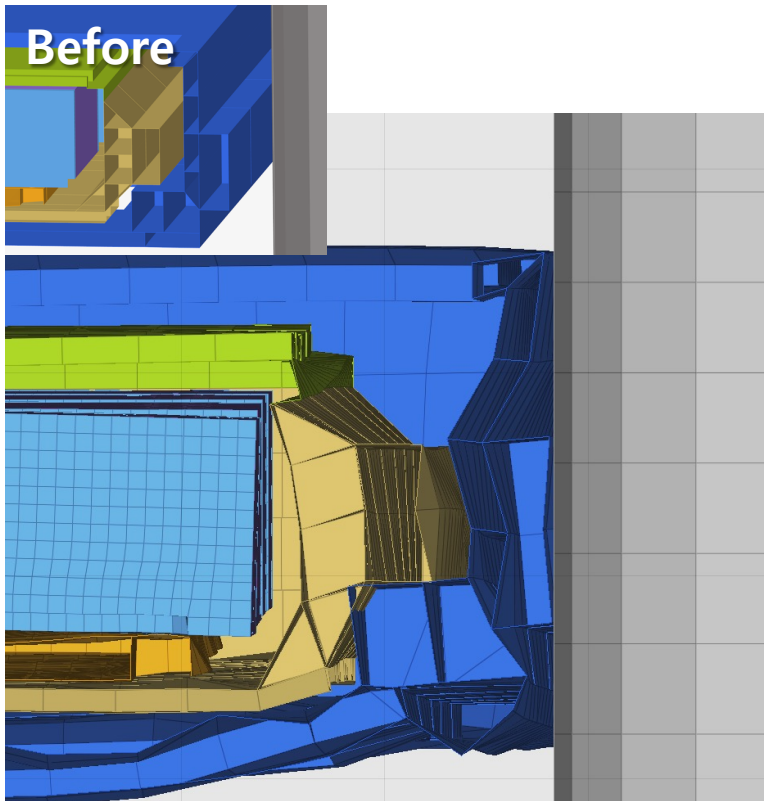


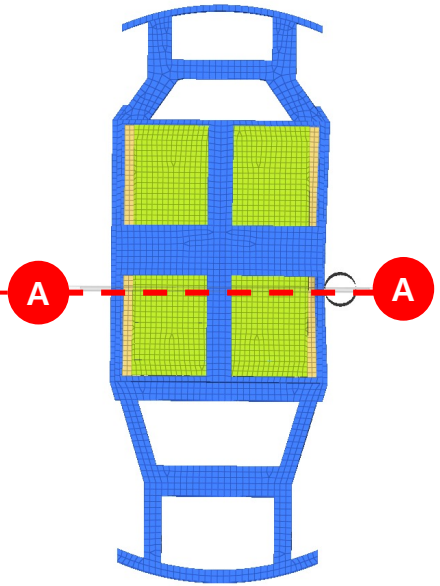
IV. 팩 구조 최적화 _ Pack body Rib 보강

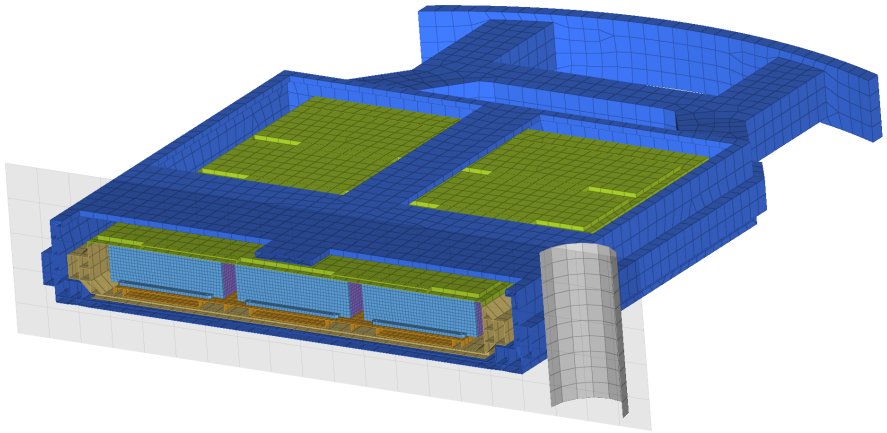
DEVELOP (Rib Model)

Crash Velocity : 29 km/h (시험 규정 속도의 100%)

Section Cut View : A







IV. 팩 구조 최적화 _ Setting Process (Hyperstudy)

Modeling

Pack 구조 최적화

Side Pole Crash

Pack body Rib 보강

Select Design Variable & Response

Thickness Size **OPT**

결과 분석

Hyper Study

Design Variable Input & boundary Setting

Label	Varname	Type	Resource	Solver Input File	Solver Execution Script	Solver Input Arguments
Parameterize...	m_1	{ } Parame..	D:₩...₩st...	20230725_small_...	RADIOSS	${filepath} ...

Test Model Run

Test			
Write	Execute	Extract	All

Response & Constraints & Goal Setting

	..	Label	Varname	A..n	Type	... 1 ...	... 2 ...
1	☑	MASS	MASS		Minimize	N/A	N/A
2	☑	displacement_Y...	displacement_Y...		Constraint	<=	9.0000000
3	☑	dispalcement_X...	dispalcement_X...		Constraint	<=	40.000000
4	☑	dispalcement_X...	dispalcement_X...		Constraint	<=	40.000000
5	☑	dispalcement_X...	dispalcement_X...		Constraint	<=	40.000000
6	☑	E44582	stress_1		Constraint	<=	20.000000
7	☑	E41944	stress_2		Constraint	<=	20.000000
8	☑	dispalcement_X...	dispalcement_X...		Constraint	<=	50.000000
9	☑	E44597	stress_3		Constraint	<=	20.000000
10	☑	E41930	stress_4		Constraint	<=	20.000000

Optimization 1 & 2

Global Response Search Method

	Value
Number of Evaluations	50
On Failed Evaluation	Ignore failed evaluations

IV. 팩 구조 최적화 _ Setting Process (Hyperstudy)

Select Design Variable & Response

Design Variable Input & boundary Setting

Label	Varname	Type	Resource	Solver Input File	Solver Execution Script	Solver Input Arguments
Parameterize...	m_1	{} Parame..	D:₩...₩st...	20230725_small_...	RADIOSS	${filepath}

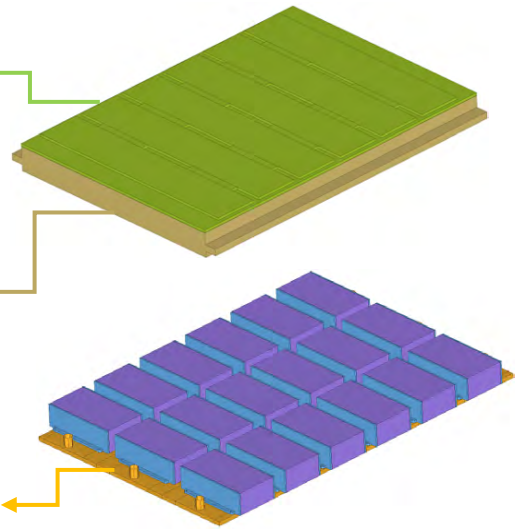
Boundary Setting			
	INITIAL	LOWER	UPPER
Pack body	10	5	10
Pack cover	10	5	10
Cooling plate	3	1	3

```
##HWCOLOR properties 2 49
/PROP/SHELL/2
10T_pack_body
#   Ishell     Ismstr     Ish3n     Idrill     Ipinch                P_Thick_Fail
        24          2         0          0
#                  Hm                   Hf                   Hr                   Dm                   Dn

#         N                  Thick                Ashear               Ithick     Iplas
          1                  10.00
#---1----|----2----|----3----|----4----|----5
##HWCOLOR properties 3 31
/PROP/SHELL/3
10T_pack_cover
#   Ishell     Ismstr     Ish3n     Idrill     Ipinch                P_Thick_Fail
        24          2         0          0
#                  Hm                   Hf                   Hr                   Dm                   Dn

#         N                  Thick                Ashear               Ithick     Iplas
          1                  10.00
#---1----|----2----|----3----|----4----|----5
##HWCOLOR properties 4 6
/PROP/SHELL/4
3T_cooling_plate
#   Ishell     Ismstr     Ish3n     Idrill     Ipinch                P_Thick_Fail
        24          2         0          0
#                  Hm                   Hf                   Hr                   Dm                   Dn

#         N                  Thick                Ashear               Ithick     Iplas
          1                  3.00
#---1----|----2----|----3----|----4----|----5
```

Pack Body Shell thickness

Pack Cover Shell thickness

Cooling plate Shell thickness



	Active	Label	Varname	Lower Bound	Nominal	Upper Bound
1	☑	body_thick	body_thick	5.0000000	10.000000	10.000000
2	☑	cover_thick	cover_thick	5.0000000	10.000000	10.000000
3	☑	coolingplate_thick	coolingplate_thick	1.0000000	3.0000000	3.0000000

Discrete
Discrete
Discrete

Body & Cover

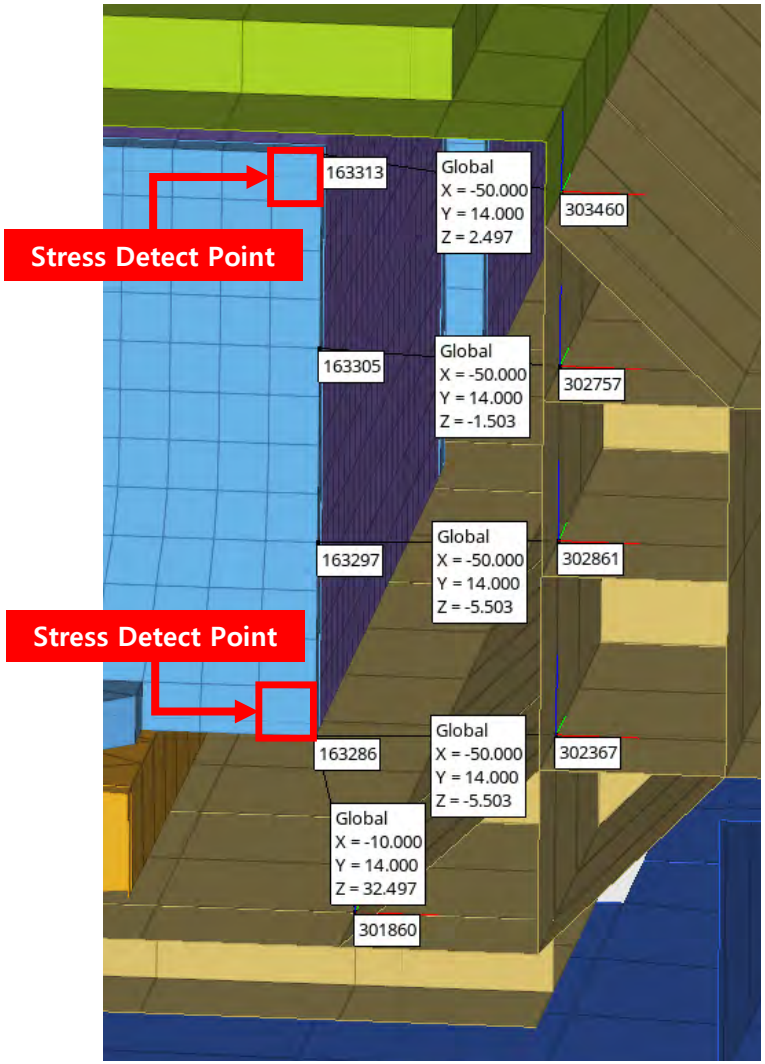
	Value
1	5.0000000
2	7.5000000
3	10.000000

Cooling plate

	Value
1	1.0000000
2	2.0000000
3	3.0000000

IV. 팩 구조 최적화 _ Setting Process (Hyperstudy)

Select Design Variable & Response



Response 1

Side Pole Crash 발생시 Module 과 Pack body 사이의 거리를 Response로 정의하여 **안전 거리 10mm**를 Constraints 정의

Response 2

Module 과 pack body 의 접촉이 발생시 최적화 부적합 판단을 위해 **Element Stress** 를 Constraints 정의

Goal

Minimum Mass

IV. 팩 구조 최적화 _ Setting Process (Hyperstudy)

Select Design Variable & Response

Test Model Run

Test: Write | Execute | Extract | All

Response & Constraints & Goal Setting

Data Sources

	...	Label	Varname	File	Tool	...	Value
1	☑	N163286_Y	N163286_Y	...		...	(0.0000000 .....
2	☑	N301860_Y	N301860_Y	...		...	(0.0000000 .....
3	☑	N163286_X	N163286_X	...		...	(0.0000000 .....
4	☑	N302367_X	N302367_X	...		...	(0.0000000 .....
5	☑	N163297_X	N163297_X	...		...	(0.0000000 .....
6	☑	N302861_X	N302861_X	...		...	(0.0000000 .....
7	☑	N163305_X	N163305_X	...		...	(0.0000000 .....
8	☑	N302757_X	N302757_X	...		...	(0.0000000 .....
9	☑	E44582	E44582	...		...	(0.0000000 .....
10	☑	E41944	E41944	...		...	(0.0000000 .....
11	☑	mass_2	mass_2	...		...	(0.6347648)
12	☑	mass_3	mass_3	...		...	(0.0909285)
13	☑	mass_4	mass_4	...		...	(0.1077472)
14	☑	mass_5	mass_5	...		...	(0.1274525)
15	☑	mass_6	mass_6	...		...	(0.2090189)
16	☑	N163313_X	N163313_X	...		...	(0.0000000 .....
17	☑	N303460_X	N303460_X	...		...	(0.0000000 .....
18	☑	E44597	E44597	...		...	(0.0000000 .....
19	☑	E41930	E41930	...		...	(0.0000000 .....

Define Output Responses

	...	Label	Varname	Expression	Value	Goals
1	☑	displacement_Y...	min_displace_Y_G1	max(ABS(N163286_Y)-abs(N301860_... ...	2.6930351	<= 9.0000000 ...
2	☑	displacement_X...	displacement_X_G2	max(ABS(N163286_X)-abs(N302367_... ...	21.985413	<= 40.000000 ...
3	☑	displacement_X...	displacement_X_G3	max(ABS(N163297_X)-abs(N302861_... ...	23.856651	<= 40.000000 ...
4	☑	displacement_X...	displacement_X_G4	max(ABS(N163305_X)-abs(N302757_... ...	30.202316	<= 40.000000 ...
5	☑	module_stess_1	module_stess_1	max(E44582) ...	1.2822983	<= 20.000000 ...
6	☑	module_stess_2	module_stess_2	max(E41944) ...	3.0847497	<= 20.000000 ...
7	☑	PACK_mass	PACK_mass	max(mass_2+mass_3+mass_4+mass_... ...	1.1699119	Minimize ...
8	☑	displacement_X...	displacement_X_G5	max(ABS(N163313_X)-abs(N303460_... ...	42.582245	<= 50.000000 ...
9	☑	module_stess_3	module_stess_3	max(E44597) ...	0.5791573	<= 20.000000 ...
10	☑	module_stess_4	module_stess_4	max(E41930) ...	0.9093386	<= 20.000000 ...

Objectives/Constraints - Goals

	...	Label	Varname	A...n	Type	... 1 ...	... 2 ...	
1	☑	MASS	MASS		Minimize	N/A	N/A	Objective
2	☑	displacement_Y...	displacement_Y...		Constraint	<=	9.0000000	Constraints
3	☑	dispalcement_X...	dispalcement_X...		Constraint	<=	40.000000	Constraints
4	☑	dispalcement_X...	dispalcement_X...		Constraint	<=	40.000000	Constraints
5	☑	dispalcement_X...	dispalcement_X...		Constraint	<=	40.000000	Constraints
6	☑	E44582	stress_1		Constraint	<=	20.000000	Constraints
7	☑	E41944	stress_2		Constraint	<=	20.000000	Constraints
8	☑	dispalcement_X...	dispalcement_X...		Constraint	<=	50.000000	Constraints
9	☑	E44597	stress_3		Constraint	<=	20.000000	Constraints
10	☑	E41930	stress_4		Constraint	<=	20.000000	Constraints

IV. 팩 구조 최적화 _ Optimization 1

Thickness Size **OPT**

Optimization

Global Response Search Method

	Value
Number of Evaluations	*27*
On Failed Evaluation	Ignore failed evaluations

1 차 최적화 진행

Discrete

Variables	LOWER	UPPER
Pack body	5	10
Pack cover	5	10
Cooling plate	1	3

Evaluation Data

	bod...ick	cov...ick	coo...ick	MASS	E44582	E41944	E44597	E41930
1	10.000000	10.000000	3.0000000	1.1699119	Feasible	Feasible	Feasible	Feasible
2	5.0000000	5.0000000	1.0000000	0.7352338	Feasible	Feasible	Violated	Violated
3	7.5000000	10.000000	1.0000000	0.9393893	Feasible	Feasible	Violated	Violated
4	10.000000	5.0000000	2.0000000	1.0885319	Feasible	Feasible	Feasible	Feasible
5	5.0000000	7.5000000	3.0000000	0.8297974	Feasible	Feasible	Violated	Violated
6	10.000000	7.5000000	1.0000000	1.0753483	Feasible	Feasible	Violated	Violated
7	7.5000000	5.0000000	3.0000000	0.9657564	Feasible	Feasible	Violated	Violated
8	7.5000000	7.5000000	2.0000000	0.9525729	Feasible	Feasible	Violated	Violated
9	5.0000000	10.000000	2.0000000	0.8166138	Feasible	Feasible	Violated	Violated
10	7.5000000	5.0000000	2.0000000	0.9298407	Feasible	Feasible	Violated	Violated
11	10.000000	5.0000000	1.0000000	1.0526162	Feasible	Feasible	Violated	Violated
12	10.000000	7.5000000	2.0000000	1.1112641	Feasible	Feasible	Feasible	Feasible
13	10.000000	7.5000000	3.0000000	1.1471798	Feasible	Feasible	Feasible	Feasible
14	10.000000	10.000000	2.0000000	1.1339962	Feasible	Feasible	Feasible	Feasible
15	7.5000000	7.5000000	1.0000000	0.9166571	Feasible	Feasible	Violated	Violated
16	10.000000	5.0000000	3.0000000	1.1244477	Feasible	Feasible	Feasible	Feasible
17	7.5000000	5.0000000	1.0000000	0.8939250	Feasible	Feasible	Violated	Violated
18	5.0000000	10.000000	3.0000000	0.8525295	Feasible	Feasible	Violated	Violated
19	7.5000000	7.5000000	3.0000000	0.9884886	Feasible	Feasible	Violated	Feasible
20	5.0000000	5.0000000	2.0000000	0.7711495	Feasible	Feasible	Violated	Violated
21	5.0000000	10.000000	1.0000000	0.7806980	Feasible	Feasible	Violated	Violated
22	5.0000000	7.5000000	2.0000000	0.7938816	Feasible	Feasible	Violated	Violated
23	5.0000000	7.5000000	1.0000000	0.7579659	Feasible	Feasible	Violated	Violated
24	10.000000	10.000000	1.0000000	1.0980805	Feasible	Feasible	Violated	Violated
25	5.0000000	5.0000000	3.0000000	0.8070652	Feasible	Feasible	Violated	Violated
26	7.5000000	10.000000	2.0000000	0.9753050	Feasible	Feasible	Violated	Violated
27	7.5000000	10.000000	3.0000000	1.0112207	Feasible	Feasible	Violated	Violated

1차 최적화

Optimization 1 Result

	Initial	Thickness
Pack body	10	10
Pack cover	10	5
Cooling plate	3	2

Pack mass

Initial	Optimization
1.17 ton	**1.0885 ton**
6.97 % ↓	

IV. 팩 구조 최적화 _ Optimization 2

Thickness Size **OPT**

Optimization

Global Response Search Method

	Value
Number of Evaluations	50
On Failed Evaluation	Ignore failed evaluations

2 차 최적화 진행
설계 변수 boundary 조정

Continuous

Variables	LOWER	UPPER
Pack body	8	10
Pack cover	2.5	6
Cooling plate	1	2.5

Optimization 2 Result

	Initial	Thickness
Pack body	10	9.06
Pack cover	10	2.57
Cooling plate	3	2.43

Pack mass

Initial	Optimization
1.17 ton	1.022 ton
12.65 % ↓	

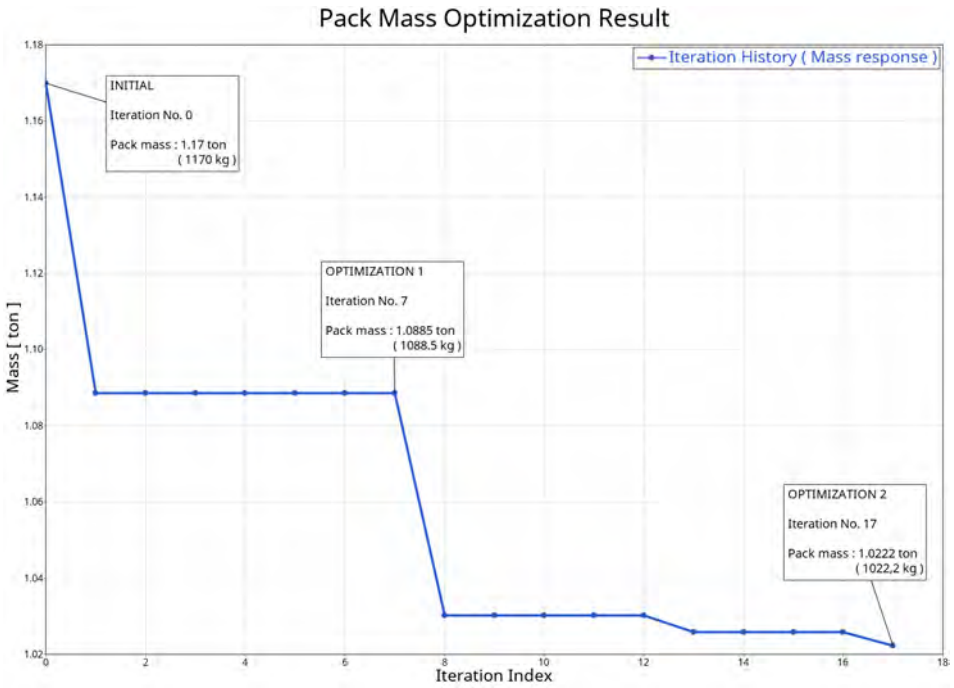
Evaluation Data

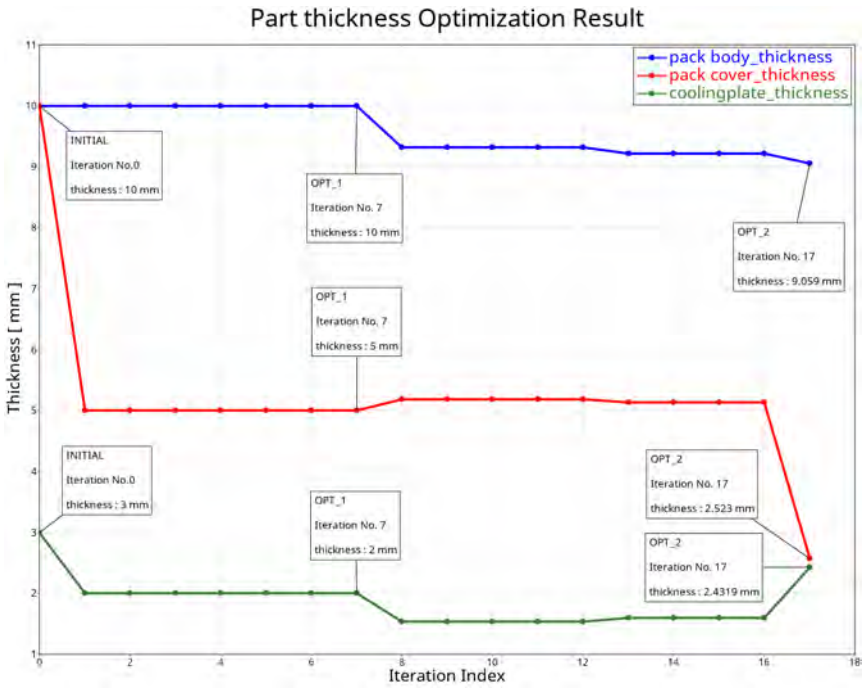
	bod...ick	cov...ick	coo...ick	MASS	E44582	E41944	E44597	E41930
4	10.000000	5.0000000	2.0000000	1.0885319	Feasible	Feasible	Feasible	Feasible
53	9.1721075	5.3135909	1.6987288	1.0278905	Feasible	Feasible	Feasible	Violated
54	9.7388800	3.9828800	1.3494400	1.0394081	Feasible	Feasible	Feasible	Feasible
55	9.9948800	4.0388800	2.4774401	1.0964076	Feasible	Feasible	Feasible	Feasible
56	9.2305256	5.1048260	1.5873910	1.0258389	Feasible	Feasible	Violated	Violated
57	9.2730434	5.1352861	1.4979222	1.0255092	Feasible	Feasible	Violated	Violated
58	9.2201806	5.1311372	1.5989372	1.0258361	Feasible	Feasible	Feasible	Feasible
59	9.7651200	5.7211200	2.4025600	1.0948455	Feasible	Feasible	Feasible	Feasible
60	8.4883200	3.6043200	1.4641600	0.9605580	Feasible	Feasible	Violated	Violated
61	9.3011460	5.0526385	1.5420209	1.0280318	Feasible	Feasible	Violated	Violated
62	9.1320491	5.1511813	1.6010950	1.0203050	Feasible	Feasible	Violated	Violated
63	9.3060235	5.0392816	1.5364128	1.0285756	Feasible	Feasible	Feasible	Feasible
64	9.1475200	3.2235200	2.4937600	1.0359904	Feasible	Feasible	Violated	Feasible
65	9.4355200	5.9115200	1.1377600	1.0303721	Feasible	Feasible	Violated	Violated
66	9.2297720	5.1866637	1.6291914	1.0280939	Feasible	Feasible	Violated	Violated
67	9.1702270	5.1557049	1.6040090	1.0229350	Feasible	Feasible	Feasible	Violated
68	9.2330482	5.1914478	1.6264155	1.0280939	Feasible	Feasible	Violated	Violated
69	8.0857600	2.9737600	1.0028800	0.9129176	Feasible	Feasible	Violated	Violated
70	9.4617600	4.1497600	2.1908800	1.0533497	Feasible	Feasible	Feasible	Feasible
71	9.2012259	5.0647417	1.5727080	1.0228526	Feasible	Feasible	Feasible	Violated
72	9.1312722	2.5001086	2.2999790	1.0213500	Feasible	Feasible	Feasible	Violated
73	9.2028840	5.0679584	1.5714082	1.0229435	Feasible	Feasible	Feasible	Violated
74	8.6329600	3.8809600	2.4764800	1.0086247	Feasible	Feasible	Feasible	Violated
75	8.7513600	5.9193600	2.4356800	1.0333547	Feasible	Feasible	Feasible	Feasible
76	9.2012259	5.0937417	1.5762068	1.0234845	Feasible	Feasible	Violated	Feasible
77	9.0589122	2.5721925	2.4318813	1.0222122	Feasible	Feasible	Feasible	Feasible

1차 최적화

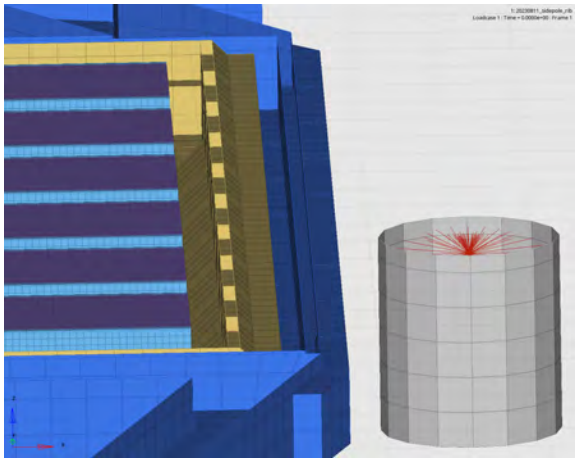
2차 최적화
해석 케이스 : 77 회
Iteration : 17 회

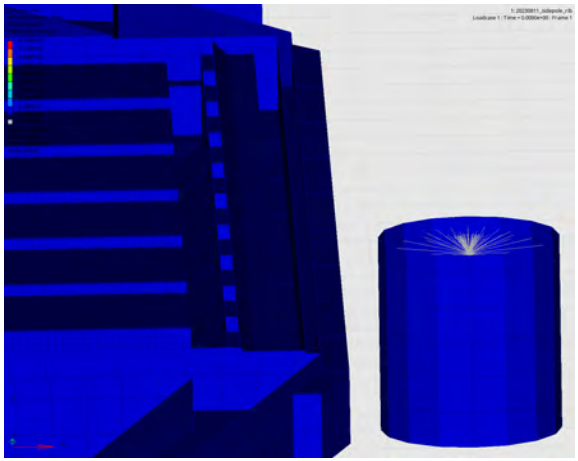
IV. 팩 구조 최적화 _ Result





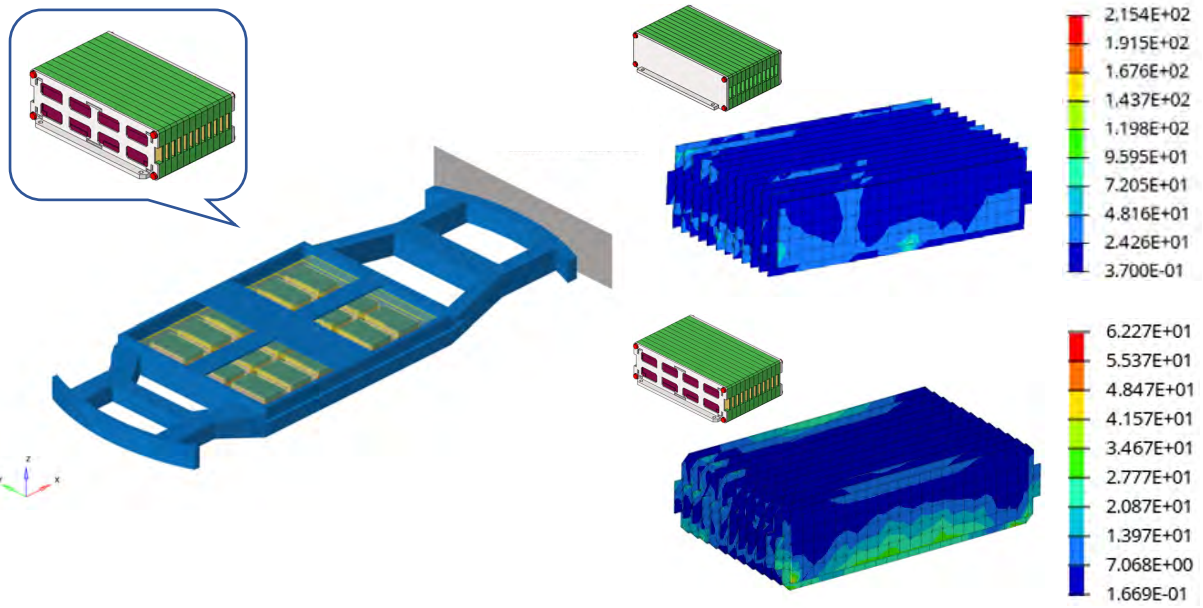
Pack mass	
Initial	Optimization
1.17 ton	1.022 ton
12.65 % ↓	



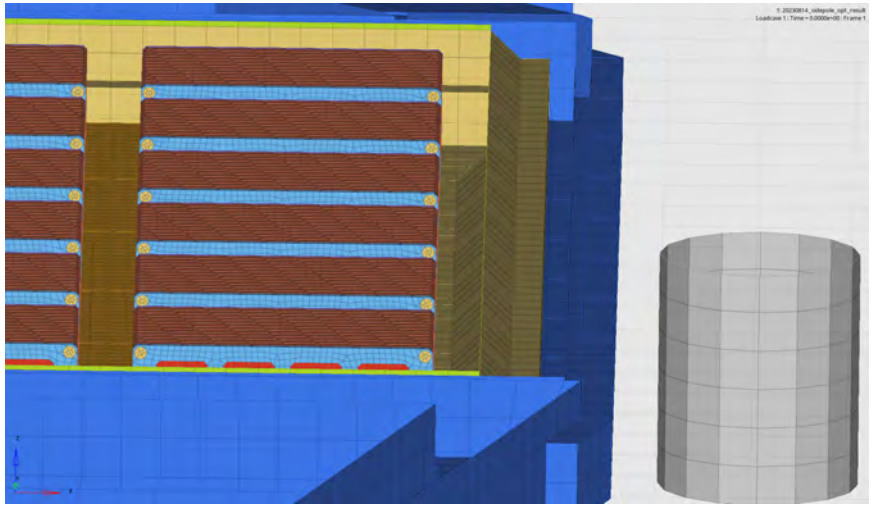


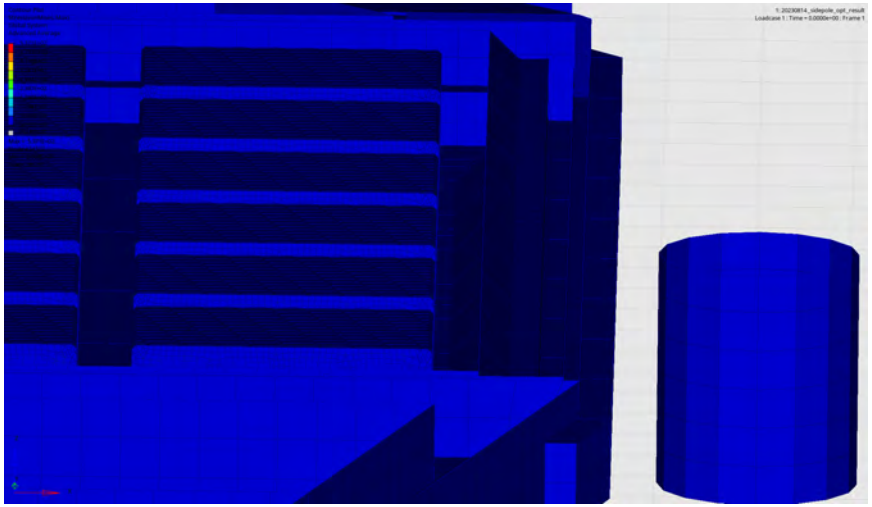
V. 최적화 결론

V. 최적화 결론



Module OPT + Pack OPT		
	INITIAL	FINAL OPT
PACK Total Mass [ton]	1.2333	1.039
	15.75 % ↓	
Cell Max Stress [MPa]	215	62.3
	71 % ↓	





감사합니다