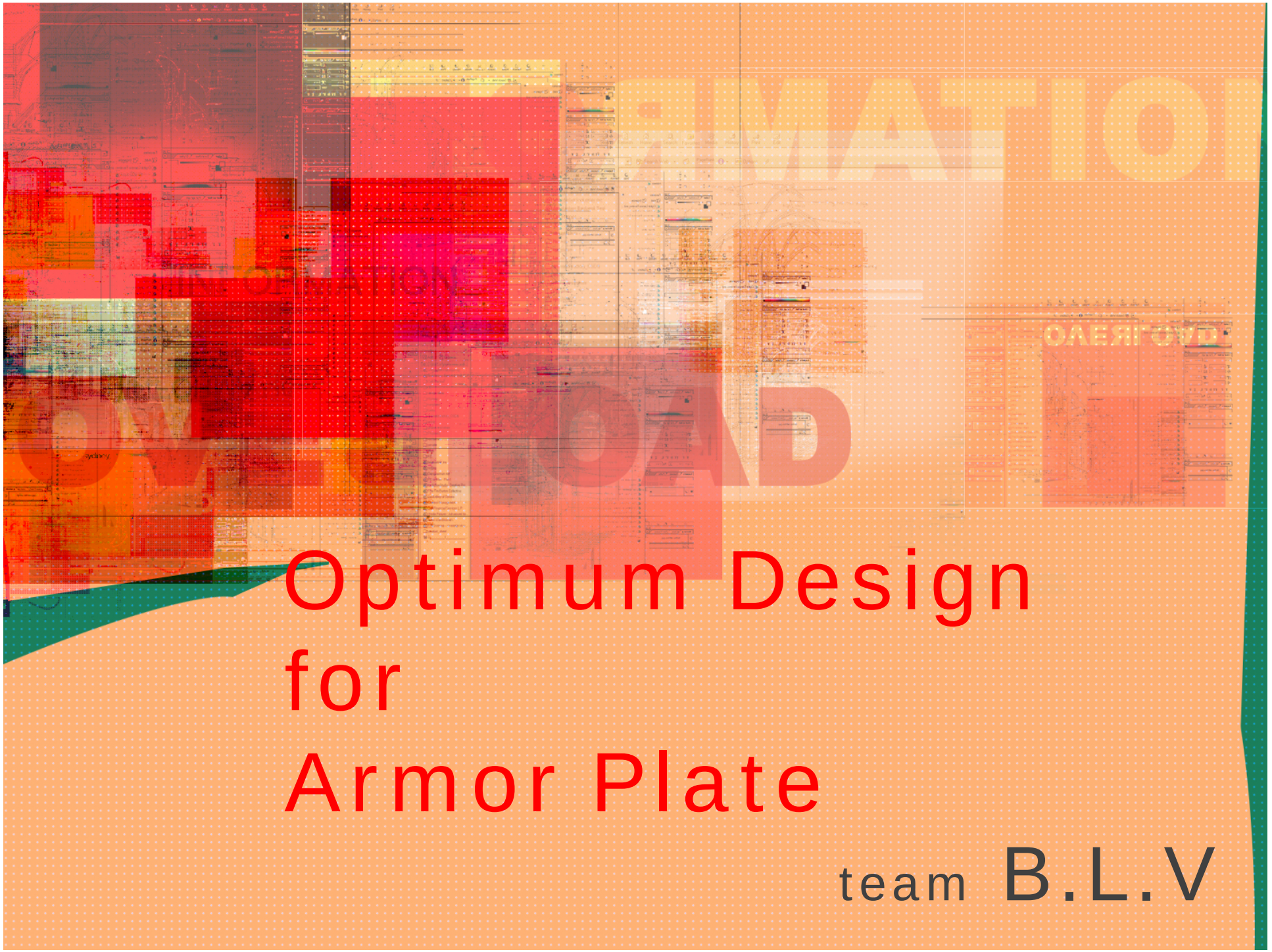

Optimum Design for Armor Plate

team B.L.V

Contents

- Summary of Previous Project
- Solution:
  - Continuous Solution
  - Integer Solution
  - Branch and Bound Method
- Conclusion
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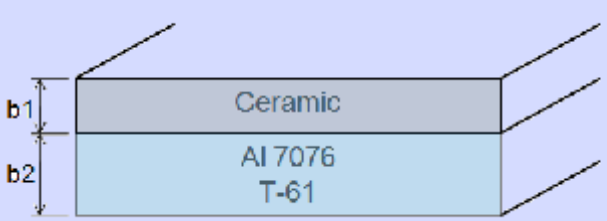
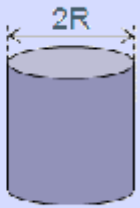
Project Statement

Design an armor plate which can be attached to a car. A bullet forming a cylinder - 7.62 mm of diameter and 24g of mass - strikes the plate with velocity of 700 m/s. The armor has to have proof of this shot. The plate is a compound body of ceramic and aluminum, and the maximum total thickness of the plate is 20 mm. In industry, aluminum and ceramic plates are produced in 1 mm. Minimize the mass of this plate. Put factor of safety 1.1 to velocity.





<figure>

Assumptions

Assumptions

1) The bullet forms a cylinder.
2) The bullet strikes the plate normally.
3) Use theory of BLV (Florence's model)
4) The plate is infinite, but assume it is a square, 10 cm each side, when calculate mass of the plate.

Formulation

Minimize $m(b_1, b_2) = \gamma_1 A b_1 + \gamma_2 A b_2$

($\gamma_1 = 3.96\ \text{g/cc}$ $\gamma_2 = 2.84\ \text{g/cc}$ $A = 10\ \text{cm} \times 10\ \text{cm} = 100\ \text{cm}^2$)

Subject to

$$g_1 = (770)^2 - \frac{\alpha \epsilon_2 \sigma_2 b_2 z[(\gamma_1 b_1 + \gamma_2 b_2)z + m]}{0.91\ \text{m}^2} \leq 0$$

$z = \pi(R + 2b_1)^2$

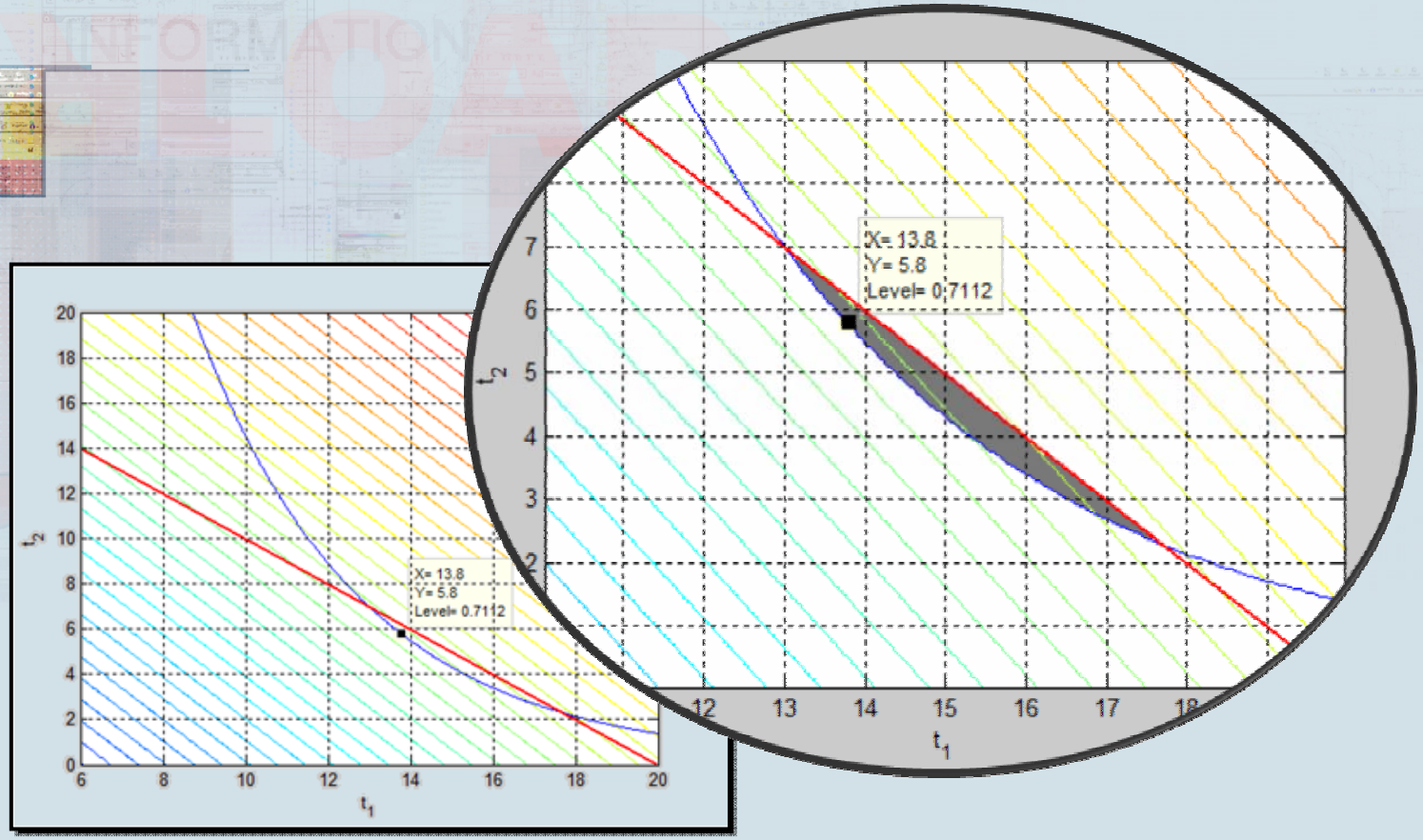
$\alpha = 1$

$$g_2 = b_1 + b_2 \leq 0.02$$

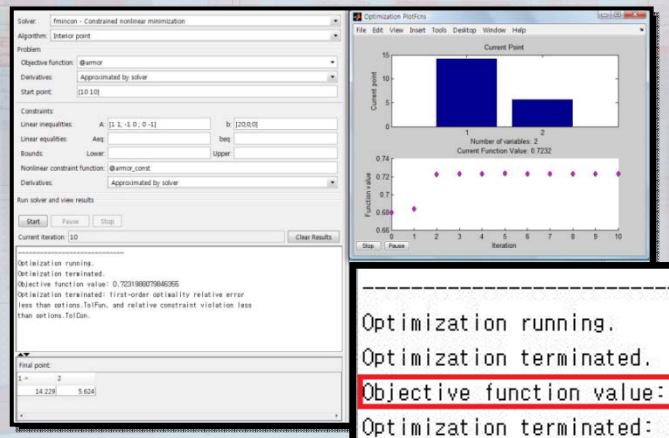
$$g_3 = -b_1 \leq 0$$

$$g_4 = -b_2 \leq 0$$

Graphical Method



Solution (by Matlab)



Matlab	
b1	14.229㎜
b2	5.624㎜
function value	0.7232㎏

```
Optimization running.
Optimization terminated.
Objective function value: 0.7231988079846355
Optimization terminated: first-order optimality relative error
less than options.TolFun, and relative constraint violation less
than options.TolCon.
```

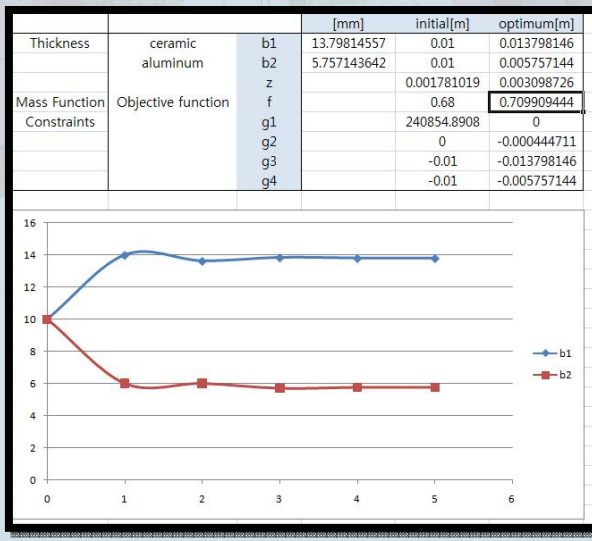
Final point:

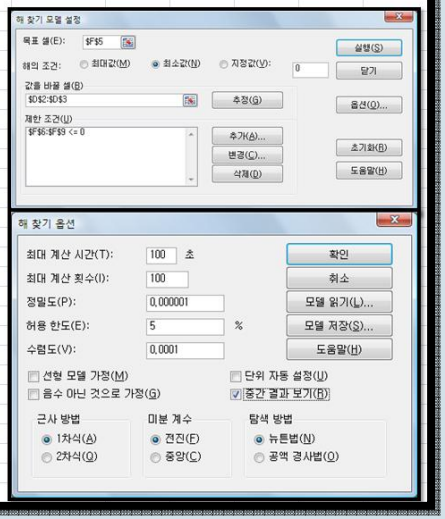
1	2
14.229	5.624

Solution (by Excel Solver)

Excel Solver		Matlab	
b1	13.798㎜	b1	14.229㎜
b2	5.757㎜	b2	5.624㎜
function value	0.7099kg	function value	0.7232kg

			[mm]	initial[m]	optimum[m]
Thickness	ceramic	b1	13.79814557	0.01	0.013798146
	aluminum	b2	5.757143642	0.01	0.005757144
		z		0.001781019	0.003098726
Mass Function	Objective function	f		0.68	0.709909444
Constraints		g1		240854.8908	0
		g2		0	-0.000444711
		g3		-0.01	-0.013798146
		g4		-0.01	-0.005757144





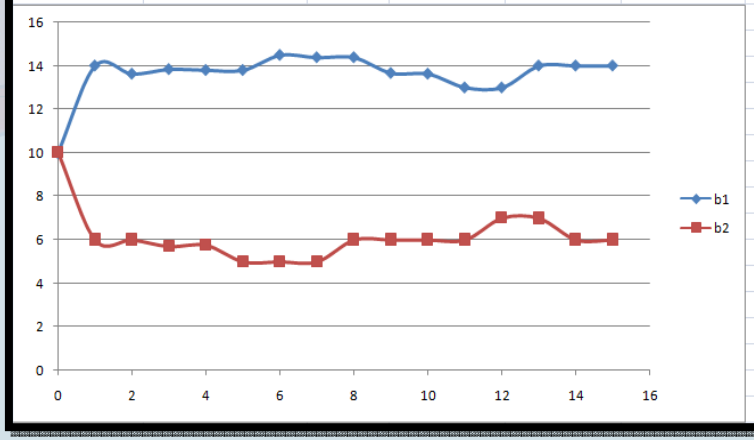
Comparison

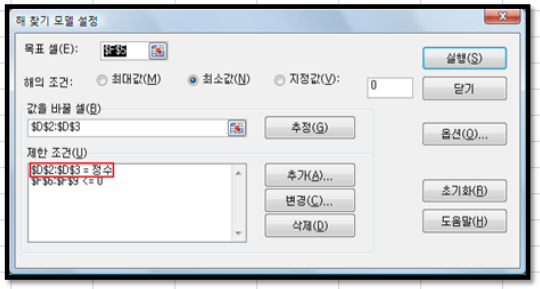
fmincon		genetic algorithm	
b1	14.229㎜	b1	14.262㎜
b2	5.624㎜	b2	5.579㎜
function value	0.7232㎏	function value	0.7232㎏
iteration	10	iteration	6
pattern search		**Excel Solver**	
b1	14.335㎜	b1	13.798㎜
b2	5.661㎜	b2	5.757㎜
function value	0.7284㎏	function value	0.7099㎏
iteration	5	iteration	5

* Initial point: $[10\ 10]^T$

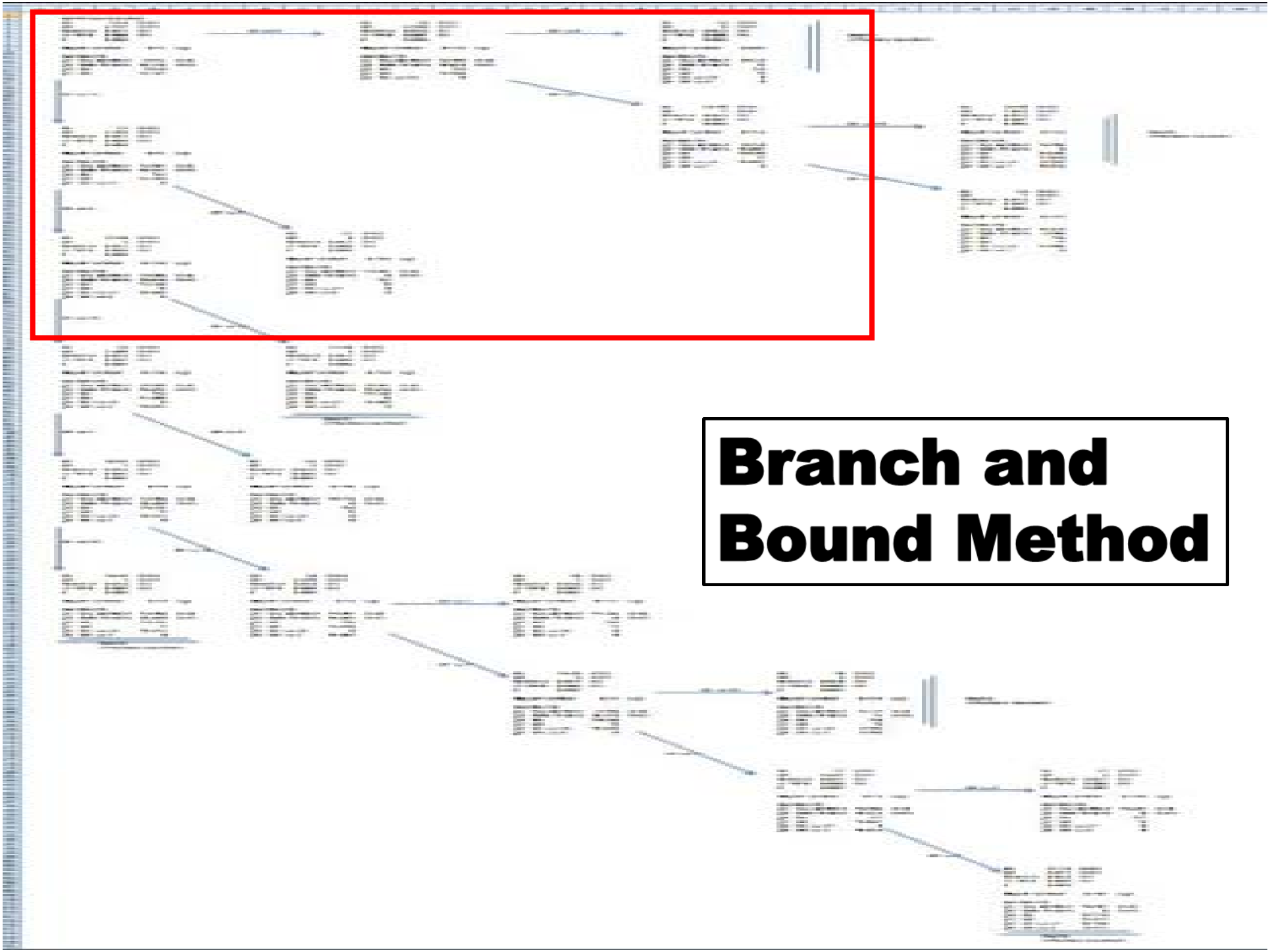
Solution (Integer)

			[mm]	initial[m]	optimum[m]
Thickness	ceramic	b1	14	0.01	0.014
	aluminum	b2	6	0.01	0.006
		z		0.001781019	0.003178903
Mass Function	Objective function	f		0.68	0.7248
Constraints		g1		240854.8908	-68085.00338
		g2		0	0
		g3		-0.01	-0.014
		g4		-0.01	-0.006

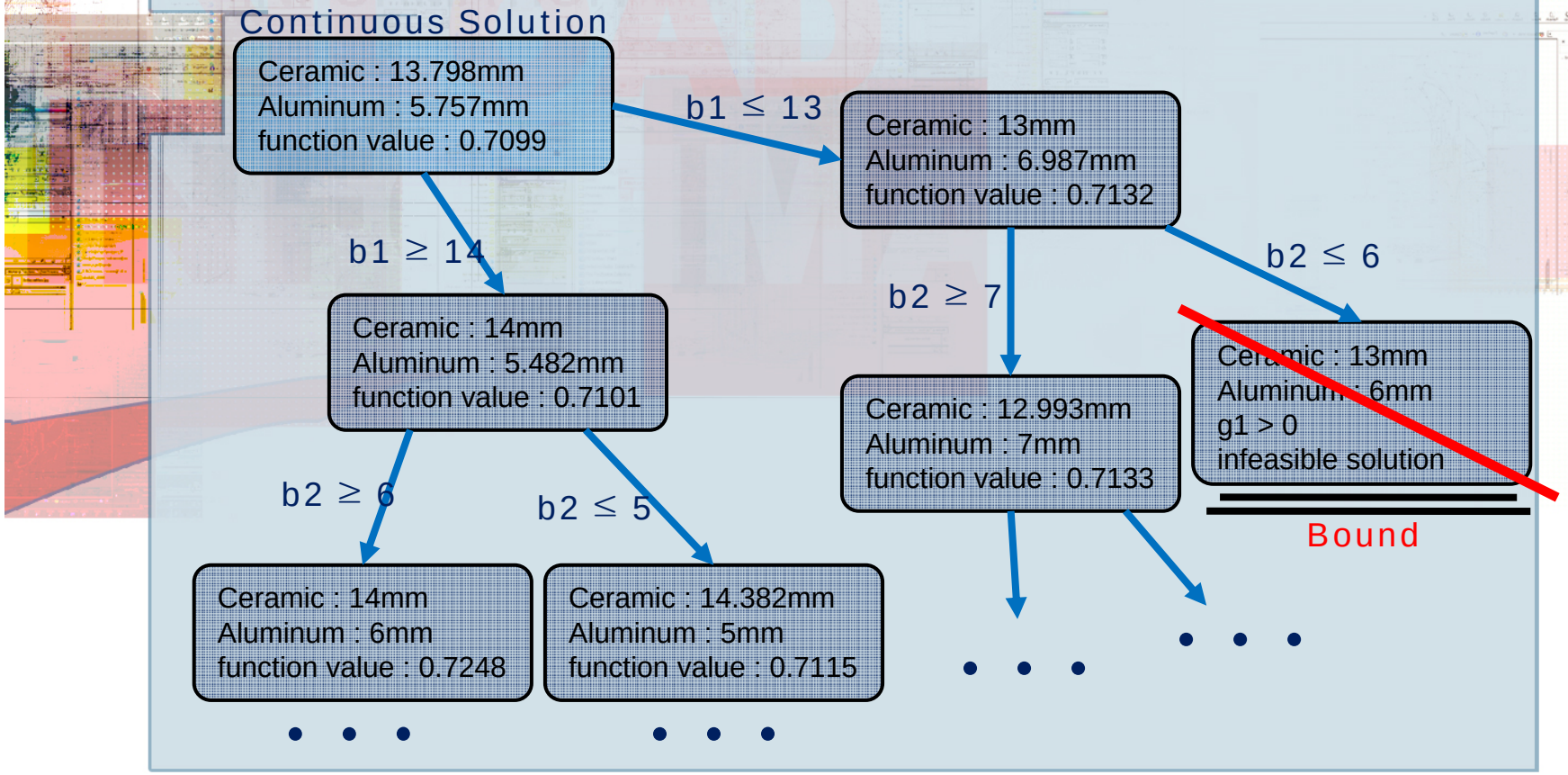




Excel Solver(int.)	
b1	14㎜
b2	6㎜
function value	0.7248kg


Branch and
Bound Method

Branch and Bound Method



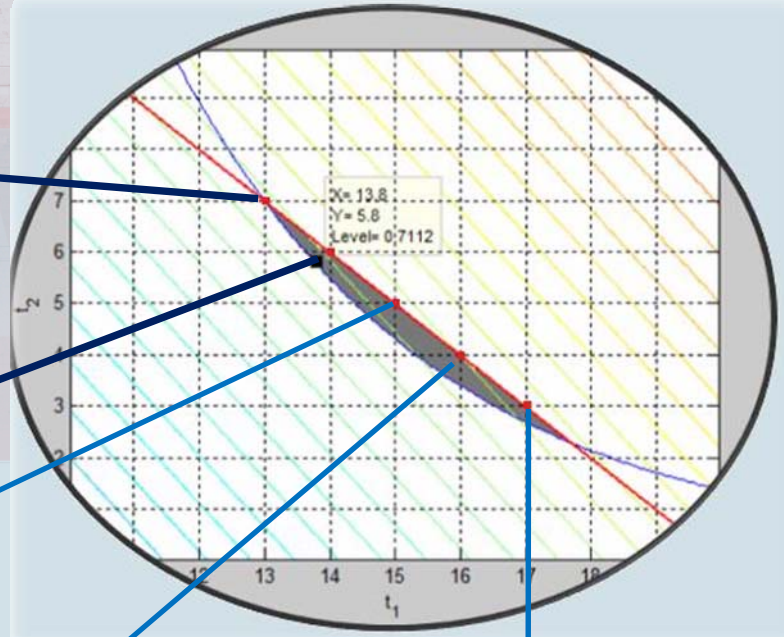
Branch and Bound Method

Ceramic : 13mm
Aluminum : 7mm
function value : 0.7136

BBM

Ceramic : 14mm
Aluminum : 6mm
function value : 0.7248

Solver(Integer)



Ceramic : 15mm
Aluminum : 5mm
function value : 0.7360

Ceramic : 16mm
Aluminum : 4mm
function value : 0.7472

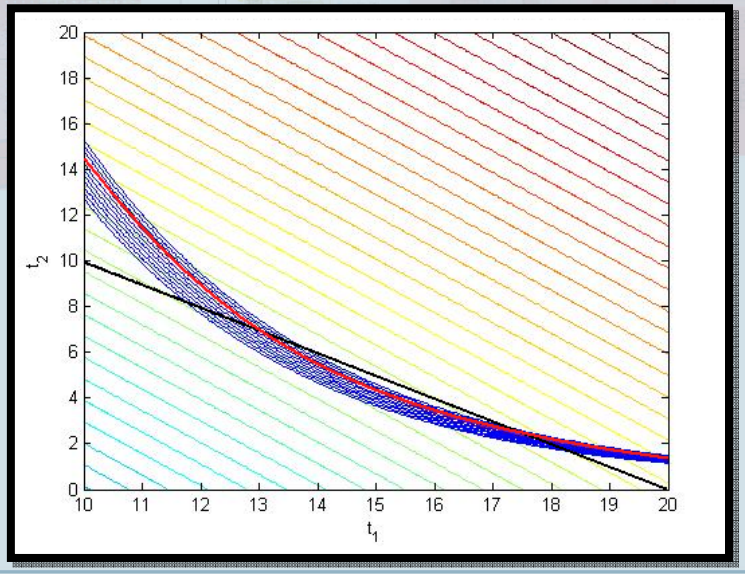
Ceramic : 17mm
Aluminum : 3mm
function value : 0.7584

Conclusion

A. Continuous Solution

GRG2(Excel solver) vs SQP(MATLAB)

In general, SQP > GRG2 , but ...



fmincon	
function value	0.7232kg
iteration	10
Excel Solver	
function value	0.7099kg
iteration	5

Conclusion

B. Integer Solution

Excel Solver(Integer) vs BBM

algorithm of Int. solver is based on BBM, but...

Integer Solver		BBM	
b1	14㎜	b1	13㎜
b2	6㎜	b2	7㎜
function value	0.7248㎏	function value	0.7136㎏
iteration	15	iteration	21

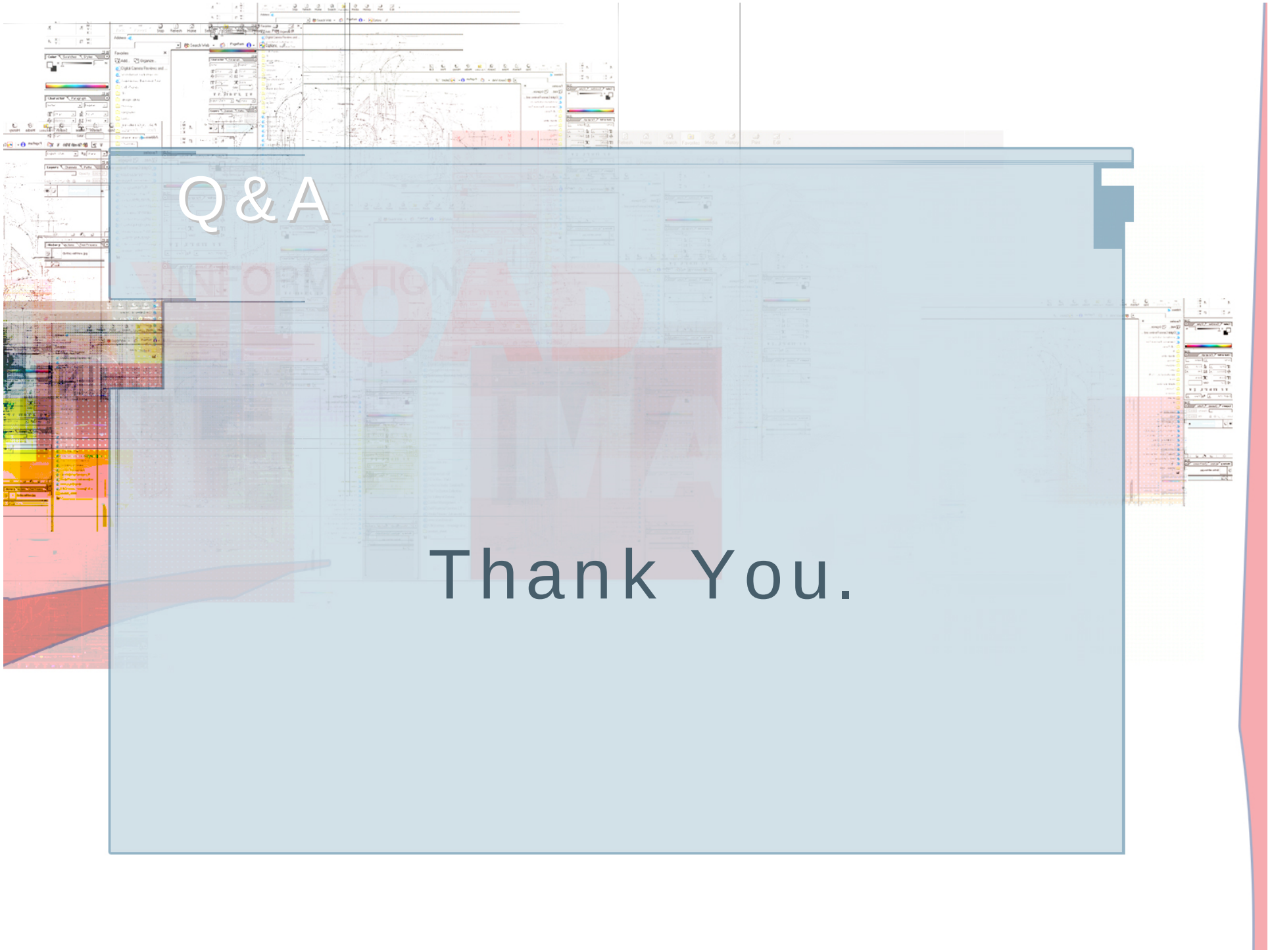
Reference

[1] Ben-Dor G, Dubinsky A, Elperin T, Frage N. Optimization of two component ceramic armor for a given impact velocity. Theor ApplFract Mech 2000.

[2] Ben-Dor G, Dubinsky A, Elperin T. Improved Florence model and optimization of two-component armor against single impact or two impacts.

[3] Mustafa Ubeyli, R. Orhan Yildirim, Bilgehan Ogel. On the comparison of the ballistic performance of steel and laminated composite armors.

[4] http://www.matweb.com/


Q&A
Thank You.