Research Background

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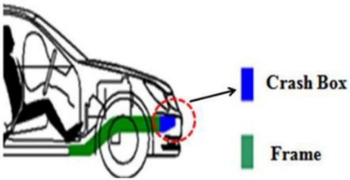
June 10, 2021

Contents

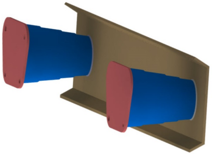
Education

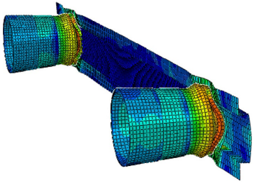
- MSc in Mechanical Engineering - Applied Design
- BSc in Mechanical Engineering - Solid Design

Crash-boxes



The front structural components in a vehicle (Hussain et al. 2017)

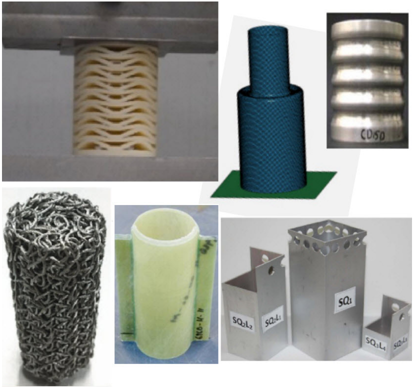




The model of front structural with a pair of crash boxes

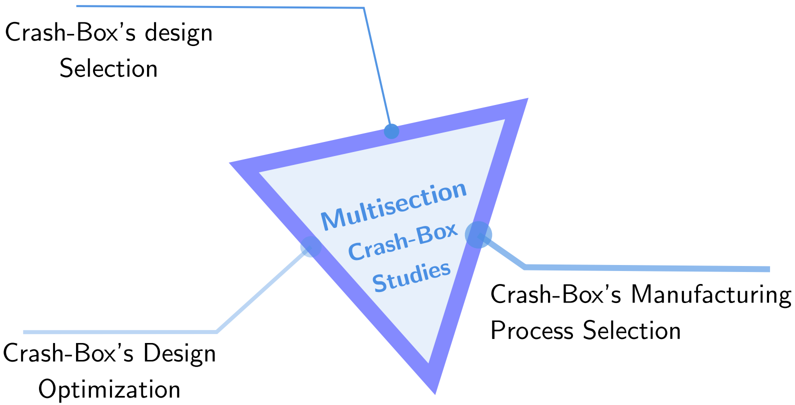
Crash-boxes

The Crash-boxes' design indicators based on the force-displacement curve: Absorbed energy ($E_{absorbed}$), Initial peak load (F_i), Maximum peak load (F_i), CFE, SEA and Mass of the structure (M).



Different design of crash-boxes (Abdullah et al. 2020, Yusof et al. 2017)

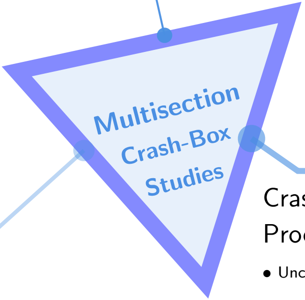
Summary of the core research on the Crash-boxes



Summary of the core research on the Crash-boxes

Crash-Box's design Selection

- NL-MULIMOORA (MADM)



Crash-Box's Manufacturing Process Selection

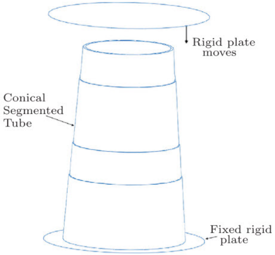
- Uncertainty
- Monte Carlo joining with an MADM
- Environmental criteria

Crash-Box's Design Optimization

- DOE (D-optimal)
- Surrogate-based optimzation
- Optimization scenario selection

① Master's Thesis: Crash-Box Selection employing MADM & Simulation

- Proposing a hybrid method MADM, MULTIMOORA + NL $\Longrightarrow$ NL-MULTIMOORA
- Simulating the crashing process
- Generating, Sorting and Selecting the best design in two steps:
  - The best design selection through 39 designs based on Length & Thickness
  - The best design selection through 16 designs based on Taper's Angle
- The best prototype design selected



Simulation of the conical segmented tube under axial loading (Souzangarzadeh et al. 2017)

Proposed prototype selection process:

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$\triangledown$ **Step one** $\Longrightarrow$ Modeling the crushing process of Aluminum segmented tubes with 3D Solid elements.

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Proposed prototype selection process:

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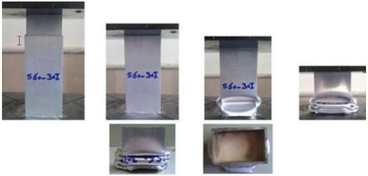
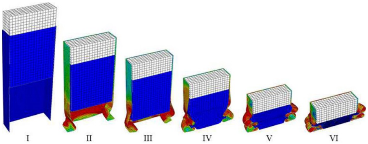
$\triangledown$ **Step two** $\Longrightarrow$ Generating 39 points $\Longrightarrow$ NL-MULTIMOORA selected the best design base on thicknesses and lengths $\Longrightarrow$ Specifying the best thicknesses and lengths for the next step

$\triangledown$ **Step three** $\Longrightarrow$ Considering different taper angles $\Longrightarrow$ Generating other 14 points + the two best designs from second step $\Longrightarrow$ Selecting the best design base on taper angle through NL-MULTIMOORA

② Foam-Filled Crash-Box with Initiator: Experimental & Numerical

- Evaluating the effect of Initiator & foam on the behavior of the Crash-box
  - Numerically
  - Experimentally
- Detecting the effect of the Initiator
- Detecting the most efficient Initiator's length

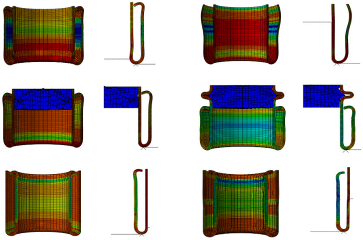




Different stages of crushing for partially foam-filled with an initiator (Razazan et al. 2018)

Inversion of Crash-Box Process: Experimental & Numerical

- Evaluating the effect of triggering, foam & inversion process on the behavior of the Crash-box
    - Numerically
    - Experimentally
- Detecting the effect of the inversion mechanism,



Crushed shapes of empty and foam-filled circular specimens derived from experimental and numerical simulation (Rezvani and Souzangarzadeh 2020)

Optimization the design of Crash-box employing DOE, MADM, & Simulation

▷ Five design variables & Ten Objective Functions

Deforming process of the selected tube under axial, 15°, and 30° loads (Souzangarzadeh et sl. 2020)

Proposed optimization and selection process:

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▽ DoE (RSM D-optimal) $\Longrightarrow$ 34 points $\Longrightarrow$ Ten regression models
$\Longrightarrow$ Comparing the regression model with FEM
$\Longrightarrow$ Adding more points to improve the regression models.

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▽ Using combinative weighting (CW) method to combine three differnt methods

▽ Selecting the best candidate/scenarios through CW-MULTIMOORA

Assumptions and Conditions:

- Cylindrical-Steel-segmented tube (Souzangarzadeh et al. 2020) and Conical-aluminum-segmented tube (Souzangarzadeh et al. 2017)
- Uncertain data in the case study location, Iran
- Extracted data of time and cost were interval not exact

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Methods:

- ELECTRE-IDAT as MADM method deals with interval and exact data
- Using Monte Carlo to simulate the selection process for 5000 times
- The most promising manufacturing processes and material-design selected

References

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Comparative study of trigger configuration for enhancement of Crashworthiness of automobile Crash box subjected to axial impact loading.
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Selection of optimum design for conical segmented aluminum tubes as energy absorbers: Application of MULTIMOORA method
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Evaluation of the Performance of Initiator on Energy Absorption of Foam-Filled Rectangular Tubes: Experimental and Numerical Assessment
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Design and materials development of automotive crash box : a review
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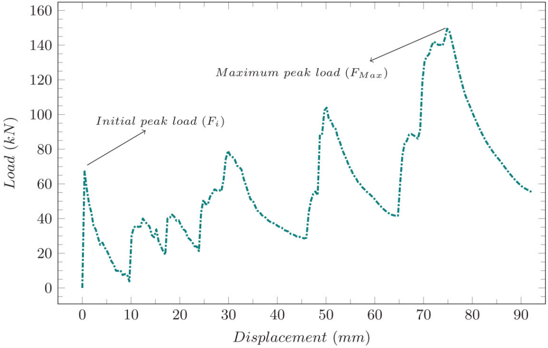
The End



Typical load-displacement curve of the conical segmented tube

Appendix 2

1 Absorbed energy

The total absorbed energy: $\Longrightarrow E_{absorbed} = \int F d\delta$
Where F and δ are the crush force and crush distance, respectively.

2 Mean crushing load

The ratio of total absorbed energy to total crushing distance. $\Longrightarrow F_m = \frac{1}{\delta_t} \int F d\delta$

3 Maximum crushing load

The initial peak load (F_i) occurs at the onset of the curve. The maximum peak load (F_{Max}) in conical segmented tubes usually occurs at the end of the crush range

4 Crush force efficiency (CFE)

This parameter is used to compare the efficiency of different energy absorbers.$\Longrightarrow CFE = \dfrac{F_m}{F_{Max}}$

5 The specific energy absorption

Energy Absorbed Per Unit Mass $\Longrightarrow SEA = \frac{E_{absorbed}}{M}$

Appendix 3

NL $\Longrightarrow$ subjective weighting method $\Longrightarrow$ any numeric weight between 0 and 1 for each criteria:

$$W_{j,NL} = \frac{\sum_{k=1}^{n} C_{jk}}{\sum_{j=1}^{n}\sum_{k=1}^{n} C_{jk}}, j \text{ and } k = \{1, \ldots, n\} \text{ and } j \neq k$$

NL weighting.

Attributes	Attributes type	Relative numeric weights (C_{jk})						Weights
$E_{absorbed}$ (kJ)	Maximize↑	0.55	0.6	0.75				0.3167
CFE ($\frac{F_m}{F_{max}}$)	Maximize↑	0.45			0.5	0.65		0.2667
F_i (kN)	Minimize↓		0.4		0.5		0.65	0.2583
M (kg)	Minimize↓			0.25		0.35	0.35	0.1583

The ratio system

Normalized matrix multiplied by the deviation of the subjective weight of beneficial attributes from the non-beneficial ones, where g is the number of beneficial attributes, and n is the number of all attributes:
$y_i^w = \sum_{j=1}^{g} w_j x_{ij}^* - \sum_{j=g+1}^{n} w_j x_{ij}^*$
Based on the ratio system, the optimum alternative has the maximum assessment value of y_i^w.

The reference point approach

the maximal attribute reference point vector (r) and the deviation of normalized rating from the reference point (d).

$$r_j = \begin{cases} \max\limits_i \ x_{ij}^*, & j \leq g, \\ \min\limits_i \ x_{ij}^*, & j > g. \end{cases} \qquad \Longrightarrow \qquad d_{ij} = (r_j - x_{ij}^*) \qquad \Longrightarrow \qquad z_i^w = \max_j \ w_j d_{ij}$$

Based on the reference point approach, the optimum alternative has the minimum assessment value of z_i^w

The full multiplicative form

The value of the full multiplicative form, which was weighted by considering the subjective weight as the exponent:
$U_i^w = \frac{\prod_{j=1}^{g} (x_{ij}^*)^{w_j}}{\prod_{j=g+1}^{n} (x_{ij}^*)^{w_j}}$
the optimum alternative has the maximum assessment value of U_i^w.

Final rank

The subordinate ranks calculated above can be conjoined to the final rank, which is known as the MULTIMOORA rank, by utilizing the dominance theory.

Appendix 5

The collapse pattern of SGMT 2-2 under axial compression.

The numerical outcomes and rankings of the NL-weighted MULTIMOORA method.

Alternatives		$E_{absorbed}$	CFE	F_i	M	Ranks			
		(kJ)	$(\frac{F_m}{F_{max}})$	(kN)	(kg)	U_i^w	y_i^w	z_i^w	Final
1	BSC 1	1.50	0.415	39.30	0.064	39	32	39	39
2	BSC 2	2.10	0.466	49.00	0.076	37	29	37	36
3	BSC 3	2.74	0.505	58.78	0.089	34	28	35	32
4	BSC 4	2.80	0.468	65.01	0.096	38	35	34	36
5	BSC 5	3.68	0.533	75.49	0.109	33	31	31	30
6	BSC 6	4.20	0.523	87.30	0.122	36	36	30	34
7	BSC 7	4.57	0.528	94.00	0.129	35	37	22	33
8	BSC 8	5.50	0.565	105.75	0.142	32	34	29	30
9	BSC 9	6.58	0.604	118.40	0.156	27	33	32	30
10	BSC 10	7.07	0.619	124.00	0.163	24	30	33	28
11	BSC 11	7.54	0.595	137.70	0.176	31	38	36	36
12	BSC 12	8.34	0.609	148.76	0.190	30	39	38	38
13	SGMT 1-1	5.02	0.398	54.09	0.126	22	22	19	22
14	SGMT 1–2	5.75	0.450	63.15	0.140	19	19	7	19
15	SGMT 1–3	7.28	0.484	70.25	0.153	9	6	4	6
16	SGMT 2-1	6.03	0.556	48.85	0.121	3	3	3	3
17	**SGMT 2-2**	**7.13**	**0.767**	**56.94**	**0.134**	**1**	**1**	**1**	**1**
18	SGMT 2–3	7.01	0.434	66.41	0.148	11	9	9	9
19	SGMT 3-1	4.45	0.440	46.29	0.115	15	18	25	18
20	SGMT 3-2	5.10	0.431	55.38	0.129	20	21	13	21
21	SGMT 3-3	6.78	0.470	63.73	0.142	6	5	5	5
22	SGMT 4-1	4.72	0.441	50.71	0.110	14	17	20	17
23	SGMT 4-2	5.16	0.473	57.98	0.123	16	16	11	14
24	SGMT 4-3	5.56	0.404	67.20	0.136	25	24	18	24
25	SGMT 5-1	4.36	0.664	45.81	0.104	4	4	26	4
26	SGMT 5-2	4.91	0.340	55.75	0.117	28	26	27	26
27	SGMT 5-3	5.43	0.415	64.49	0.131	23	23	15	23
28	SGMT 6-1	4.64	0.492	50.80	0.113	10	11	21	11
29	SGMT 6-2	5.30	0.489	59.37	0.126	12	13	8	12
30	SGMT 6-3	6.69	0.418	68.15	0.139	18	15	14	16
31	SGMT 7-1	4.52	0.493	48.00	0.110	7	8	24	8
32	SGMT 7-2	5.02	0.510	58.91	0.123	13	14	16	14
33	SGMT 7-3	5.68	0.465	66.27	0.136	21	20	6	20
34	SGMT 8-1	5.34	0.411	46.75	0.118	8	10	17	10
35	SGMT 8-2	6.26	0.431	54.06	0.131	5	7	10	7
36	SGMT 8-3	7.32	0.654	64.82	0.145	2	2	2	2
37	SGMT 9-1	4.61	0.338	51.06	0.121	29	27	28	27
38	SGMT 9-2	5.25	0.361	56.98	0.134	26	25	23	25
39	SGMT 9-3	6.65	0.426	64.07	0.147	17	12	12	14

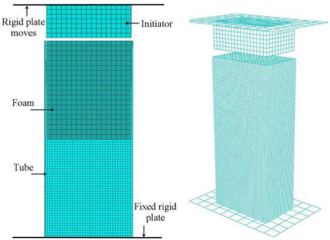
Appendix 7

The dimensions of the conical segmented tubes of the second group.

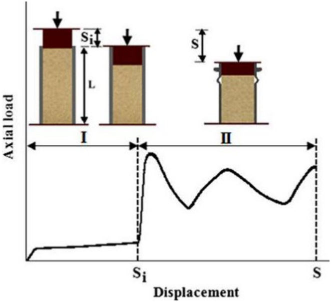
		L_1	L_2	L_3	L_4	$\alpha°$			L_1	L_2	L_3	L_4	$\alpha°$
1	SGMT 2–2	25	25	35	35	4°	9	SGMT 46	25	25	35	35	6°
2	SGMT 8–2	25	35	25	35	4°	10	SGMT 47	25	35	25	35	6°
3	SGMT 40	25	25	25	45	4°	11	SGMT 48	25	25	25	45	6°
4	SGMT 41	25	35	35	25	4°	12	SGMT 49	25	35	35	25	6°
5	SGMT 42	25	25	35	35	2°	13	SGMT 50	25	25	35	35	8°
6	SGMT 43	25	35	25	35	2°	14	SGMT 51	25	35	25	35	8°
7	SGMT 44	25	25	25	45	2°	15	SGMT 52	25	25	25	45	8°
8	SGMT 45	25	35	35	25	2°	16	SGMT 53	25	35	35	25	8°

For all tubes: $t_1 = 1.2$ mm, $t_2 = 1.7$ mm, $t_3 = 2.2$ mm, $t_4 = 2.7$ mm.

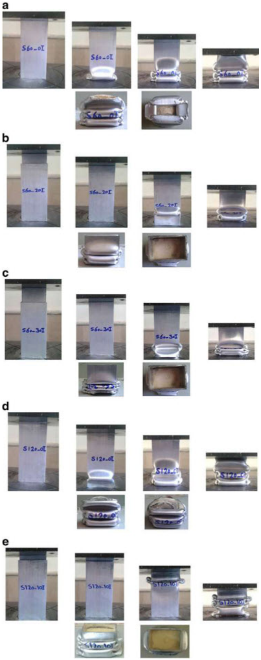
Appendix 8

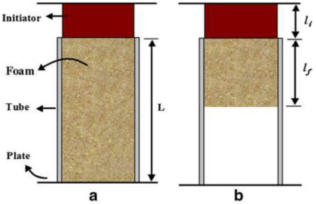


Rigid plate moves
Initiator
Foam
Tube
Fixed rigid plate

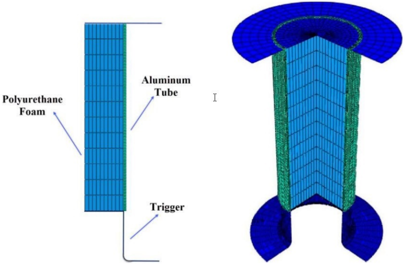


Si
S
L
Axial load
I
II
Si
S
Displacement

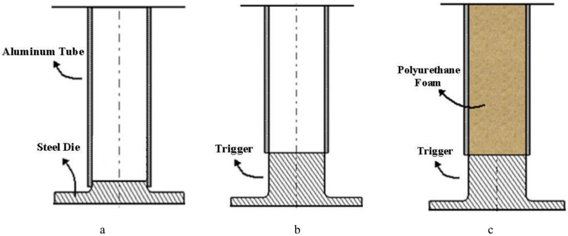




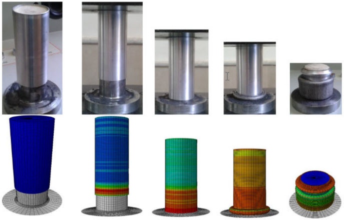
A schematic of two groups of the thin-walled rectangular tubes with the aluminum initiator: (**a**) foam-filled; (**b**) partially foam-filled

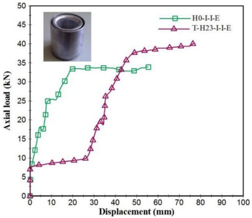


Finite element mesh and 3D view for the partially foam-filled rectangular tube with trigger.

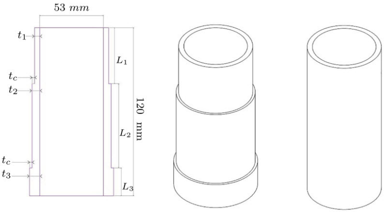


Details of the position of the specimens on the die: a) H0-E-I-E, b) T-H23-E-I-E, c) T-H23-E-I-F.




H0-I-I-E
T-H23-I-I-E
Axial load (kN)
Displacement (mm)
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90
100


(a)
(b)
(c)
(d)



(a) (b)

Variables	-1	0	+1
Length of sections (L_1, L_2, and L_3)	20	40	60
Thickness of first section (t_1)	1	1.4	1.8
Thickness factor (t_c)	0.3	0.5	0.8

$$\begin{cases} L_1: & 15 \leq x \leq 75\, mm \\ L_2: & 15 \leq x \leq 75\, mm \\ L_3: & 15 \leq x \leq 75\, mm \\ t_1: & 1 \leq x \leq 1.9\, mm \\ t_c: & 0.25 \leq x \leq 0.95\, mm \\ where & L_1 + L_2 + L_3 = 120mm \end{cases}$$

$$\begin{cases} Minimize \begin{cases} f_1 = F_i^0(x) \\ f_2 = F_i^{15}(x) \\ f_3 = F_i^{30}(x) \end{cases} \\ Minimize \begin{cases} f_4 = F_{max}^0(x) \\ f_5 = F_{max}^{15}(x) \\ f_6 = F_{max}^{30}(x) \end{cases} \\ Maximize \begin{cases} f_7 = E^0(x) \\ f_8 = E^{15}(x) \\ f_9 = E^{30}(x) \end{cases} \\ Less\ is\ better\ \ f_{10} = M(x) \\ \qquad S.t\ \ x^l \leq x \leq x^u \end{cases}$$

Appendix 13

Table The ANOVA of design factors for each response (objective function)

Responses	Factors	F value	P value	Final equation
	t_1	594.629	< 0.0001	$10^{(+4.16996+0.57713\times t_1+0.22260\times t_c-0.25329\times t_1\times t_c)}$
f_1	t_c	20.446	< 0.0001	
	$t_1 t_c$	10.213	0.0024	
	L_1	17.030	0.0001	
	L_2	19.530	< 0.0001	$10^{(4.49370-2.26674E-3\times L_1-2.21568E-3\times L_2+0.42023\times t_1+0.78968\times t_c-0.27190\times t_1\times t_c)}$
f_2	t_1	170.530	< 0.0001	
	t_c	141.450	< 0.0001	
	$t_1 t_c$	8.690	0.005	
	L_1	65.894	< 0.0001	
	L_2	31.996	< 0.0001	$10^{(3.10313-3.69279E-3\times L_1-2.34881E-3\times L_2+0.51899\times t_1+0.78189\times t_c-0.26789\times t_1\times t_c)}-0.5$
f_3	t_1	468.696	< 0.0001	
	t_c	204.036	< 0.0001	
	$t_1 t_c$	12.303	0.0010	

Appendix 14

Table Scenarios chosen for pareto front generation

	Design variables					Output responses									
	L_1 mm	L_2 mm	L_3 mm	t_1 mm	t_c	f_1 F_i^0	f_2 F_{max}^0	f_3 E^0	f_4 F_i^{15}	f_5 F_{max}^{15}	f_6 E^{15}	f_7 F_i^{30}	f_8 F_{max}^{30}	f_9 E^{30}	f_{10} M
1*	23.59	34.34	62.07	1	0.51	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	23.91	25.81	70.28	1.05	0.9	–	–	✓	–	–	✓	–	–	✓	✓
3	38.91	37.82	43.27	1	0.9	✓	–	✓	✓	–	✓	✓	–	✓	✓
4	15	30.12	74.88	1	0.81	✓	–	✓	✓	–	✓	✓	–	✓	–
5	26.89	74.99	18.12	1.88	0.25	–	✓	✓	–	✓	✓	–	✓	✓	–
6	14.21	40.82	64.97	1.9	0.8	–	–	✓	–	–	✓	–	–	✓	–
7	26.88	33.29	59.83	1	0.25	✓	–	–	✓	–	–	✓	–	–	–
8	39.07	63.12	17.81	1	0.25	✓	–	–	✓	–	–	✓	–	–	✓
9	26.04	56.06	37.9	1	0.25	–	✓	–	–	✓	–	–	✓	–	✓
10	56.74	48.23	15.03	1.14	0.25	–	✓	–	–	✓	–	–	✓	–	–
11	24.05	33.21	62.74	1	0.34	✓	✓	–	✓	✓	–	✓	✓	–	–
12	60.82	43.48	15.7	1	0.25	✓	✓	–	✓	✓	–	✓	✓	–	✓
13	15	31.9	73.1	1.01	0.36	✓	✓	✓	–	–	–	–	–	–	✓
14	48.03	16.34	55.63	1	0.55	–	–	–	✓	✓	✓	–	–	–	✓
15	41.27	41.82	36.91	1.32	0.25	–	–	–	–	–	–	✓	✓	✓	✓
16**	–	–	–	1.98	–	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

*Segmented tubes

**Basic tube

Appendix 15

Table Summarized table for the steps of CW method

Methods	Weighting strategies		Formula	
Entropy	Objective weighting	w_j^o	$\frac{1-E_j}{\sum_{k=1}^{n}(1-E_k)}$	(8)
Numeric logic	Subjective weighting	w_j^s	$\frac{\sum_{k=1}^{n} C_{jk}}{\sum_{j=1}^{n}\sum_{k=1}^{n} C_{jk}}$	(9)
Correlation's effect		w_j^c	$\frac{\sum_{k=1}^{n}(1-R_{jk})}{\sum_{j=1}^{n}(\sum_{k=1}^{n}(1-R_{jk}))}$	(11)
Combinative weighting		w_j	$\frac{(w_j^o w_j^s w_j^c)^{1/3}}{\sum_{j=1}^{n}(w_j^o w_j^s w_j^c)^{1/3}}$	(12)

Appendix 16

The multi-objective design selection results

	f_1 F_i^0 kN	f_2 F_{max}^0 kN	f_3 E^0 kJ	f_4 F_i^{15} kN	f_5 F_{max}^{15} kN	f_6 E^{15} kJ	f_7 F_i^{30} kN	f_8 F_{max}^{30} kN	f_9 E^{30} kJ	f_{10} M kg	Ranks U_i^w	Ranks y_i^w	Ranks z_i^w	Final
1*	**53.88**	**111.80**	**5.21**	**15.65**	**99.52**	**5.29**	**4.76**	**56.14**	**3.30**	**0.27**	3	6	7	4
2	54.57	189.38	**8.91**	19.60	156.83	**8.75**	6.12	86.77	**5.40**	**0.38**	7	4	1	4
3	**52.42**	161.41	**7.12**	**18.50**	116.88	**6.91**	**5.83**	69.09	**3.68**	**0.32**	10	11	5	10
4	**52.75**	170.84	**8.17**	**17.63**	151.54	**7.78**	**5.58**	80.99	**5.27**	0.36	1	1	2	1
5	155.44	**133.74**	**7.46**	39.05	**84.17**	**6.54**	9.29	**59.74**	**3.98**	0.34	14	15	4	15
6	114.71	244.31	**14.43**	41.50	204.78	**10.53**	10.91	132.80	**7.43**	0.50	15	14	3	14
7	**54.88**	81.04	3.74	**16.15**	72.92	3.95	**4.05**	43.98	2.51	0.21	8	5	12	8
8	**54.88**	65.31	2.87	**16.04**	47.58	3.31	**4.05**	35.43	2.06	**0.19**	4	3	15	4
9	54.88	**72.47**	3.33	16.16	**57.73**	3.76	4.05	**38.66**	2.26	**0.20**	2	2	13	2
10	64.77	**71.98**	3.10	18.49	**54.32**	3.54	4.89	**39.56**	2.20	0.21	12	12	14	12
11	**54.53**	**91.60**	4.27	**15.76**	**82.89**	4.37	**4.30**	**48.26**	2.80	0.23	5	7	11	6
12	**54.88**	**64.44**	2.65	**15.83**	**49.90**	3.00	**4.05**	**36.73**	1.93	**0.19**	11	9	16	11
13	**55.07**	**99.74**	**4.80**	15.98	92.79	4.47	4.41	51.85	3.13	**0.25**	6	8	9	7
14	53.73	113.14	4.89	**15.51**	**95.02**	**5.17**	4.87	56.04	2.88	**0.26**	9	10	8	9
15	80.14	93.30	4.41	22.67	74.13	4.93	5.96	**48.53**	**2.78**	**0.25**	13	13	10	13
16**	**107.41**	**107.41**	**5.82**	**44.73**	**84.84**	**6.27**	**13.26**	**55.37**	**3.82**	**0.32**	16	16	6	16

*Regression models

**Finite element method