Material Selection for Competition–A Case Study for Air Coolers

Luma A. H. Al Kindi **Amjad Husien Jasim**
Production Engineering and Metallurgy , University of Technology
Luma.alkindi@gmail.com amjadbaghdad36@yahoo.com
Entsar Nife Farhan
Directorate of vocational education
entsarnifefrhan@gmail.com
Batool Ibraheem Jameel
Production Engineering and Metallurgy , University of Technology
battol_alassaf07@yahoo.com

Abstract

Competition is one of the most important challenges that is facing the marketing of industrial products in today's markets. In this research study of the impact of material selection factor for air coolers of different materials is applied. Investigation on the air cooler windows which are part of the body of air coolers is conducted. Corrosion resistance, thermal conductivity, strength of material, weight, shape, cost and manufacturing process are the factors that are applied and calculated on three types of materials Aluminum, Galvanized steel and polypropylene. The physical properties of the three mentioned materials are used to calculate Merit Index .The corrosion average, according to Tafel Method depending the corrosion current and adopting contactors for the anodic and cathodic metals behaviors is performed. ANSYS is adopted using the three samples for the selected materials Aluminum, Galvanized steel and polypropylene to measure maximum stress and deflection are measured. Accordingly, the results are compared to choose the best alternative. It is observed that the polypropylene is the best choice depending three factors while the aluminum material is better depending two factors and the galvanized steel is regarded as the best in only one factor, the rest factors are identical when choosing an alternative material for manufacturing the air cooler windows.

Keywords: Competition, Air coolers, Material selection, Corrosion resistance, Aluminum, Galvanized steel and Polypropylene.

الخلاصة

تعتبر المنافسة من اهم التحديات التي تواجه تسويق المنتجات الصناعية في الوقت الحاضر. في هذا البحث تمت دراسة تأثير عامل اختيار المواد لمنتج صناعي (شباك مبردات الهواء) باعتماد معايير مقاومة التأكل، التوصيل الحراري، مقاومة المواد، الوزن، الشكل، الكلفة واسلوب التصنيع. تم التطبيق على شباك مبردة الهواء بموجب المواصفات الفنية المعتمدة في شركة الهلال واعتمدت الاختبارات ثلاث نماذج من كل من سبيكة الالمنيوم 3003 والحديد المغلون والبولي بروبلين باسماك واوضاع مختلفة. باعتماد المواصفات الهندسية لكل مادة تم حساب الـMerit Index وكذلك تم اجراء اختبارات مقاومة التآكل اضافة الى اعتماد برنامج ANSYSلحساب معدلات التشوه والاجهادات القصوى لكل عينة. تمت مقارنة النتائج للوصول الى الخيار الانسب من بين الخيارات التي اعتمدت وبينت النتائج ان سبيكة الالمنيوم 3003 هي الاختيار الامثل باعتماد معيارين في حين ان البولي بروبلين كان الخيار الانسب بمقارنة ثلاث معايير، اما الحديد المغلون فكان افضل الخيارات في معيار واحد فقط، المعايير الاخرى كانت متماثلة في اختيار المادة البديلة المعتمدة في تصنيع شباك مبردة الهواء.

الكلمات المفتاحية : المنافسة ، مبردات الهواء ، اختيار المواد ، مقاومة التأكل ، الالمنيوم ، الحديد المغلون والبولي بروبلين.

Introduction

To design an engineering part **(Michael, 1999)** three interrelated problems are to be considered: (i)Material selection, (ii) Shape specifying, and (iii) The suitable manufacturing process.

If the selection is right from the first time, then the optimal arrangement of the design will have massive benefits for any engineering-based industry. It might lead to lesser product costs, quicker time to market, decrease the number of in service faults besides significant benefits related to competition.

To understand these benefits, engineers have to deal with a very complicated issue. There are ten thousands of materials and hundreds of industrial processes. No engineer can imagine to recognize more than a minor subset of this growing frame of information. Additionally, there are challenges and instable design necessities such as cost, performance, protection, danger and aesthetics, as well as environmental influence and recyclability.

The main theory throughout mechanical selection for design **(Jeremy, 2005)** is how to choose among technology varieties through:

- Economic Assessment
- Cost Demonstrating
- Life Cycle Analysis

By focusing on the economic assessment of the alternatives and if they are appropriate to the greater technology selected problem.

Material selection in mechanical design according to Ashby's methodology (Ashby 11) **(Michael , 2005)** has four basic steps which are:

1. Translation: rapid design desires as constraints &goals .
2. Screening: reduce materials that cannot perform the job.
3. Ranking: discover the materials that perform the job better.
4. Supporting information: discover pedigrees of top-ranked nominees.

(David *et.al.,* 1993) discovered the material resolution process so that producers, component providers, and material suppliers may well recognize the interlocking web of compromises that form the pursuit of value-added options and the prevention of unprofitable compromises.

The researchers assume that the reader is familiar with the topics facing today's automotive production. Cost decreasing, quality enhancement , regulatory compliance, and so on are well recognized production competitive subjects. Difficulty arises in the formation and performance of action plans to address these topics in an atmosphere of fast and multifaceted change, partial financial and human investment, and time pressure. Tomorrow's automobile will offer improved performance, function, and relaxation, while emitting lesser emissions, consuming less gallons of gasoline, resulting in less human harms, and demanding fewer dollars to form and purchase. The only answer to these conflicting goals is to take a system vision of the product and production. Though, systems discipline is not yet standard functioning procedure.

(Maleque *et.al.,* 2010) improve the material choice process and select the best material for the application of the disc brake system emphasizing on the replacement of cast iron By other lightweight material. Two procedures are presented for the choice of materials, Such as the cost for each unit property and digital logic procedure .Different solutions were evaluated to best choices among cast iron, aluminum alloy, titanium alloy, ceramics and combinations. Mechanical properties such as compressive strength, friction factor, wear resistance, thermal conductivity and specific gravity besides cost, were used as crucial factors for material selection. The investigation led to aluminum metal matrix composite as the best suitable material for disc brake system.

(Ibuchim and Junli , 2012) examined the relate disuses or variables needed to improve a systematic and effective material selection method. According to the analysis of frequency data and the results of the preliminary study, they identified some of the possible factors that will influence designers decisions in the selection of green vernacular construction materials, during the decision making of the design process. They discussed the quantitative calculation and choice of the finest alternative for construction material, by means of the Analytic Hierarchy Process (AHP) method. They developed a multi-factorial methodical decision support to help designers assess their significances for whether or not the material selection is likely suitable for sustainability objectives. The argument of the material selection process involves the assessment of social, economic, technical, sensorial and environmental significances of possible material choice.

2. Material selection as a competitive factor:

Three forces are affecting today’s enterprises; they are the three Cs: Customers, Change and Competition **(Hammer and Champy , 1993).** Marketing and competition deal directly with three factors Time, cost and quality. The enterprise that could catch the market with a satisfactory product or service and best price would catch a sale. Cost and quality are the most important factors in the economics of companies' .In this work evaluation of competitive factors that affect air coolers is applied. The main competitive factor that is pointed for such products is how long may be its age, besides weight, nice shape finishing, manufacturing process and of course cost.

Cost is affected with all these factors, the customer is ready to pay the extra cost for a long life product. In this work focusing on the best material to be selected for manufacturing air coolers' windows out of three types of materials usually used. Several tests are conducted to select the best material. These tests are Merit index, corrosion tests and ANSYS.

3. Materials and Methods:

Air coolers are industrial products which are widely used in the countries that suffers from high summer temperature. This product could be produced using different types of material with good corrosion resistance; for the function of this product is cooling using water pumps and fans. The main part that suffers from its short life is the air cooler windows. The shape of the air cooler's window is shown in figure (1). The technical specification for air cooler windows is shown in Table (1), taking into consideration the three main materials used for fabricating them. These materials are Aluminum, Galvanized steel and plastic.

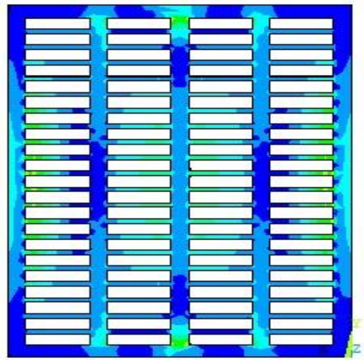


Figure (1): The shape of the air cooler's window

Three materials are selected after visits to dependent manufacturing companies for air cooler fabrication, which are **(Eugene *et.al.*, 2007)** Aluminum Alloy 3003 and Galvanized steel as samples from Al Hilal company according to their used raw material; and Polypropylene from Al Nuaman company, these companies are related to the ministry of industry and minerals in Iraq. Three samples for each material with different thicknesses are chosen.

3.1 Aluminum Alloy 3003

Aluminum alloy3003 is in the wrought aluminum-manganese group (3xxx chain). This alloy can be worked on cold to create tempers that have greater strength with lesser ductility. Similar to other Al-Mn alloys, 3003 is a general purpose alloy that has reasonable strength, respectable workability, besides good resistance to corrosion. This alloy is generally rolled and extruded and not forged. For being a wrought alloy, it will not be used in casting process, but it has good weld ability. Sheet metal applications are its main uses especially for roofing, and siding .Table (2) shows its physical properties.

3.2 Galvanized steel

Hot-galvanization is the process of covering iron and steel with a film of zinc by dipping a metal in a bath of melted Zn at a temperature of about 840 °F (449 °C). Galvanized steel is commonly used in corrosion resistance applications products without bearing the cost of stainless steel . Galvanized steel could be recognized through the crystallization designing on a surface which frequently termed "spangle" .The Galvanized steel is proper for high temperature uses up to 392 °F / 200 °C and could be welded. Electro galvanized steel plates are regularly used in the manufacturing of automotive in order to improve the corrosion routine of external body panels. This is totally different process which requires attaining minor layer thicknesses of Zn .Similar to other corrosion protection methods, galvanizing shields steel by substitute as a barrier between the steel and the atmosphere surrounding. Table (3) shows its physical properties.

Table (1): Technical specification for air cooler window

Type of material	Plate thickens	Product dimension	Product weight before operation	Product weight after operation	No. of Pieces	No. of slices	Slots weight after operations	Total weight for the product	
Galvanized steel	0.7mm	777*590mm	3,610kg	3,610 kg	3	4	Upper/ 0.540 gr. Lower/ 0.410 gr.	4,560kg	ASTM Closs G 9- hot Dipped galvanized
Aluminum	1 mm	777*590mm	1,5891 kg	1,5891 kg	3	4	Upper/ 0.2008 gr. Lower/ 0.1564 gr.	1,9463 kg	3003 H121 1/4 hand
Plastic	2.5 mm	777*590mm	1,440 kg	1,340 kg	3	4	Only Upper/ 0.110 gr. Accessories / 0.225 gr.	1,675 kg (with the accessories)	Poly propylene

Table (2): Aluminum Alloy 3003 Properties (Aluminum,2003)

1	Density	2.7
2	Thermal Conductivity	237
3	Expansion Coefficient	23.1
4	Melting Point	660°C

Table (3) Galvanized steel physical properties (steel structure designer handbook , 1999)

1	Density	8.22
2	Thermal Conductivity	40
3	Expansion Coefficient	13.9
4	Melting Point	1355°C

3.3 Polypropylene

Polypropylene PP is a thermoplastic polymer. This polymer is used in an extensive diversity of applications which might be packaging and labeling, textiles such as ropes, thermal underwear and carpets. Other applications are for recyclable containers of different styles, laboratory kits, loudspeakers, motorized machine ries, in addition to polymer. Additionally polymer prepared depending the monomer propylene is rough; oddly resist numerous chemical solvents besides bases and acids. The physical properties of poly propylene are shown in Table (4).

Table (4): The physical properties of polypropylene (Polymer , 1999)

1	Density	0.964
2	Thermal Conductivity	0.16
3	Expansion Coefficient	13
4	Melting Point	160°C

4. Merit Index .

Using the physical properties mentioned above the Merit Index is calculated **(Michael , 2005 ; Van *et.al.*, 2007)**. Calculating the Merit Index 1 for each material and density regarded as 8.22is the largest density according to the Reference as shown in Table (5).

Table (5): Merit Index 1 for each material with density 8.22

NO	Material	Density g/cm^3	MI1
1	Al	2.7/8.22	0.328
2	Pp	0.946/8.22	0.115
3	Fe	8.22/8.22	1

Calculating the Merit Index 2 for each material and melting point regarded as 1355°C as the greatest melting point according to the Reference, the results are shown in Table (6).

Table (6): Merit Index 2 for each material with melting point 1355°C

NO	Material	Melting Point °C	MI2
1	Al	660/1355	0.487
2	Pp	160/1355	o.118
3	Fe	1355/1355	1

Calculating the Merit Index 3 for each material and thermal conductivity regarded as 237 is the greatest thermal conductivity according to the Reference, the results are shown in Table (7).

Table (7): Merit Index 3 for each material with thermal conductivity 237

NO	Metal	Thermal Conductivity Watt/m/Kelvin	MI3
1	Al	237/237	1
2	Pp	0.16/237	0.00067
3	Fe	40/237	0.146

Calculating the Merit Index4 for each material and Expansion Coefficient regarded as 23.1 is the largest Expansion Coefficient according to the Reference, the results are shown in Table (8).

Table (8): Merit Index4 for each material with Expansion Coefficient 23.1

NO	Material	Expansion Coefficient	MI4
1	Al	23.1/23.1	1
2	Pp	13/23.1	0.563
3	Fe	3.9/23.1	0.169

Calculating the total merit index for each material, the results are shown in Table (9).

Table (9): Total Merit Index for each material

NO	Material	MI1	MI2	MI3	MI4	(Total Merit Index) *100%
1	Al	0.328	0.487	1	1	281.5
2	Pp	0.115	0.118	0.00067	0.563	79.7
3	Fe	1	1	0.146	0.169	231.5

Depending the results for total Merit Index in table (9), it is shown that Aluminum is the best choice and due to our case is a special one, the comparison is made by taken different materials as shown in Tables(5)-(9) to observe the best one for manufacturing the cooler's window.

5. Corrosion Test

To perform corrosion test the following steps are done **(Van *et.al.*, 2007)**:

1- The liquid medium in which flooding will be done is prepared the laboratory in the University of Technology/ Baghdad, which contains (35) grams of seawater and (3.5%) of sodium chloride with distilled water (1000 grams). PH meter is used to measure PH and it was (6.9).

2- Electro-chemical corrosion is performed by Tafel's process, which involves passing an electrical current on an electro-chemical cell containing:

a- Positive pole indicating the tested specimen.

b- Negative pole indicating the pole that the electrons are released to form the anode pole, platinum component is used as a pole in the cell.

c- Electrolyte depending sea-water.

d- An electrical current source.

Electrical current is passed at a defined potential based on the metal type as shown in figure (2) (The Electro-chemical Cell). When the current passes, the potential variance will be changed, which indicates that corrosion is caused due to it. This measurement represents the corrosion average, according to Tafel Method depending the corrosion current and adopting contactors for the anodic and cathodic metals behaviors. Intersection point in the graphs denotes the corrosion current. The results are illustrated in figures (3), (4) and (5).

Figure (2)The Electrochemical Cell

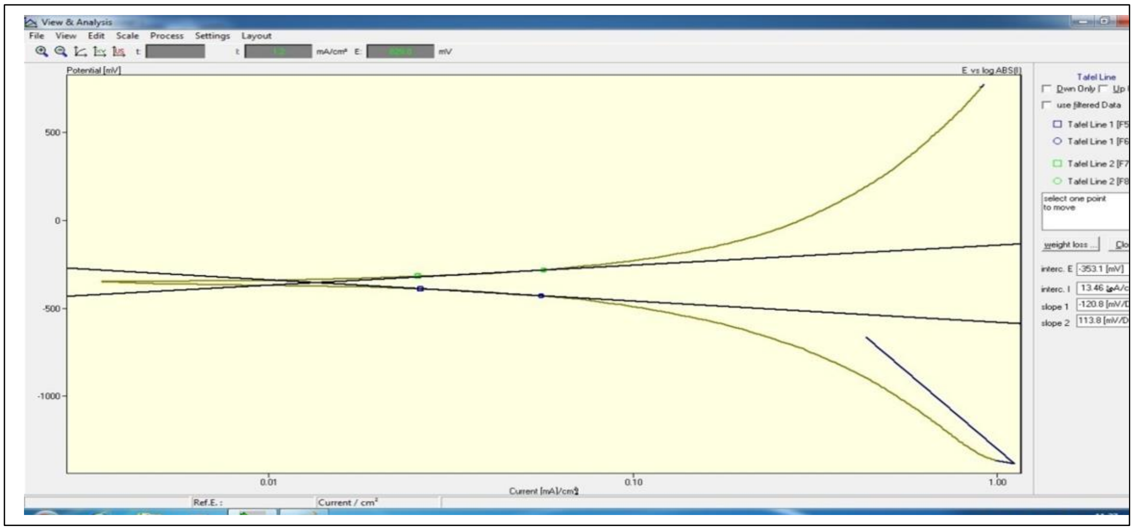


Figure (3):Tafel polt of Aluminum 3003 alloy/seawater system

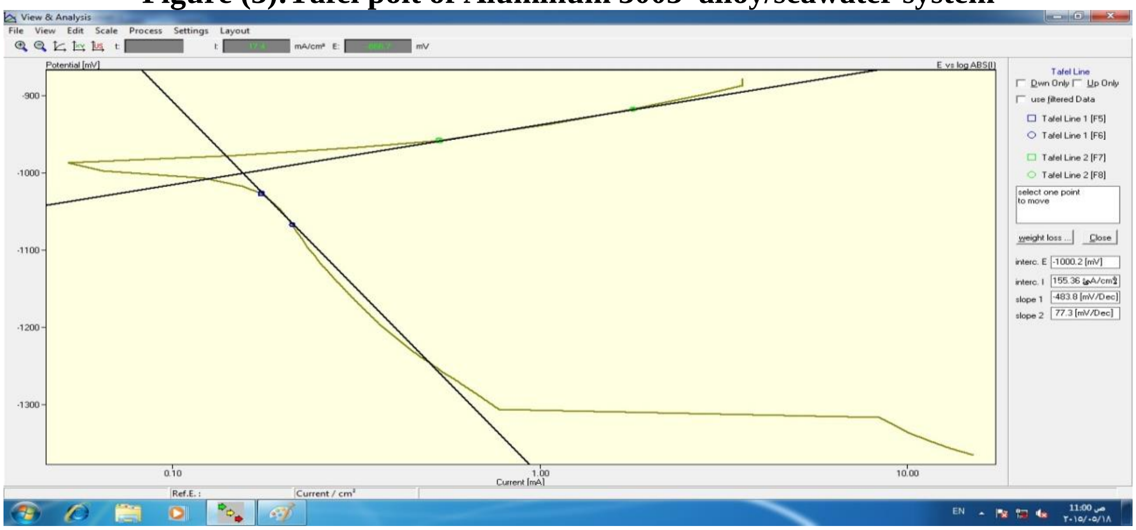
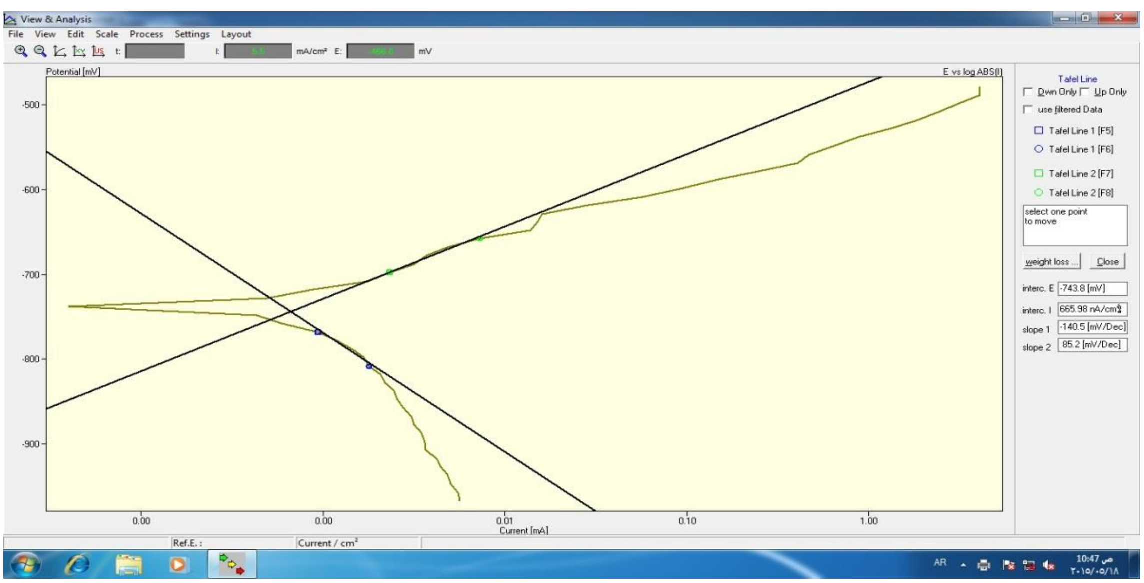


Figure (4): Tafelpolt of galvanized steel /seawater system



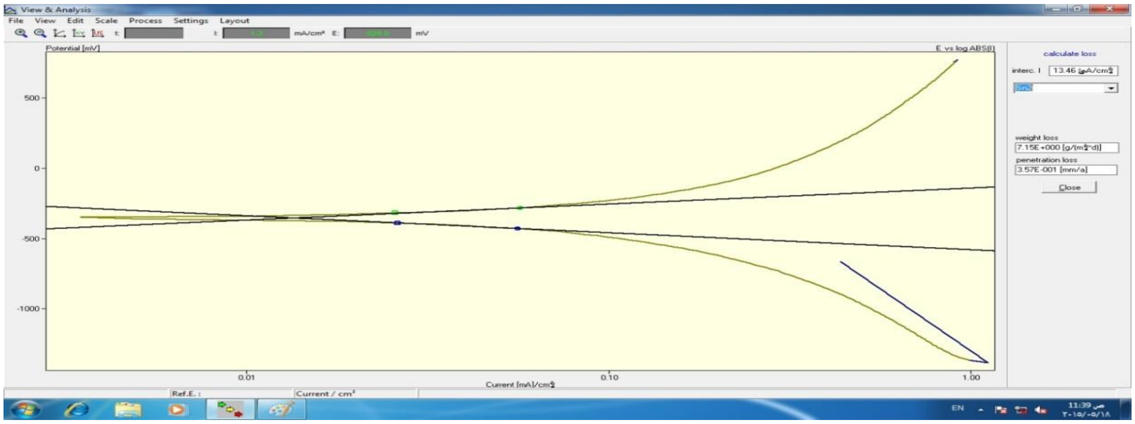


Figure (5):Tafel Polt Of Polypropylene /Seawater System

The corrosion results can be shown in Table (10) which illustrate that Polypropylene is the best choice; This results differs from the results due to Merit index shown in table (9).

Table (10): Corrosion Results

	E_{cor} (mV)	I_{cor} (mA)
Galvanized Steel	**-1000**	**155.36**
Aluminum	**-353**	**13.46**
Polypropylene	**-743.8**	**Nano 665.98**

6. ANSYS Analysis

Simulation using ANSYS software supports establishments to predict their products operation in the actual environment confidently. Numerical simulations allow the analysis of a complex phenomenon avoiding costly patterns and different investigational measurements **(ANSYS, 2013)**. This software package is used for analyzing finite elements and solves an extensive range of different cases, such as the pipe structural analysis, the fluid flow analysis and the fluid-structure interaction problem.

In this work ANSYS is adopted using the three samples for the selected materials Aluminum, Galvanized steel and polypropylene. Maximum stress and deflection are measured in three samples of each material using samples with thickness 0.7mm, 1mm, 2.5 mm. The results are shown in tables (11), (12) and (13) which summarize the outputs of ANSYS shown in figures (6), (7) and (8); these figures are well illustrated in appendices A, B and C.

Table (11): ANSYS Results for Aluminum

Thickness	Deflection-Stress	position			
		First	Second	Third	Forth
0.7	Deflection (mm)	0.096634	0.096634	0.096634	0.096634
	Equivalent stress (MPa)	0.096634	0.837727	0.837727	0.096634
1	Deflection (mm)	0.058723	0.058723	0.058723	0.058723
	Equivalent stress (MPa)	0.058723	0.594122	0.594122	0.058723
2.5	Deflection (mm)	0.010277	0.010277	0.010277	0.010277
	Equivalent stress (MPa)	0.010277	0.172614	0.172614	0.010277

Table (12): ANSYS Results for Galvanized steel

Thickness	Deflection-Stress	Position			
		First	Second	Third	Forth
0.7	Deflection (mm)	0.058623	0.058623	0.058623	0.058623
	Equivalent stress (MPa)	0.058623	1.21838	1.21838	0.058623
1	Deflection (mm)	0.03259	0.03259	0.03259	0.03259
	Equivalent stress (MPa)	0.03259	0.811994	0.811994	0.03259
2.5	Deflection (mm)	0.004266	0.004266	0.004266	0.004266
	Equivalent stress (MPa)	0.004266	0.189852	0.189852	0.004266

Table (13): ANSYS Results for Polypropylene

Thickness	Deflection-Stress	Position			
		First	Second	Third	Forth
0.7	Deflection (mm)	3.84335	3.84335	3.84335	3.84335
	Equivalent stress (MPa)	3.84335	1.21751	1.21751	3.84335
1	Deflection (mm)	2.13698	2.13698	2.13698	2.13698
	Equivalent stress (MPa)	2.13698	0.808362	0.808362	2.13698
2.5	Deflection (mm)	0.279591	0.279591	0.279591	0.279591
	Equivalent stress (MPa)	0.279591	0.208896	0.208896	0.279591

For the same boundary condition and load, it can be seen that the max. Deflection and equivalent stress for the three types of materials are as shown in table (14). It could be noticed that Aluminum alloy 3003 is the best choice for the three samples with different thicknesses when comparing maximum equivalent stress. But Galvanize steel is the best when taking into consideration the maximum deflection results.

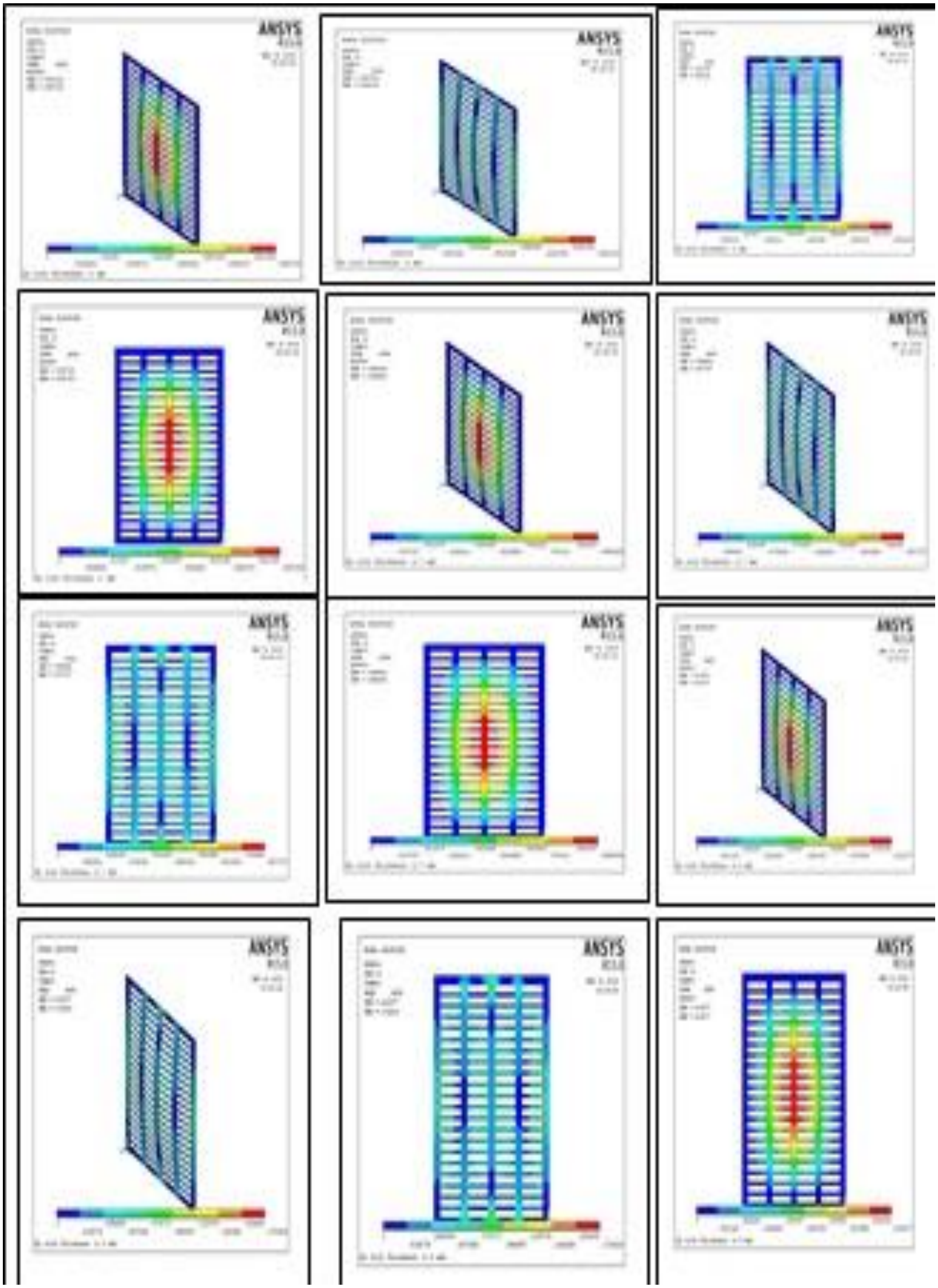


Figure (6): ANSYS for Aluminum

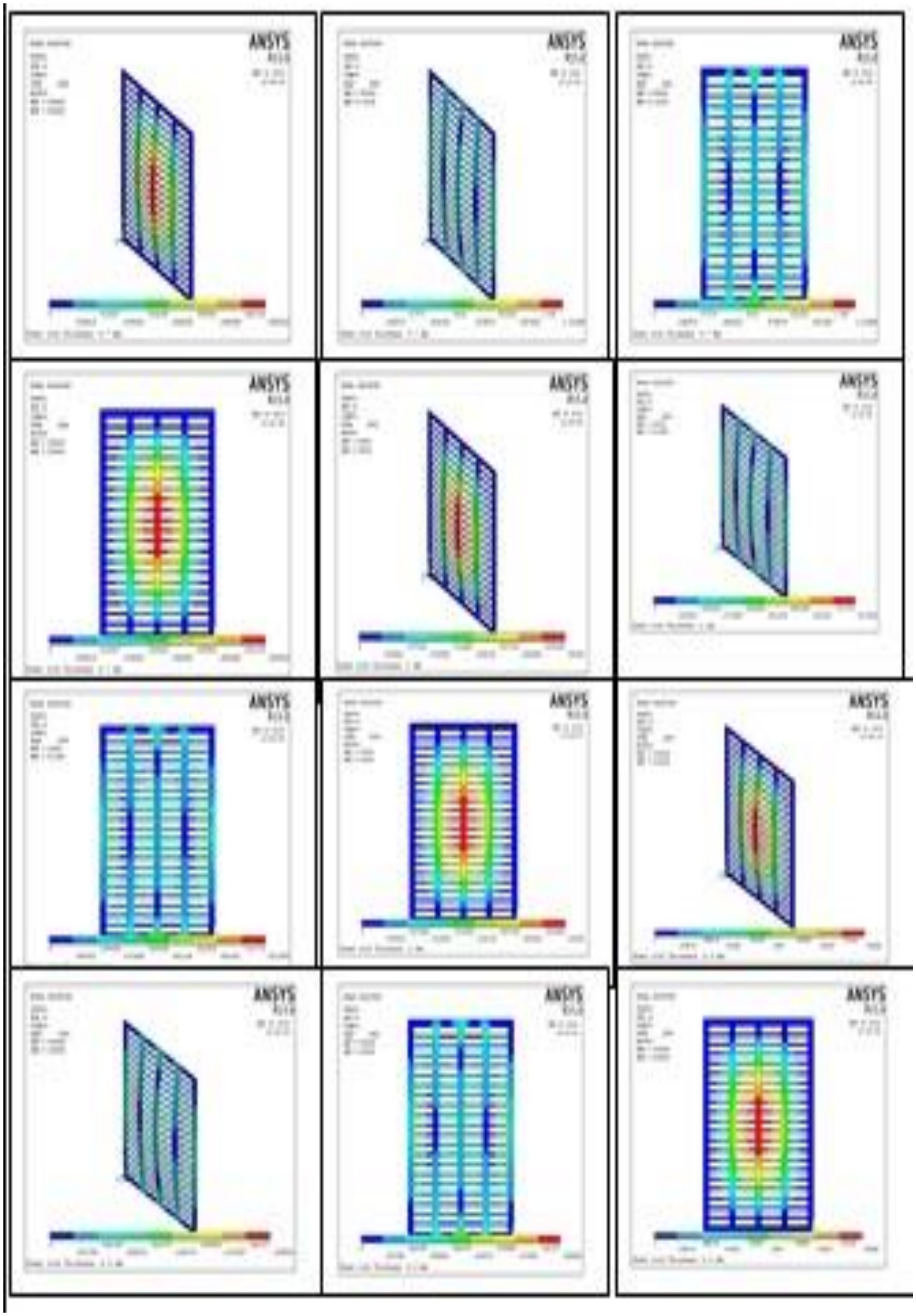


Figure (7): ANSYS for Galvanized Steel

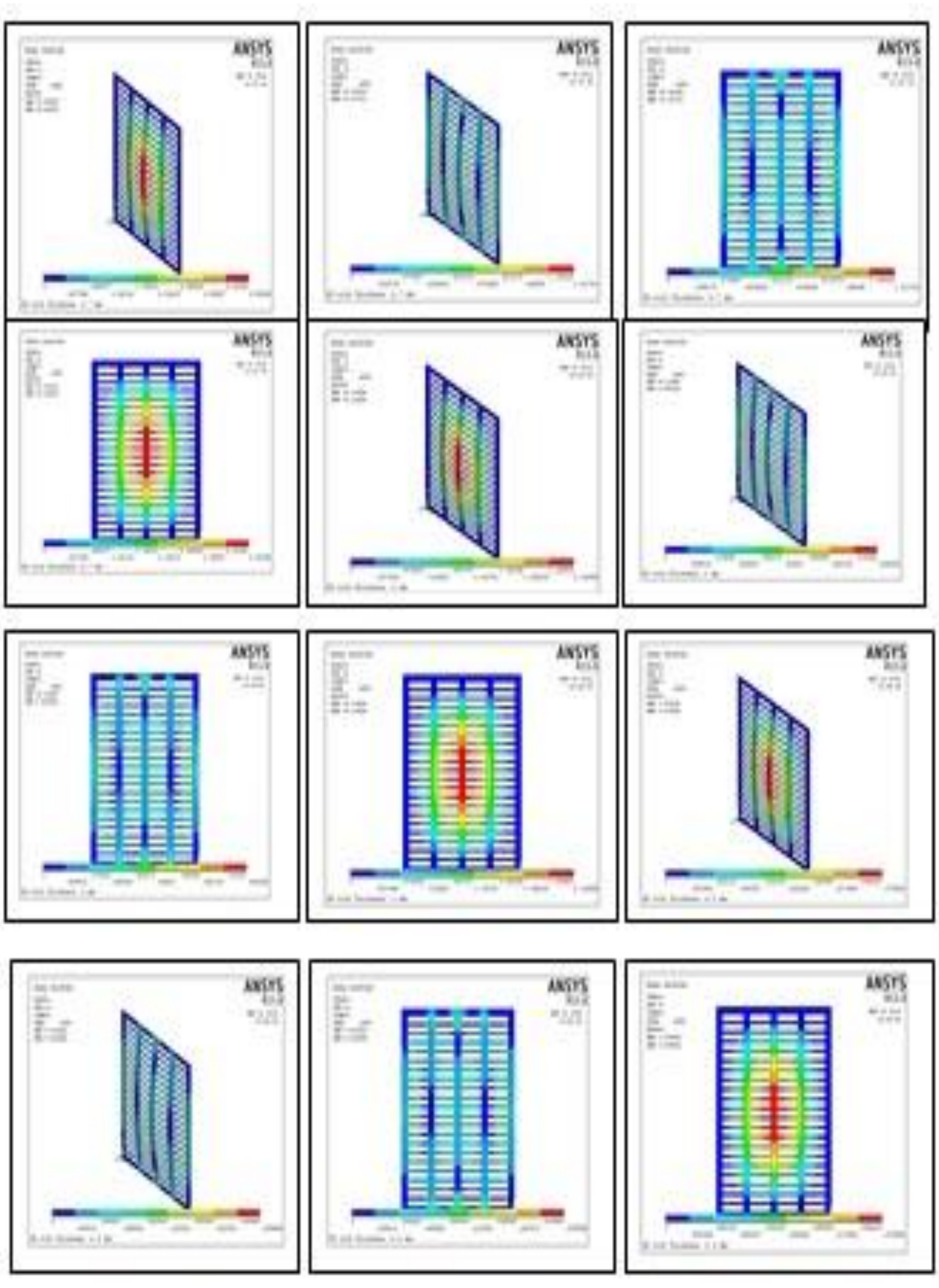


Figure (8): ANSYS for Polypropylene

Table (14): Max. Deflection and Equivalent Stress for the Three Type of Materials

Material type	Thickness (mm)	Max. deflection (mm)	Max. equivalent stress (Mpa)
Galvanized Steel	**0.7**	0.058623	1.21838
	1	0.03259	0.811994
	2.5	0.004266	0.189852
Aluminum alloy 3003	0.7	0.096634	0.837727
	1	0.058722	0.594122
	2.5	0.010277	0.172614
Polypropylene	0.7	3.84335	1.21751
	1	2.13698	0.808362
	2.5	0.279591	0.208896

6. Cost, Shape and Other Factors

To perform cost and shape factors comparison regarding the product under study, it is noticed in table (1) about the technical specification for air cooler window that the dimension is the same for the three selections, which means that the size is the same and doesn't affect the best selection. Regarding the weight for the product it is noticed from table (1) that the galvanized steel weight is 4.560 kg, the aluminum weight is 1.9463 kg, while the weight for the Polypropylene is 1.675 kg; which means that Polypropylene is the best choice regarding the weight factor. Electricity consumption depends on the type of the used motors which is not considered in this study. Regarding the cost which is an important factor for selection under the competitive environment, it is noticed that the cost of the aluminum window is 4.5738 $, the steel galvanize window's cost is 3.648 $ and the polypropylene window's cost is 3.35 $. These results are summarized in table (15). Beside that the effect of weight is observed from Table(15) where Galvanized steel has more weight than Aluminum alloy and polypropylene since the density of each other are different which means that Galvanized steel is better regarding vibration test which is not considered in this study.

Table (15):Size, Cost and other factors

Material type	Size (mm)	Shape	The product's weight (kg)	Electricity consumption	The product's cost ($)
Galvanized Steel	**777*590**	**Identical**	**4.560**	**depends on the type of the used motors**	**3.648**
Aluminum alloy 3003	**777*590**	**Identical**	**1.9463**	**depends on the type of the used motors**	**4.5738**
Polypropylene	**777*590**	**Identical**	**1.675**	**depends on the type of the used motors**	**3.35**

7. Discussion and conclusion

According to the previous experiments and calculations for the three types of materials Aluminum, Galvanized steel and polypropylene regarding the shape, cost, weight, Merit Index, Corrosion resistance using Tafel . Method and Maximum equivalent stress and deflection using ANSYS software; it could be noticed that Aluminum alloy 3003 is the best choice depending merit index and maximum stress. Polypropylene is regarded as the best choice depending weight factor, cost and corrosion resistance, while the results for ANSYS depending the maximum deflection pointed to the galvanized steel as the better choice. The other factors are identical to the three samples of Aluminum alloy3003, galvanized steel and Polypropylene used for manufacturing the windows of air coolers.

References

"ANSYS Structural Analysis Guide", 2013 , ANSYS Release 15.0, ANSYS Inc.

Brandrup J., Immergut E. H., and Grulke E. A. , 1999 , " Ploymer Handbook".

David J. A. and Wesley R. B.,1993 ," Material Selection Processes in the Automotive Industry", University of Michigan Transportation Research Institute.

Entsar . N. , 2009 , "The Influence of Heating Temperature on Corrosion Resistance of High Strength Al- Alloys 7020 ", M.Sc. thesis, University of Technology.

Eugene. A; Theodore . B. and ALI.S., 2007 ," Standard Handbook for Mechanical Engineers" , Eleventh Edition , New York, McGraw-Hill.

George E. Tot ten and D. Scott MacKenzie , 2003 , " Handbook of Aluminum".

Hammer. M and Champy . J. , 1993 , "Re-engineering the Corporation", Harper Business Ibuchim . O and Junli .Y., 2012 ," Investigating Factors Affecting Material Selection: The Impacts on Green Vernacular Building Materials in the Design-Decision Making Process", Buildings , 2, 1-32.

Jeremy. G . 2005 , " A Brief Overview of a Systematic Methodology", Laboratory for Energy and Environment.

Maleque[1] M.A., S.Dyuti2 and Rahman . M.M. , 2010 , "Material Selection Method in Design of Automotive Brake Disc", Proceedings of the World Congress on Engineering .

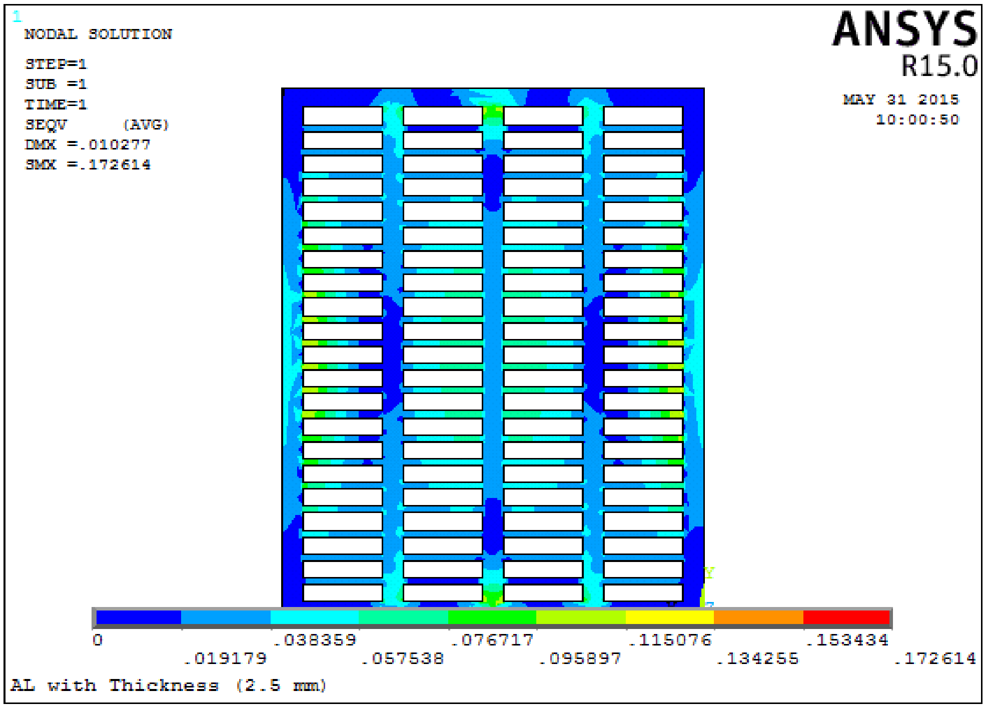
Michael .F. , 2005 , "Materials Selection in Mechanical Design", third edition, Elsevier

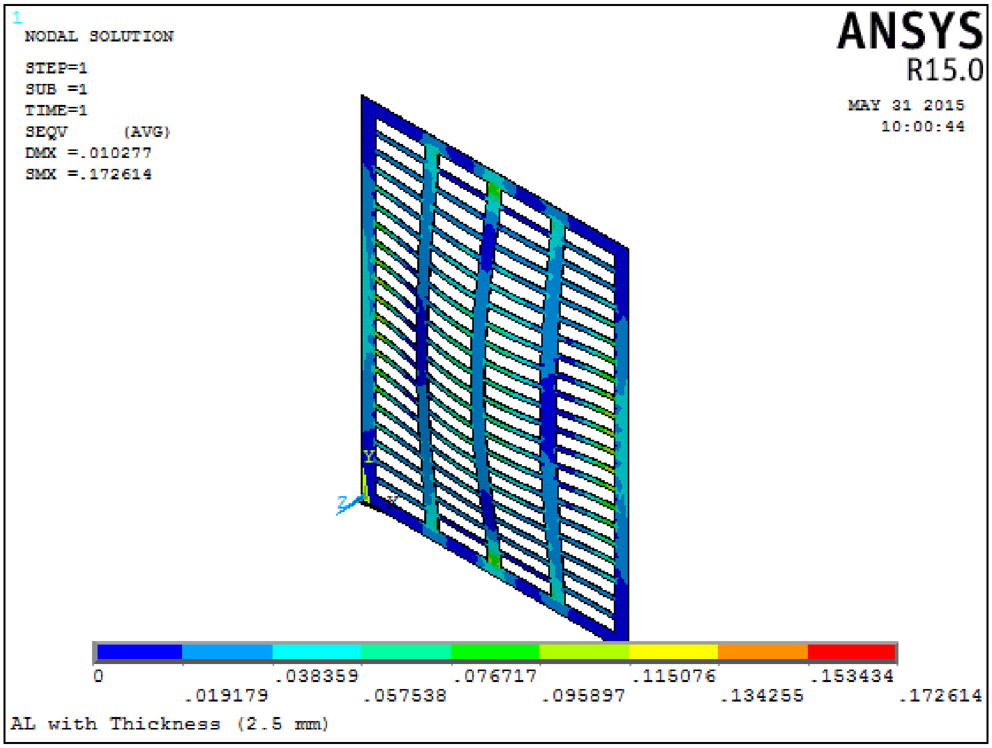
Michael F. A. , 1999 , " Materials Selection in mechanical design ", second edition , Pergamon Press Ltd

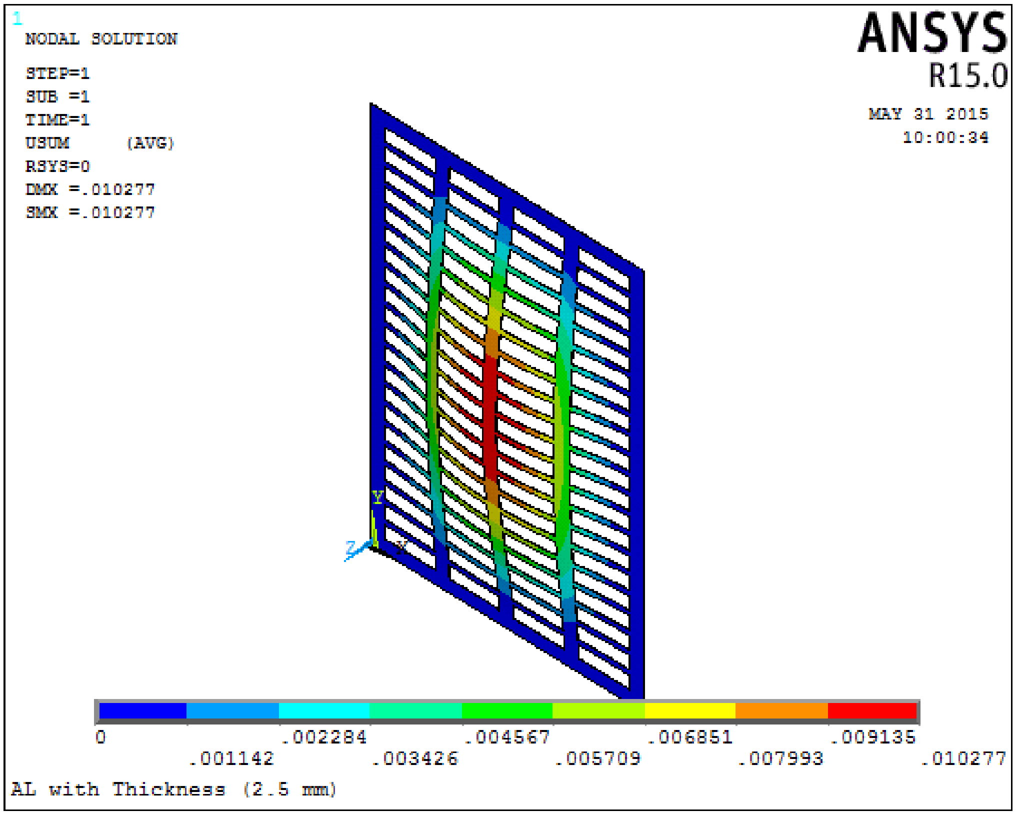
Roger L. Brockenbrough and Frederick S. Merritt , 1999 , "steel structure designer handbook".

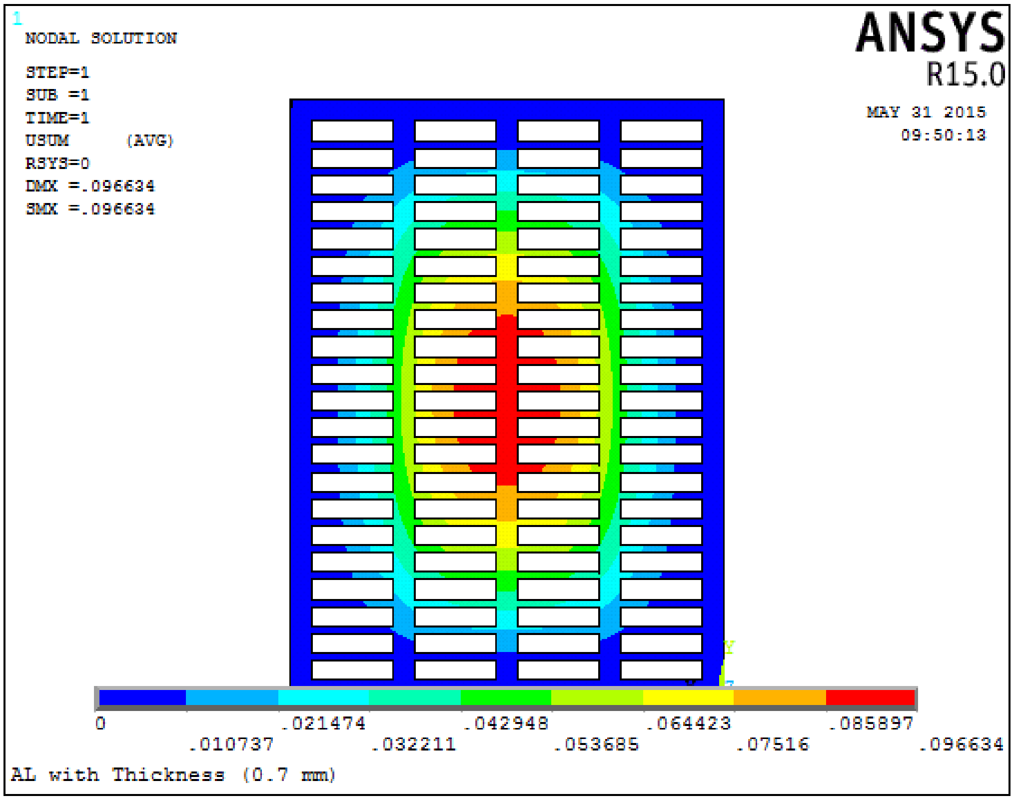
Van. K; Stappers. P and Bruijn .J., 2007 ," Materials in Products Selection: Tools for Including User-Interaction in Materials Selection ", international journal of design Vol 1, NO.3.

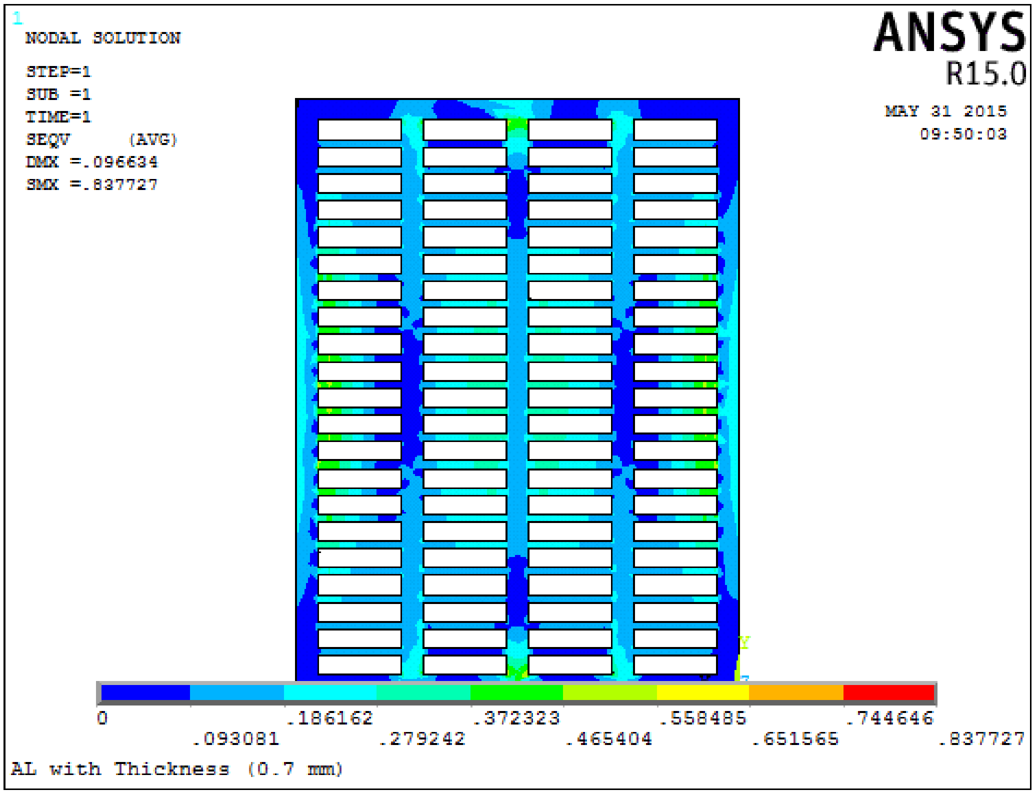
APPEDIX A: Illustration for Figure (6) ANSYS for Aluminum

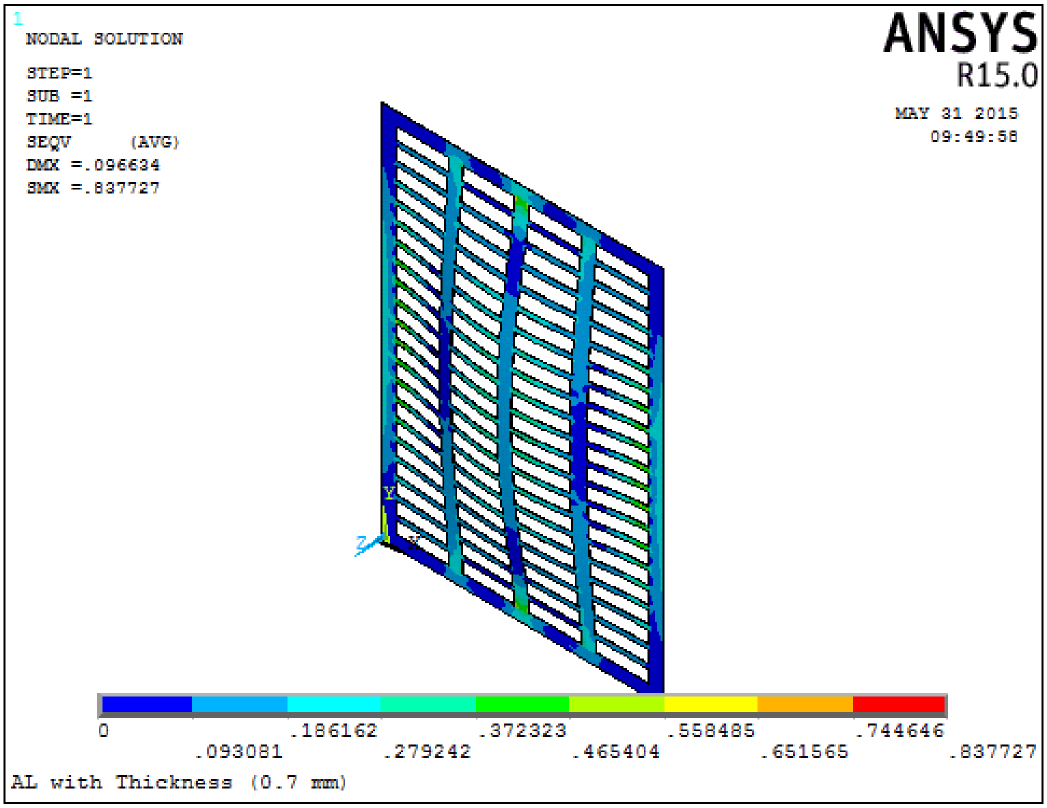


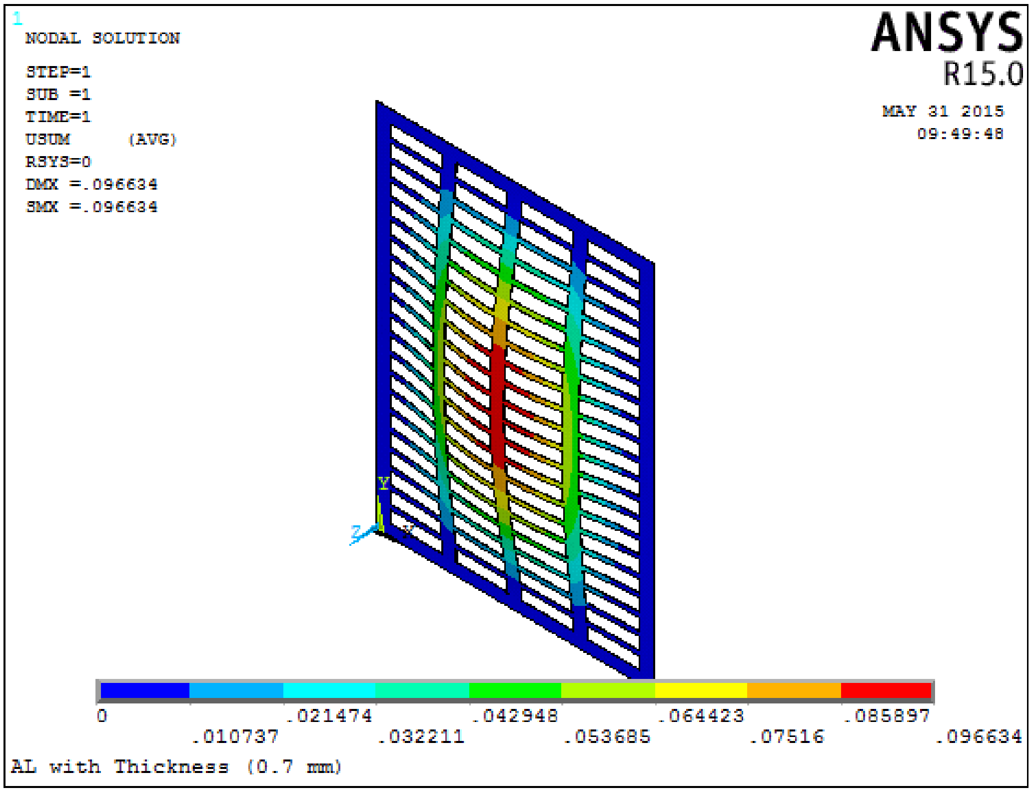


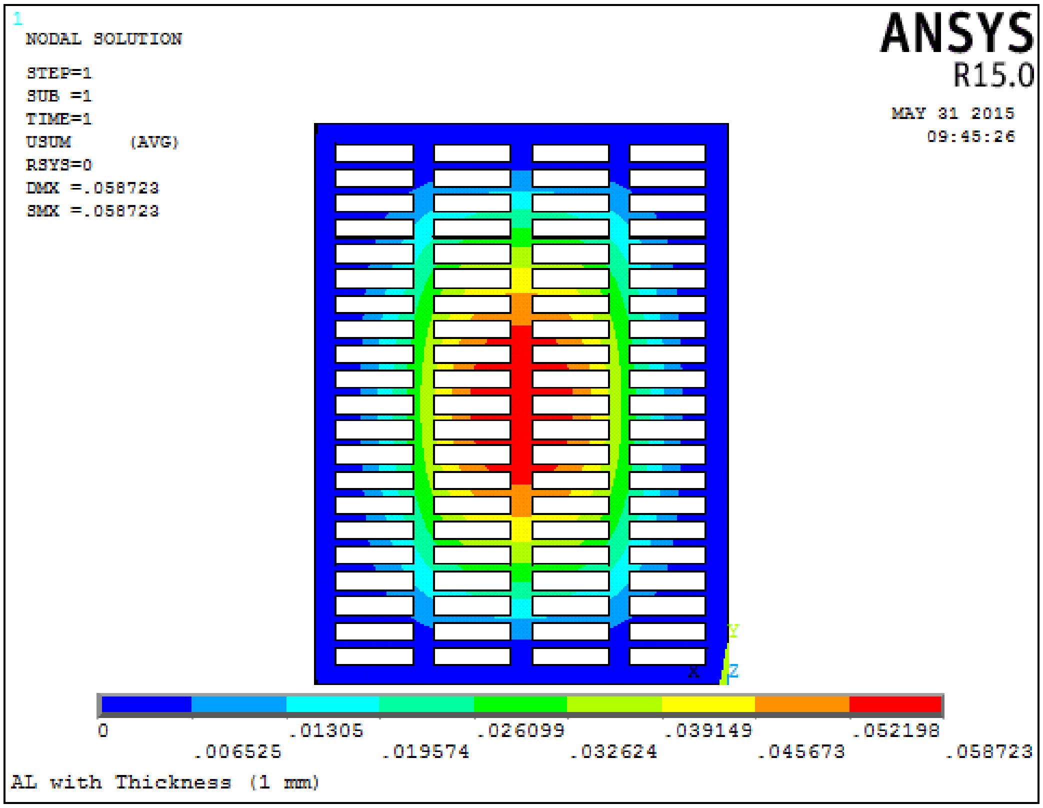

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.010277
SMX =.010277
ANSYS
R15.0
MAY 31 2015
10:00:34
0
.001142
.002284
.003426
.004567
.005709
.006851
.007993
.009135
.010277
AL with Thickness (2.5 mm)

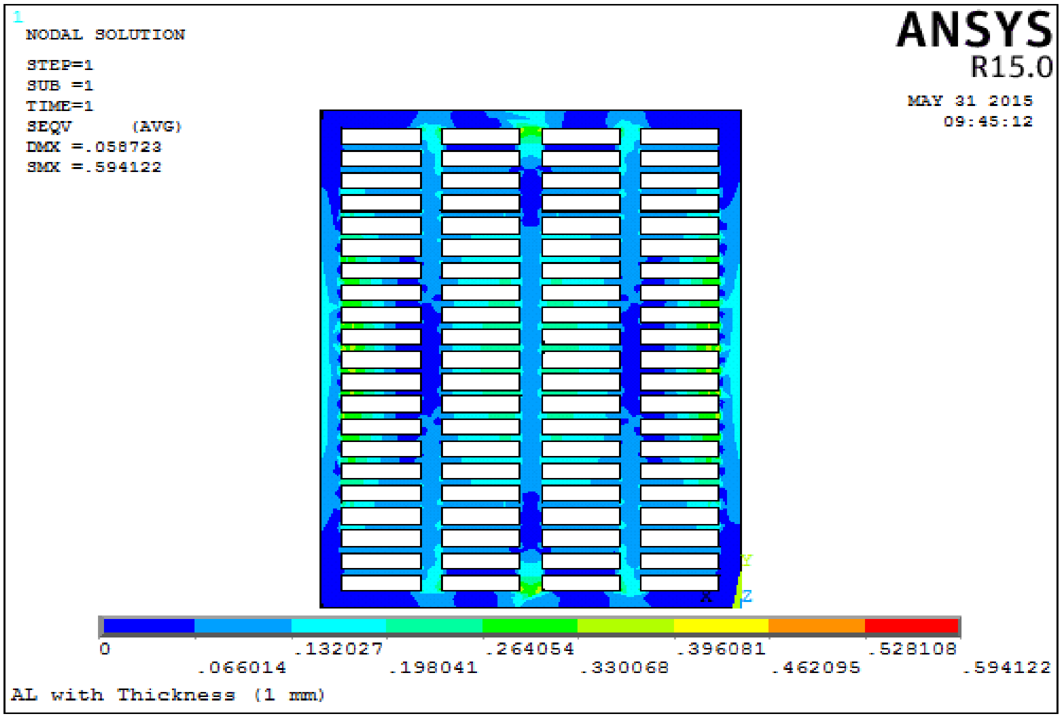

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.096634
SMX =.096634
ANSYS
R15.0
MAY 31 2015
09:50:13
0
.010737
.021474
.032211
.042948
.053685
.064423
.07516
.085897
.096634
AL with Thickness (0.7 mm)

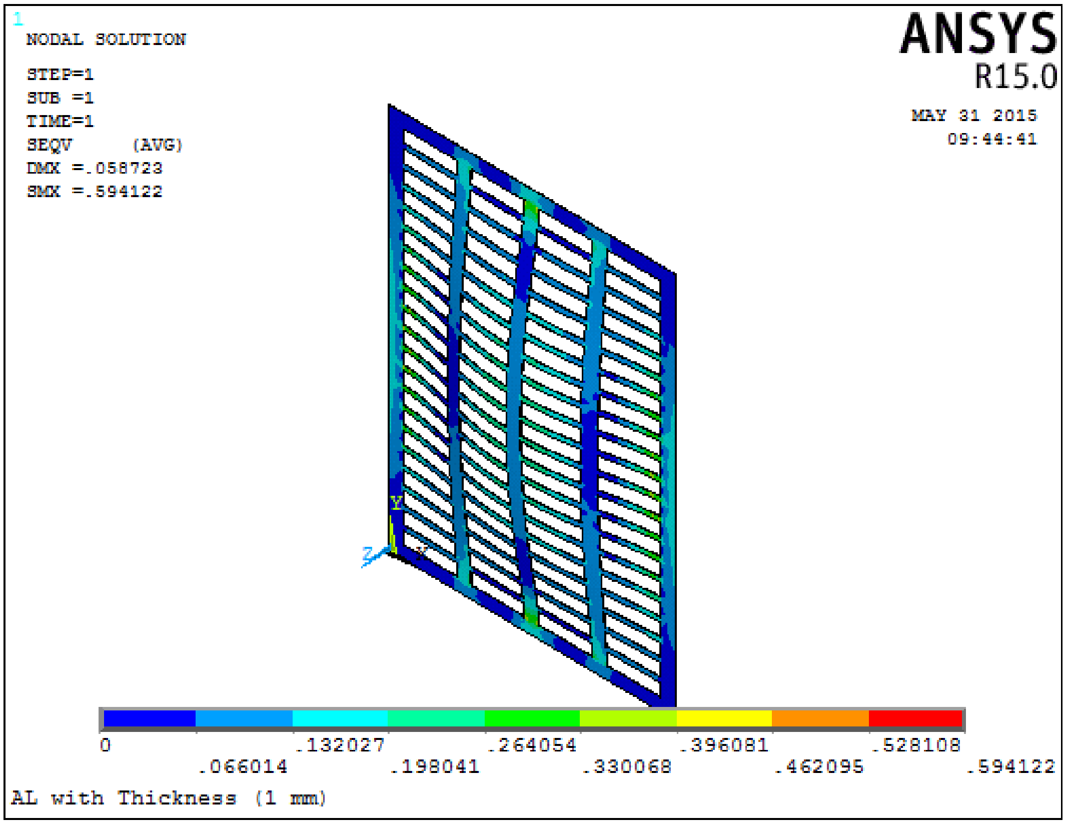

NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.096634
SMX =.837727
ANSYS
R15.0
MAY 31 2015
09:50:03
0
.093081
.186162
.279242
.372323
.465404
.558485
.651565
.744646
.837727
AL with Thickness (0.7 mm)

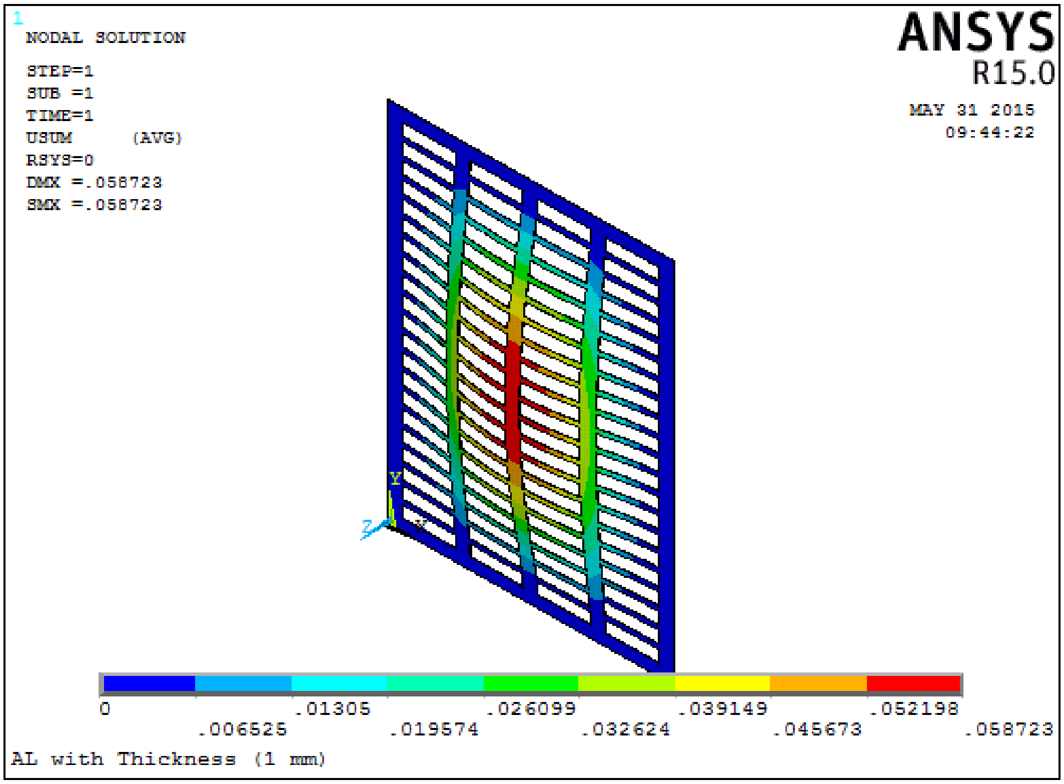

NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.096634
SMX =.837727
ANSYS
R15.0
MAY 31 2015
09:49:58
0
.093081
.186162
.279242
.372323
.465404
.558485
.651565
.744646
.837727
AL with Thickness (0.7 mm)

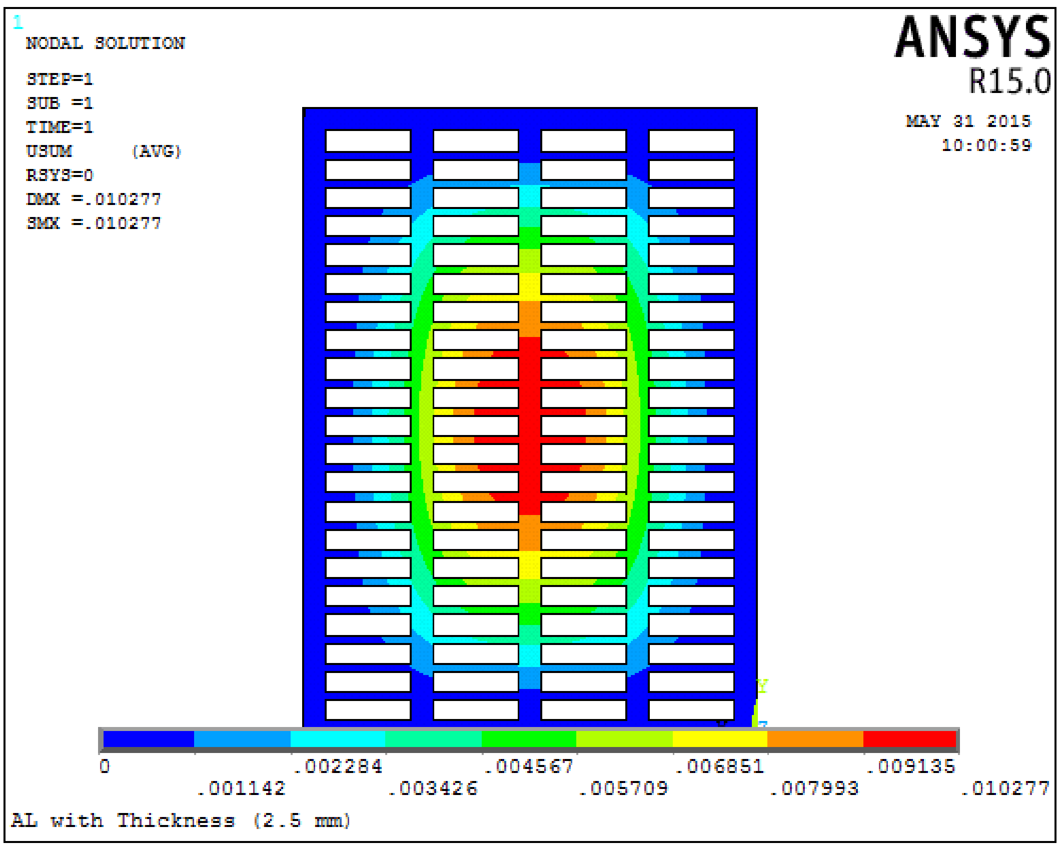

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.096634
SMX =.096634
ANSYS
R15.0
MAY 31 2015
09:49:48
0
.010737
.021474
.032211
.042948
.053685
.064423
.07516
.085897
.096634
AL with Thickness (0.7 mm)


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.058723
SMX =.058723
ANSYS
R15.0
MAY 31 2015
09:45:26
0
.006525
.01305
.019574
.026099
.032624
.039149
.045673
.052198
.058723
AL with Thickness (1 mm)

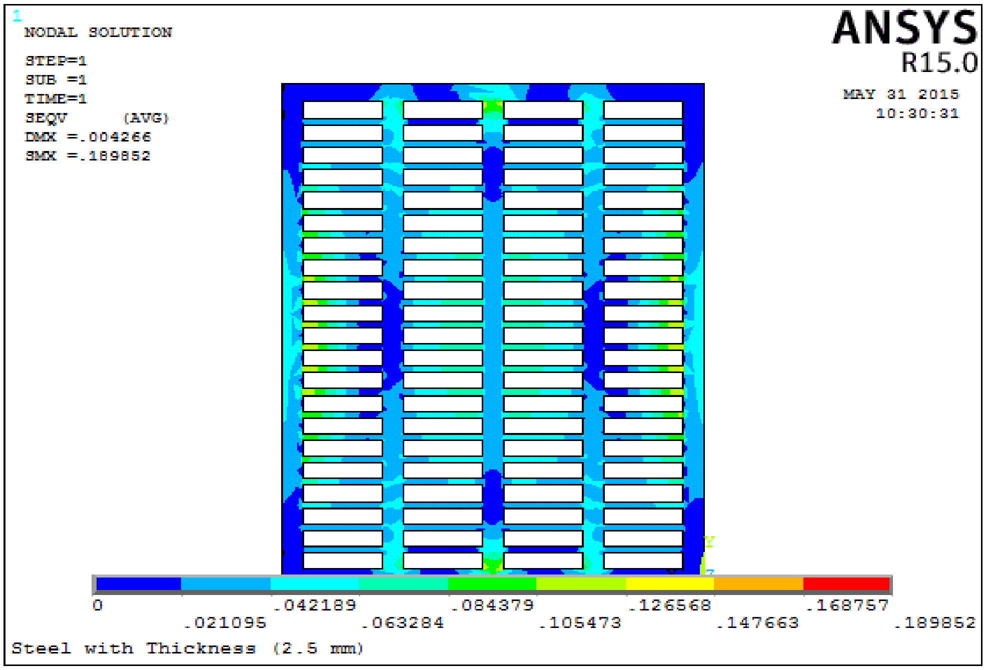

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.058723
SMX =.594122
ANSYS
R15.0
MAY 31 2015
09:45:12
0
.066014
.132027
.198041
.264054
.330068
.396081
.462095
.528108
.594122
AL with Thickness (1 mm)

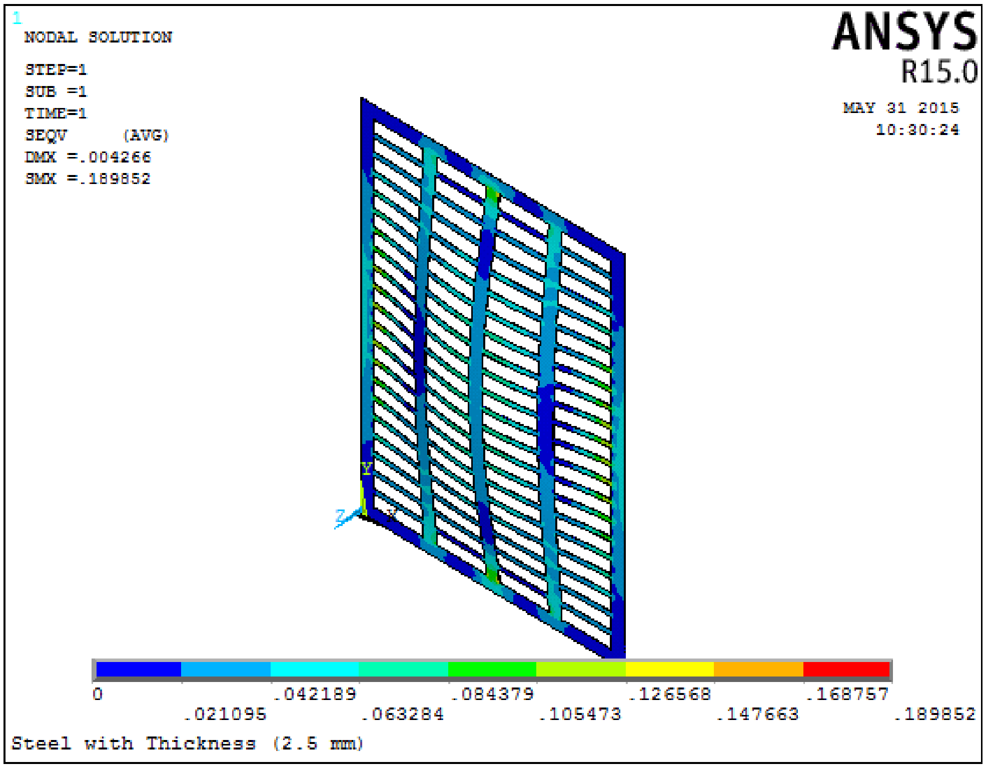

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.058723
SMX =.594122
ANSYS
R15.0
MAY 31 2015
09:44:41
0
.066014
.132027
.198041
.264054
.330068
.396081
.462095
.528108
.594122
AL with Thickness (1 mm)

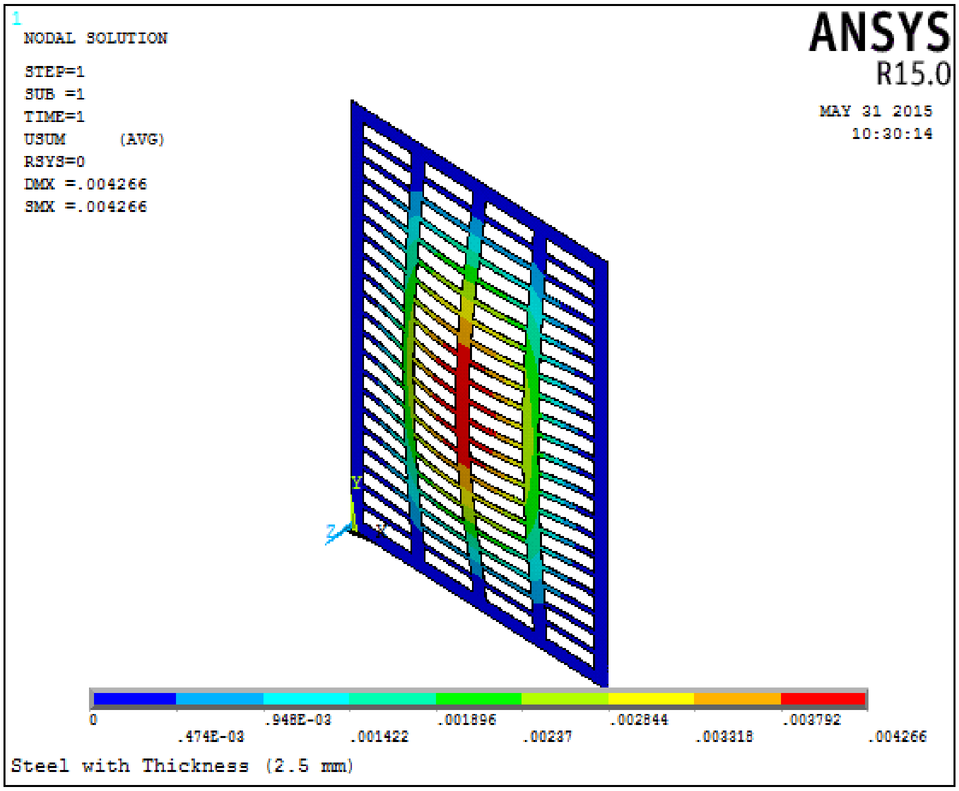

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.058723
SMX =.058723
ANSYS
R15.0
MAY 31 2015
09:44:22
Y
Z
X
0
.006525
.01305
.019574
.026099
.032624
.039149
.045673
.052198
.058723
AL with Thickness (1 mm)

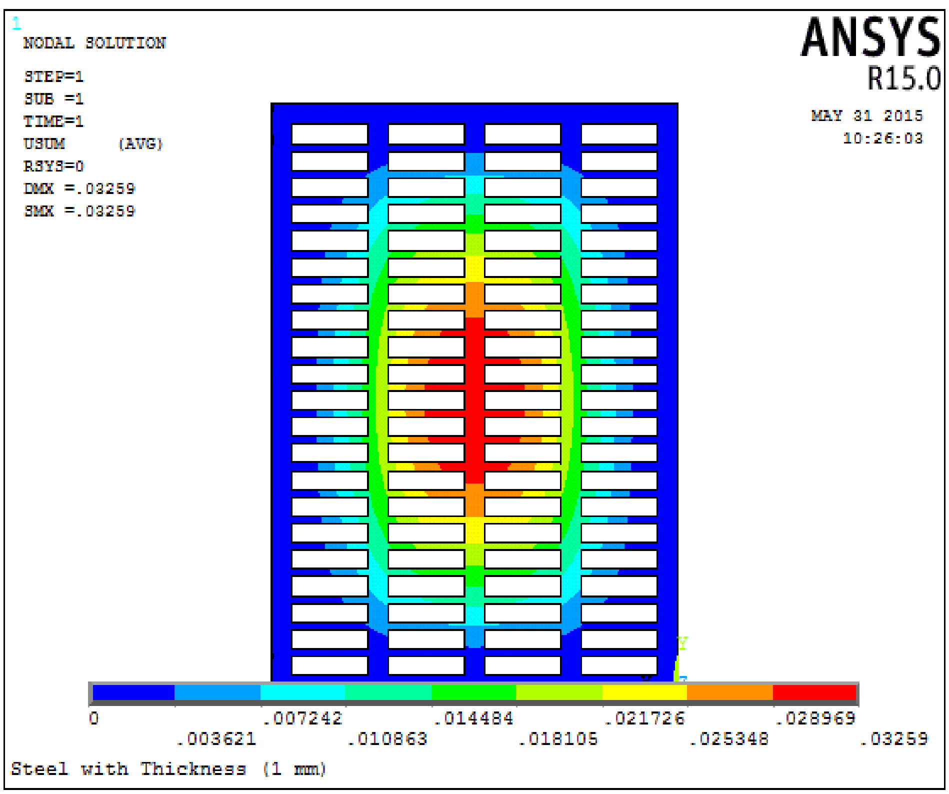

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.010277
SMX =.010277
ANSYS
R15.0
MAY 31 2015
10:00:59
Y
0
.001142
.002284
.003426
.004567
.005709
.006851
.007993
.009135
.010277
AL with Thickness (2.5 mm)

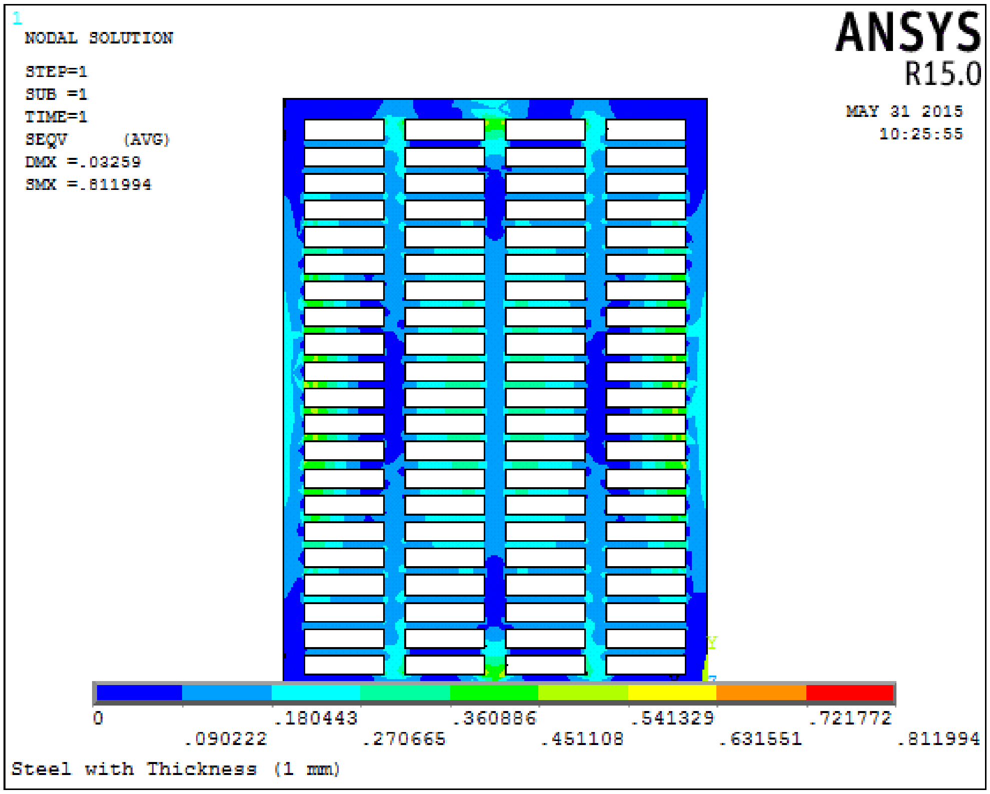
APPEDIX B: Illustration for Figure (7) ANSYS for Galvanized Steel

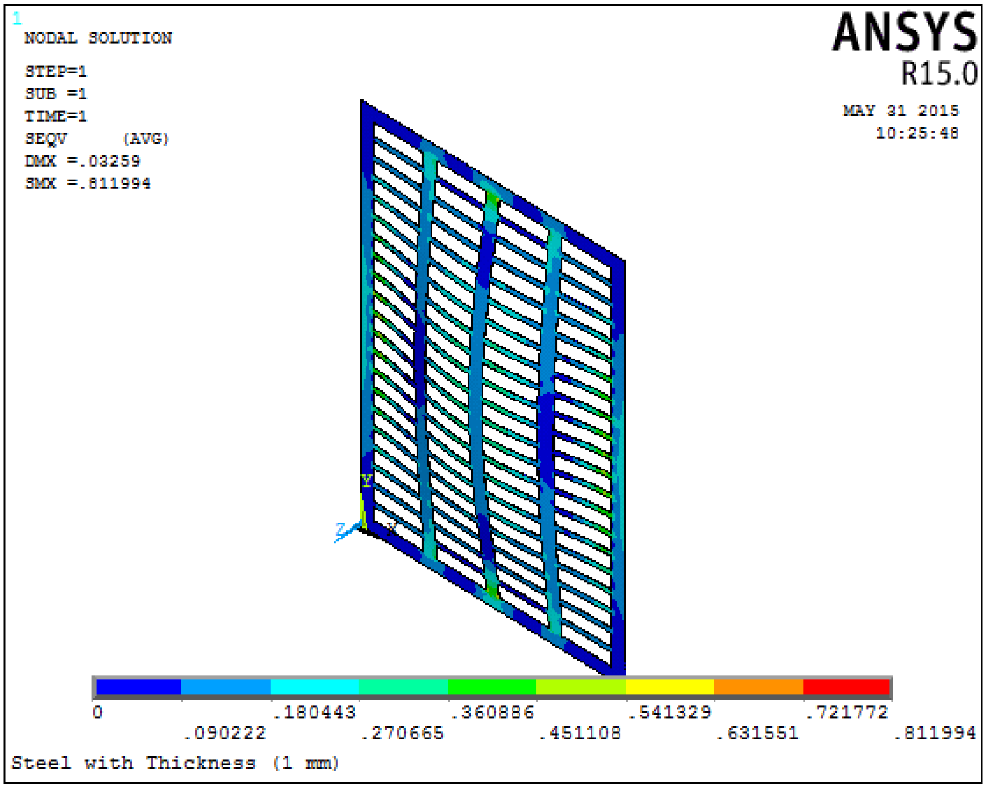


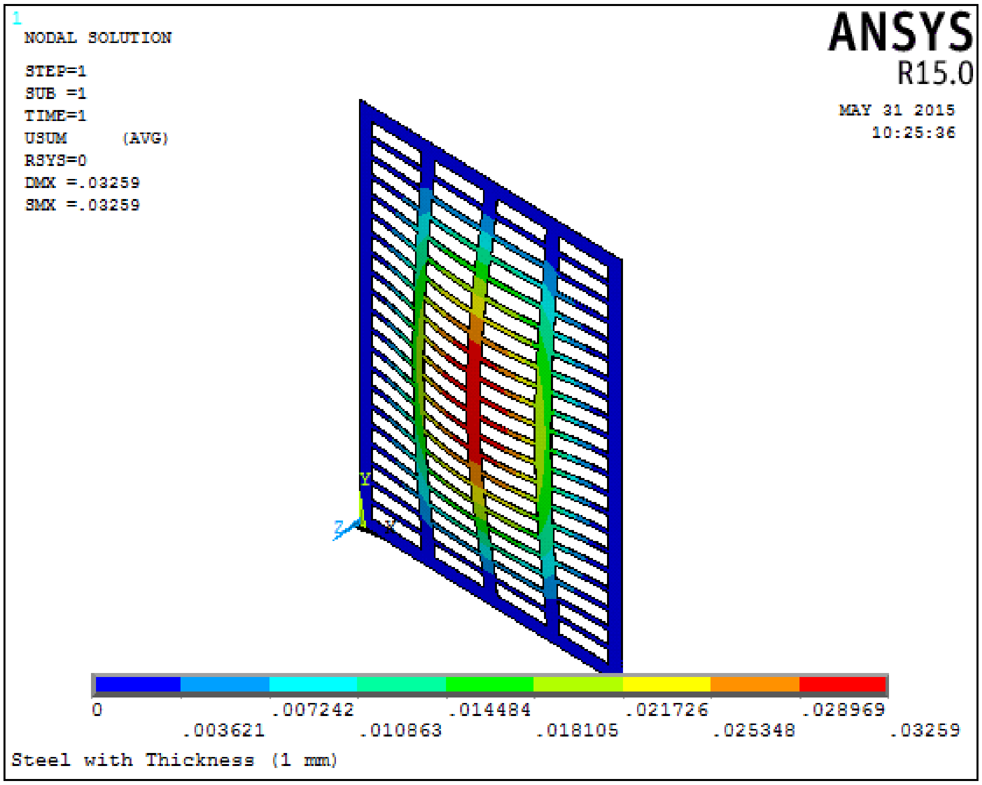


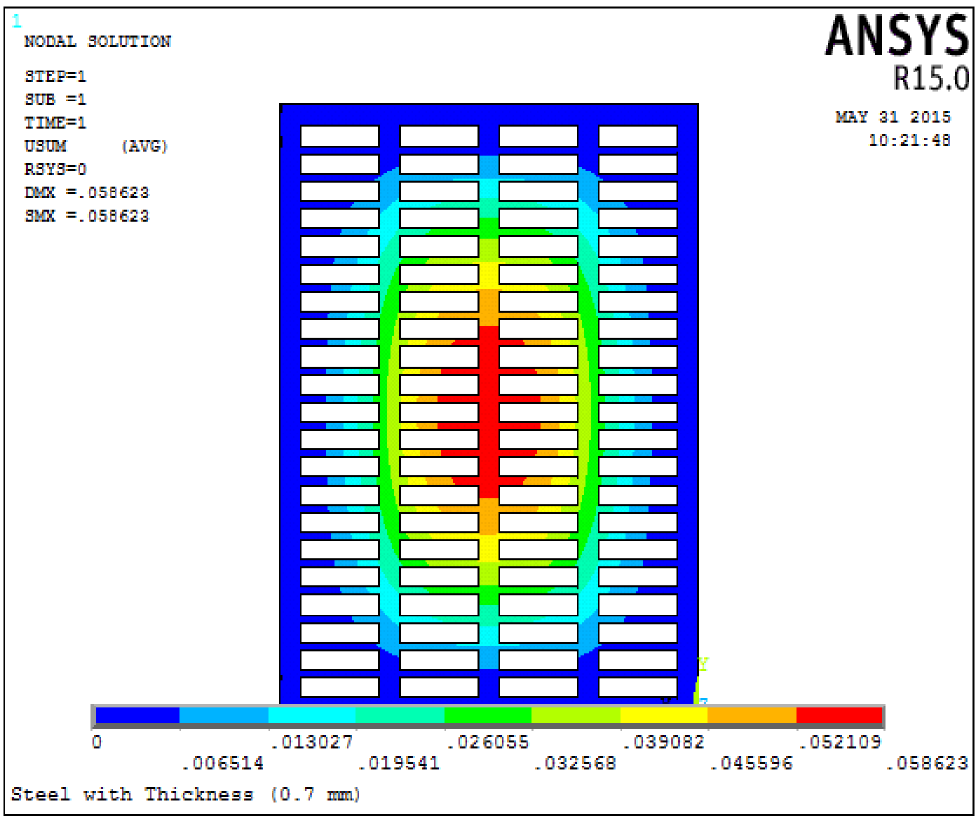

NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.004266
SMX =.004266
ANSYS
R15.0
MAY 31 2015
10:30:14
0
.474E-03
.948E-03
.001422
.001896
.00237
.002844
.003318
.003792
.004266
Steel with Thickness (2.5 mm)

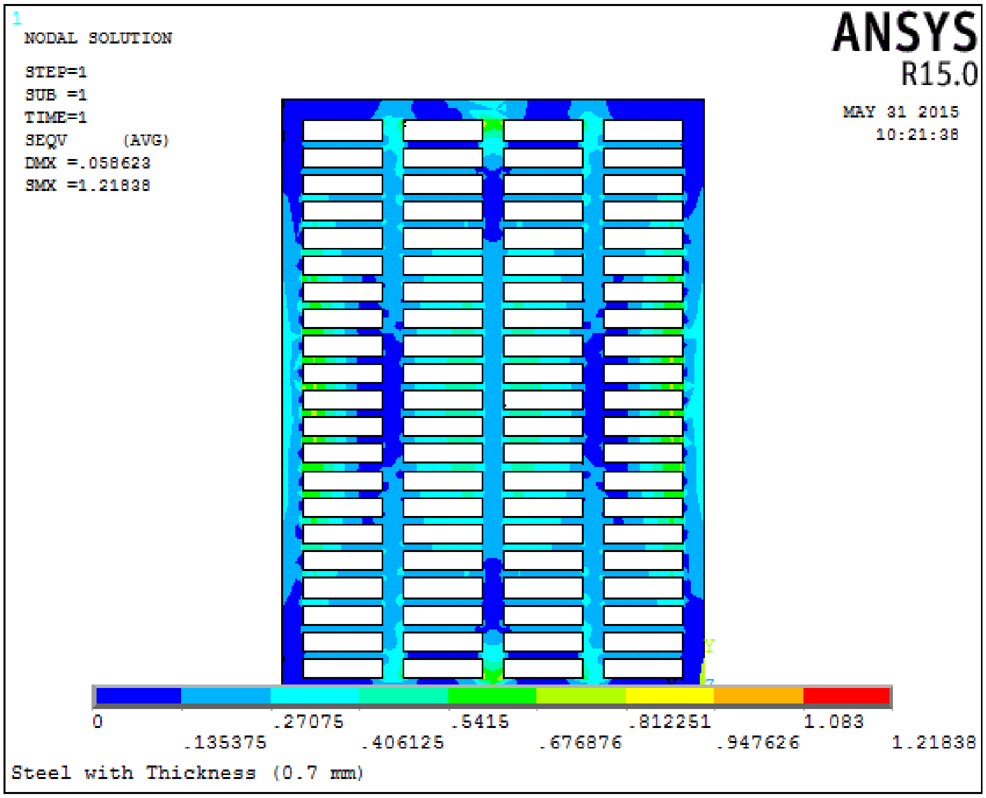

NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.03259
SMX =.03259
ANSYS
R15.0
MAY 31 2015
10:26:03
0
.003621
.007242
.010863
.014484
.018105
.021726
.025348
.028969
.03259
Steel with Thickness (1 mm)

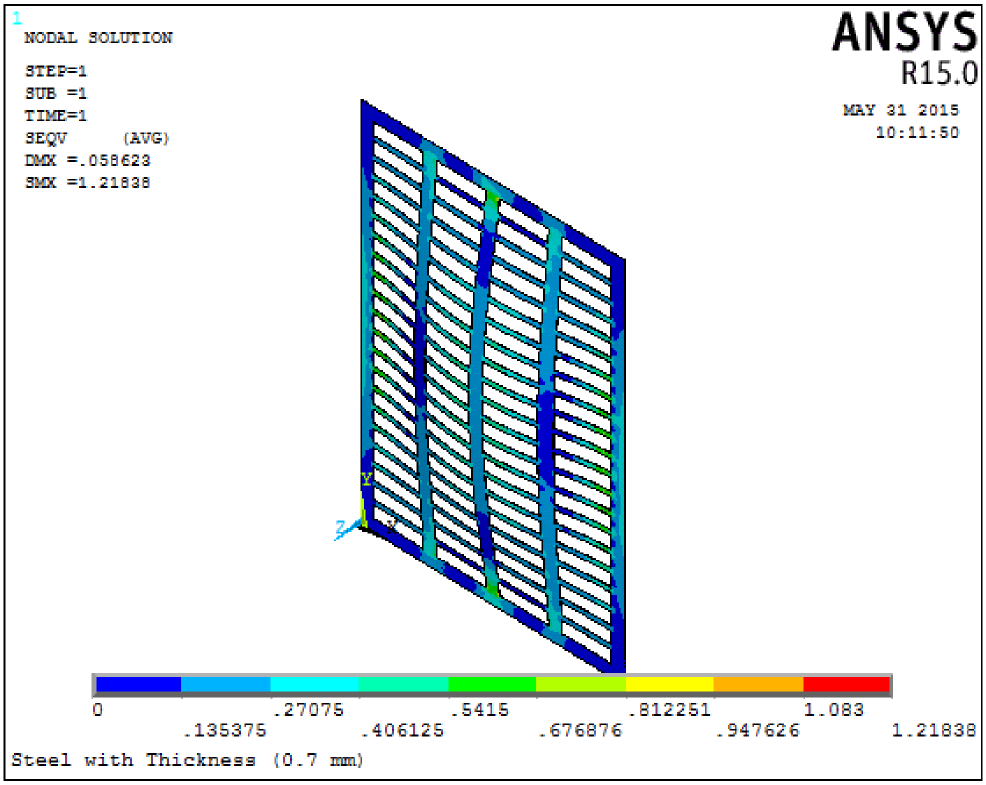

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.03259
SMX =.811994
ANSYS
R15.0
MAY 31 2015
10:25:55
0
.090222
.180443
.270665
.360886
.451108
.541329
.631551
.721772
.811994
Steel with Thickness (1 mm)

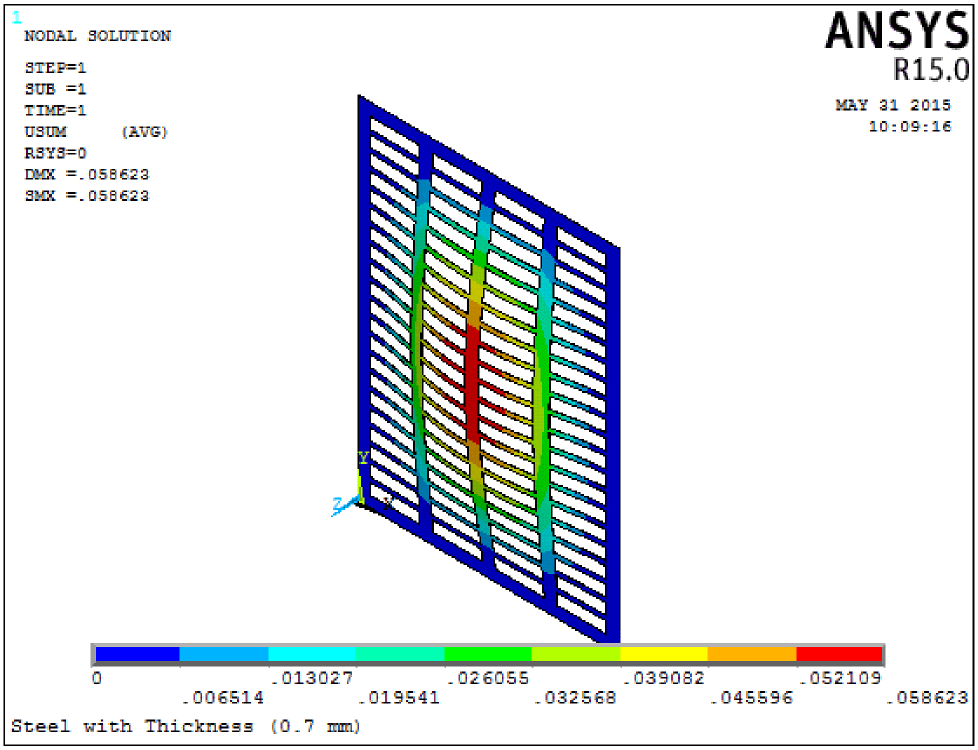

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.03259
SMX =.811994
ANSYS
R15.0
MAY 31 2015
10:25:48
0
.090222
.180443
.270665
.360886
.451108
.541329
.631551
.721772
.811994
Steel with Thickness (1 mm)

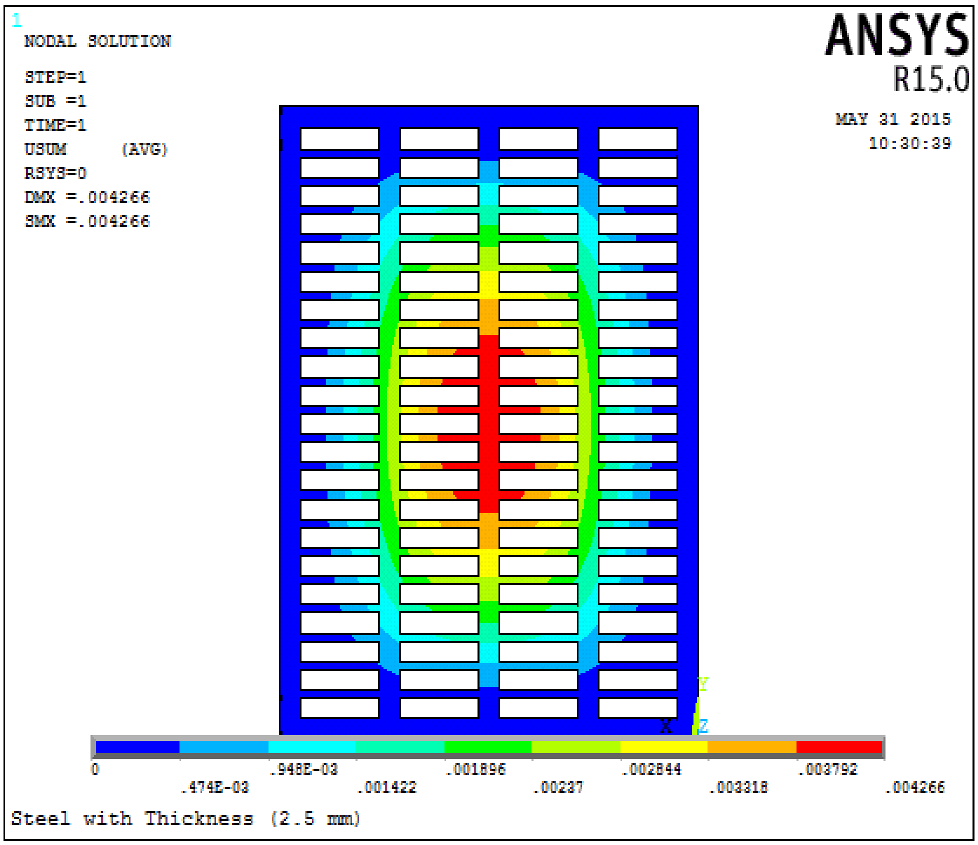

NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.03259
SMX =.03259
ANSYS
R15.0
MAY 31 2015
10:25:36
0
.003621
.007242
.010863
.014484
.018105
.021726
.025348
.028969
.03259
Steel with Thickness (1 mm)


NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.058623
SMX =.058623
ANSYS
R15.0
MAY 31 2015
10:21:48
0
.006514
.013027
.019541
.026055
.032568
.039082
.045596
.052109
.058623
Steel with Thickness (0.7 mm)

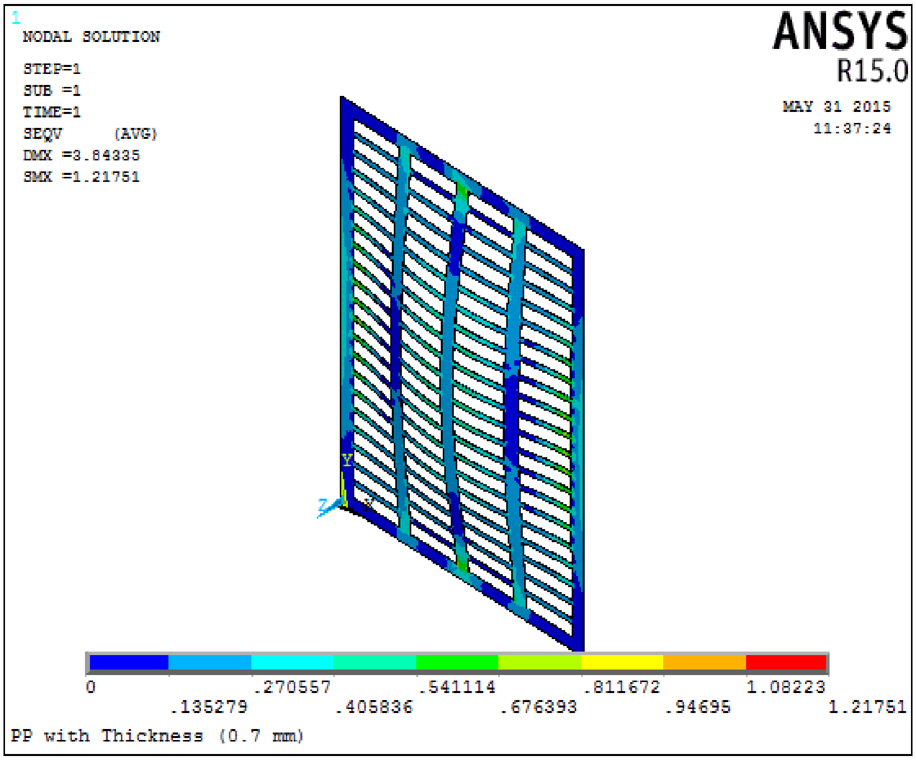

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.058623
SMX =1.21838
ANSYS
R15.0
MAY 31 2015
10:21:38
0
.135375
.27075
.406125
.5415
.676876
.812251
.947626
1.083
1.21838
Steel with Thickness (0.7 mm)

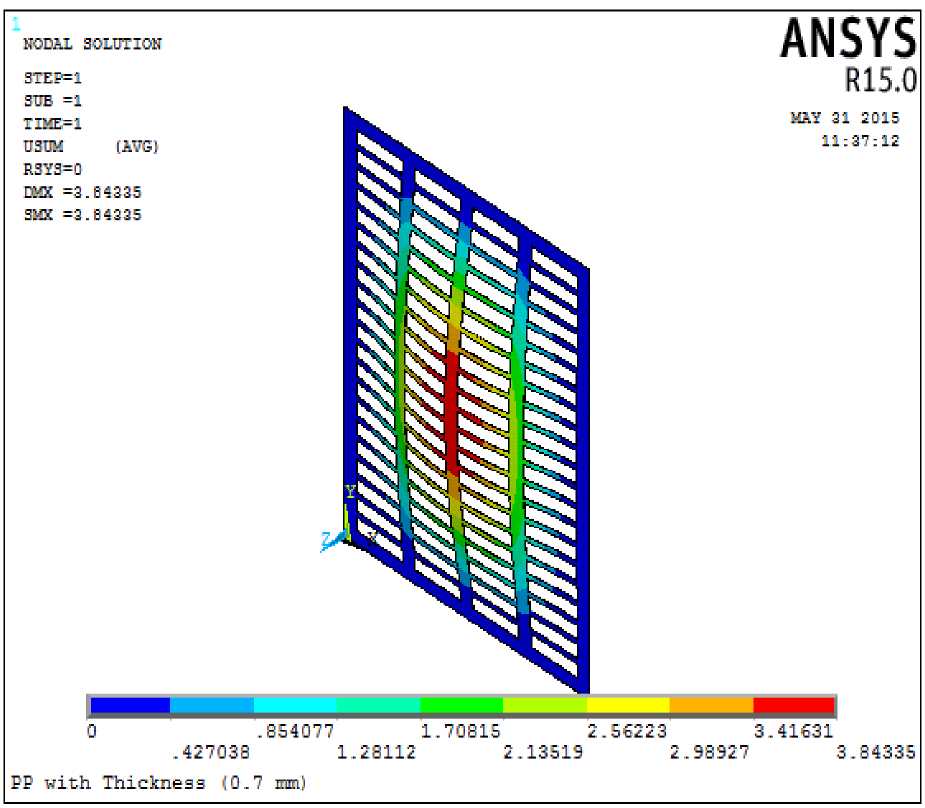

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.058623
SMX =1.21838
ANSYS
R15.0
MAY 31 2015
10:11:50
0
.135375
.27075
.406125
.5415
.676876
.812251
.947626
1.083
1.21838
Steel with Thickness (0.7 mm)

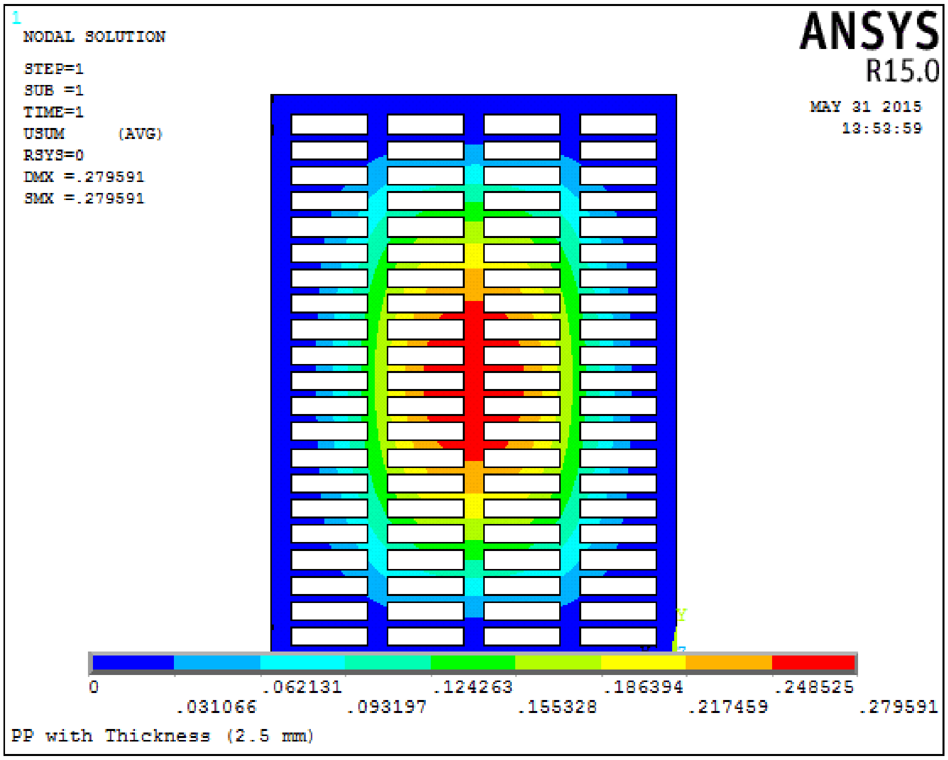

NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.058623
SMX =.058623
ANSYS
R15.0
MAY 31 2015
10:09:16
0
.006514
.013027
.019541
.026055
.032568
.039082
.045596
.052109
.058623
Steel with Thickness (0.7 mm)

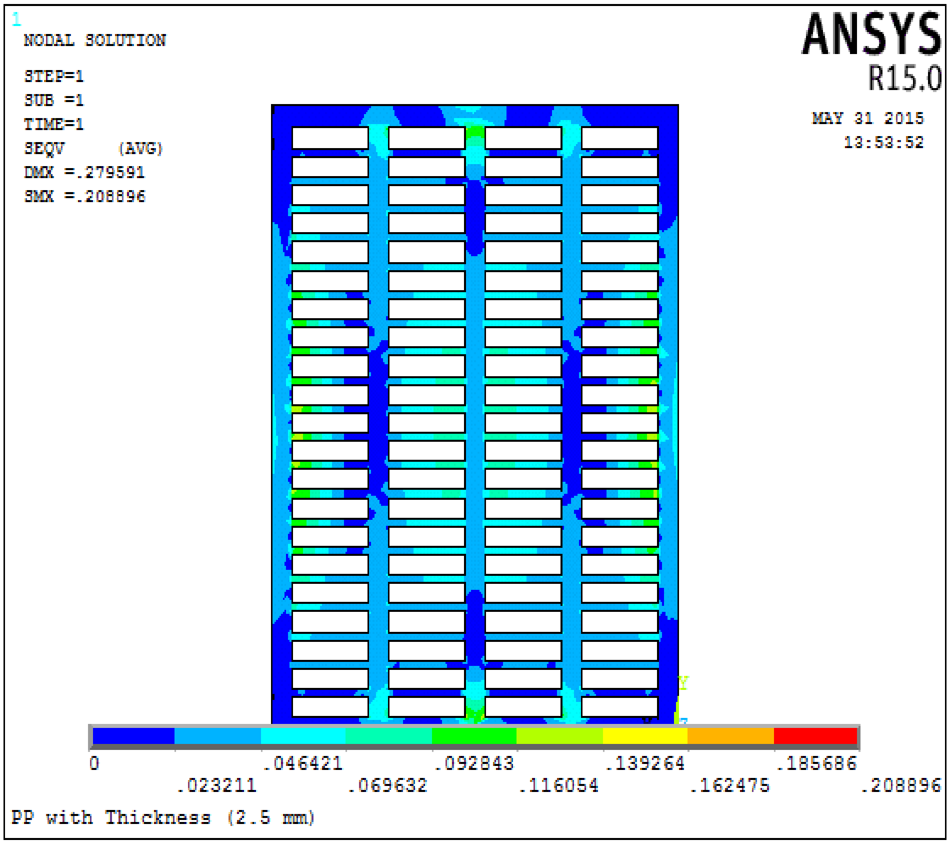

NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.004266
SMX =.004266
ANSYS
R15.0
MAY 31 2015
10:30:39
0
.474E-03
.948E-03
.001422
.001896
.00237
.002844
.003318
.003792
.004266
Steel with Thickness (2.5 mm)

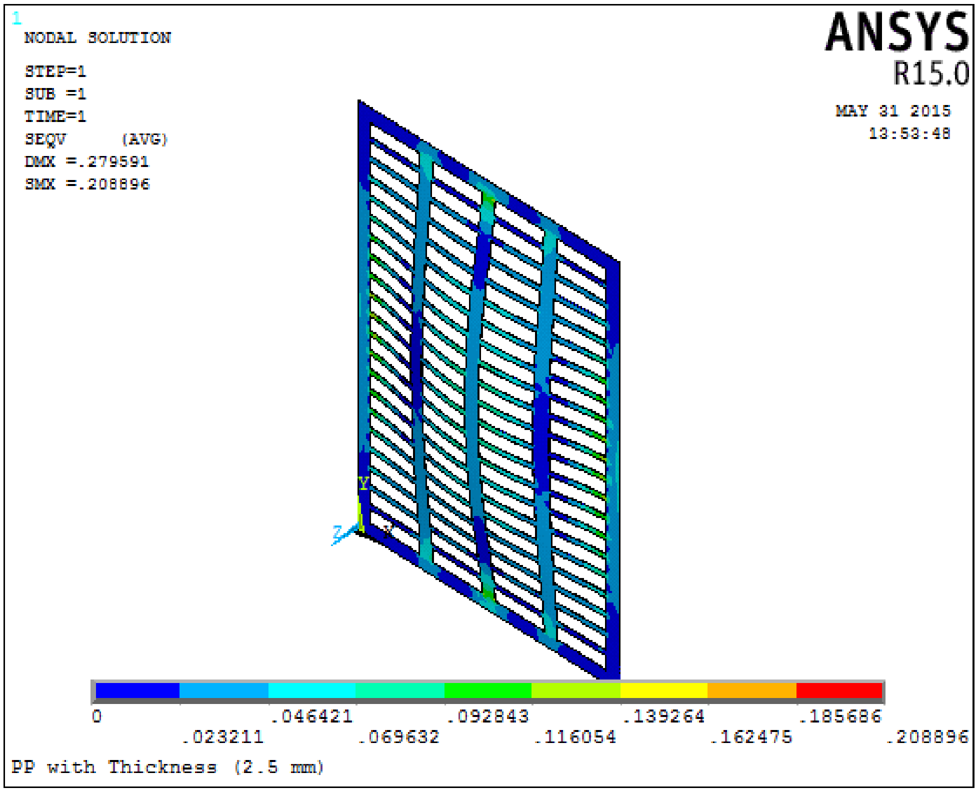
APPEDIX C: Illustration for Figure (8) ANSYS for Polypropylene

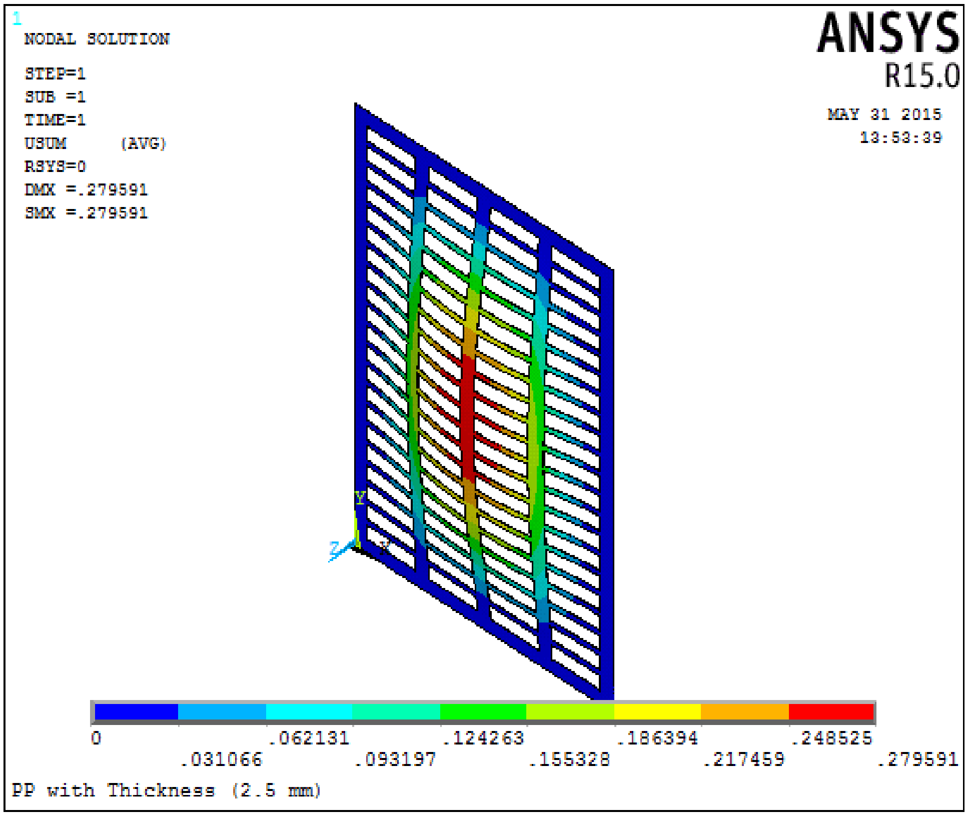


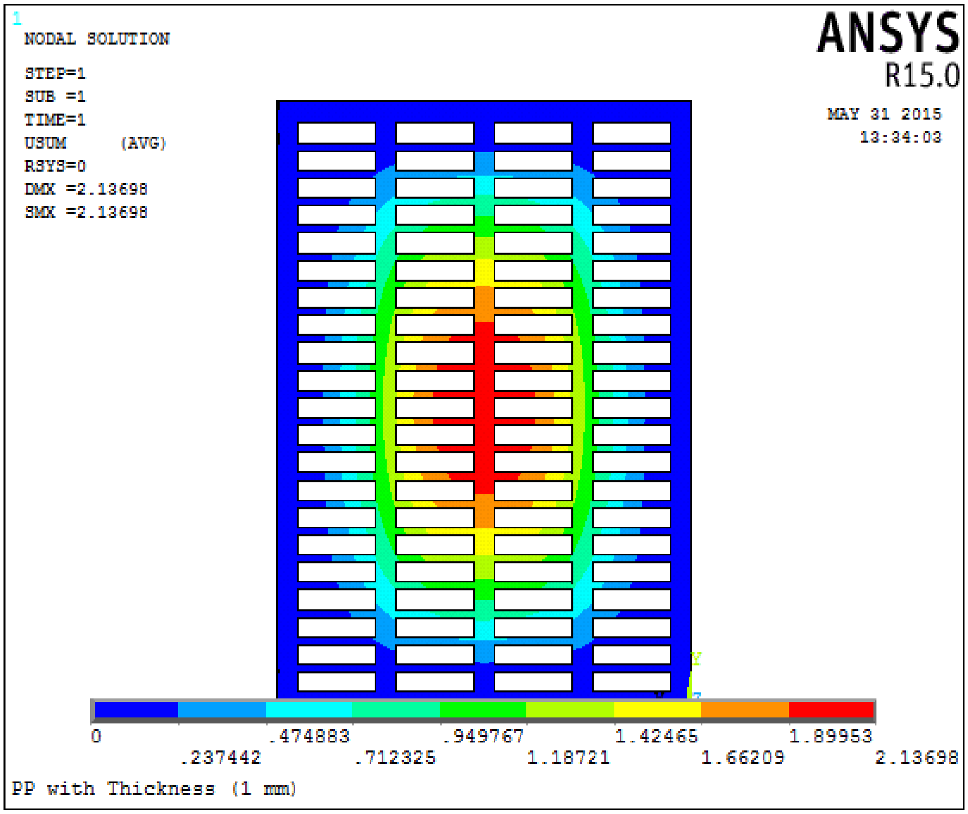


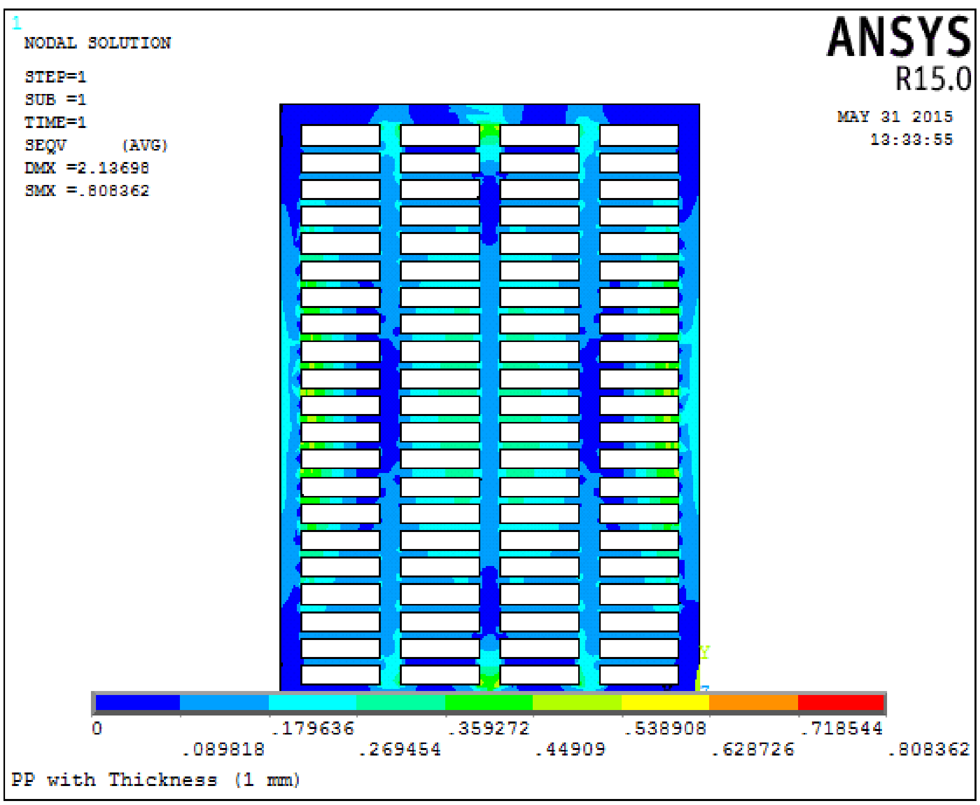

NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.279591
SMX =.279591
ANSYS
R15.0
MAY 31 2015
13:53:59
0
.031066
.062131
.093197
.124263
.155328
.186394
.217459
.248525
.279591
PP with Thickness (2.5 mm)

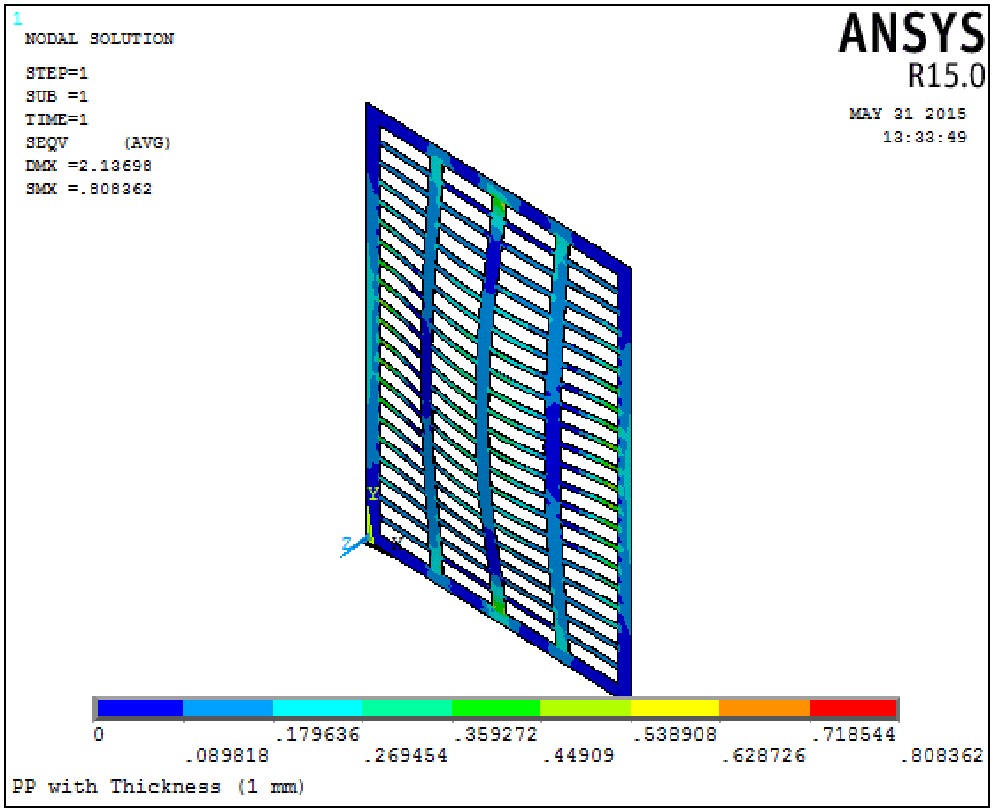

NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.279591
SMX =.208896
ANSYS
R15.0
MAY 31 2015
13:53:52
0
.023211
.046421
.069632
.092843
.116054
.139264
.162475
.185686
.208896
PP with Thickness (2.5 mm)

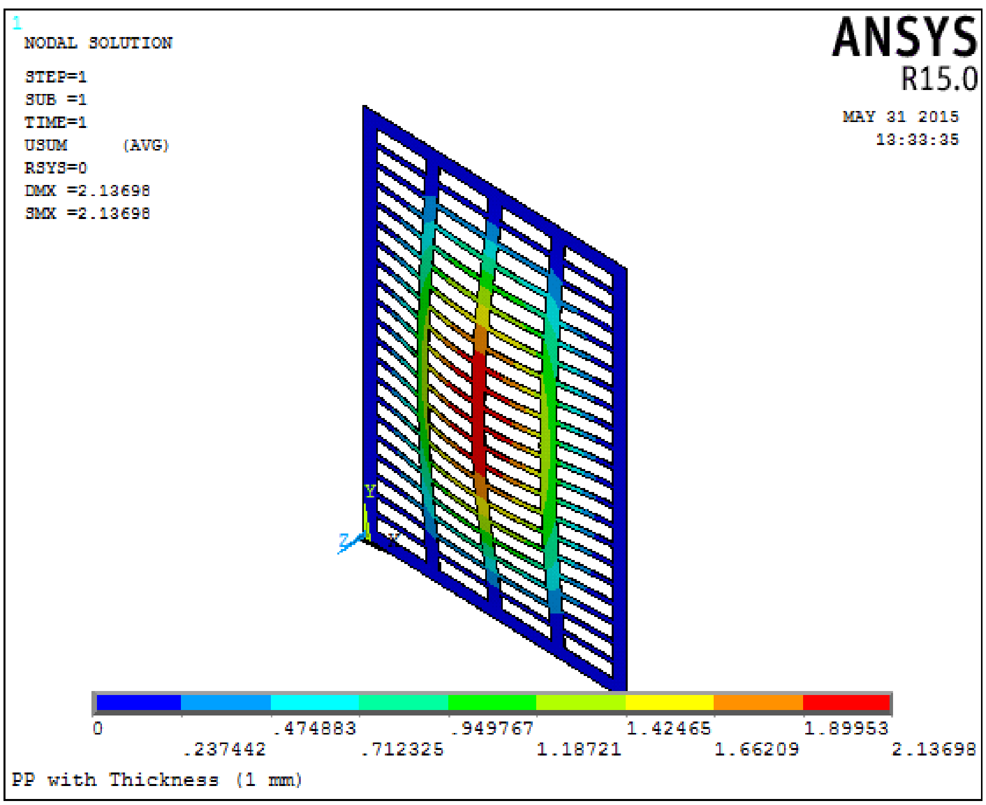

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.279591
SMX =.208896
ANSYS
R15.0
MAY 31 2015
13:53:48
Y
Z
X
0
.023211
.046421
.069632
.092843
.116054
.139264
.162475
.185686
.208896
PP with Thickness (2.5 mm)

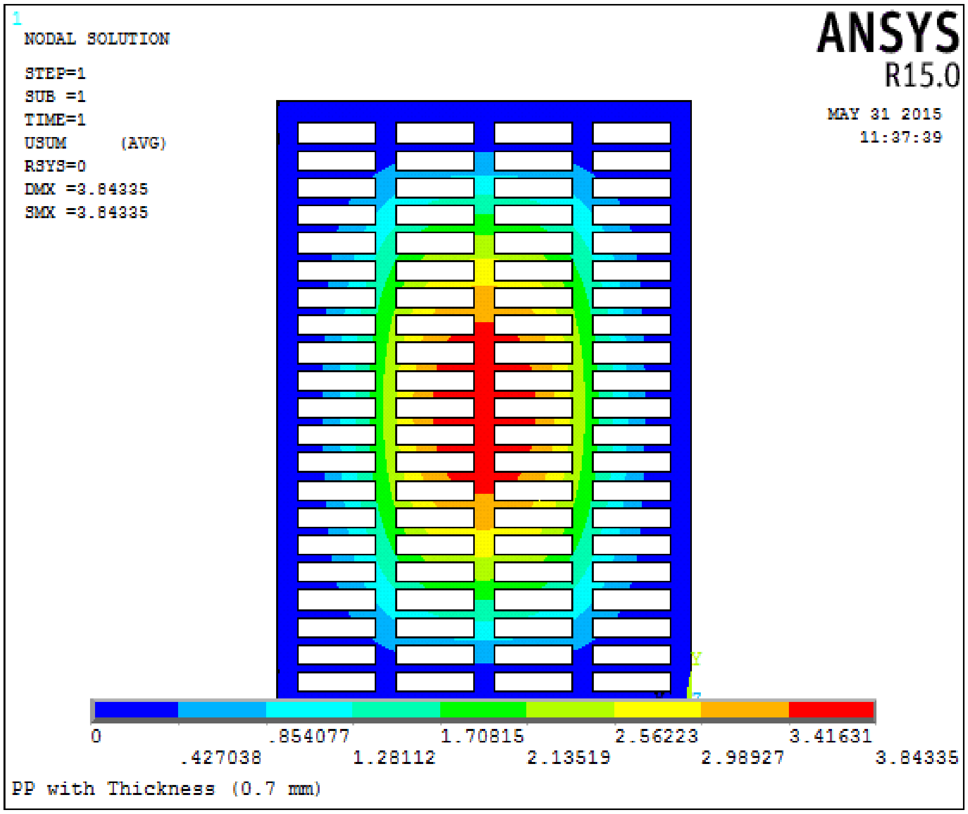

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.279591
SMX =.279591
ANSYS
R15.0
MAY 31 2015
13:53:39
Y
Z
X
0
.031066
.062131
.093197
.124263
.155328
.186394
.217459
.248525
.279591
PP with Thickness (2.5 mm)

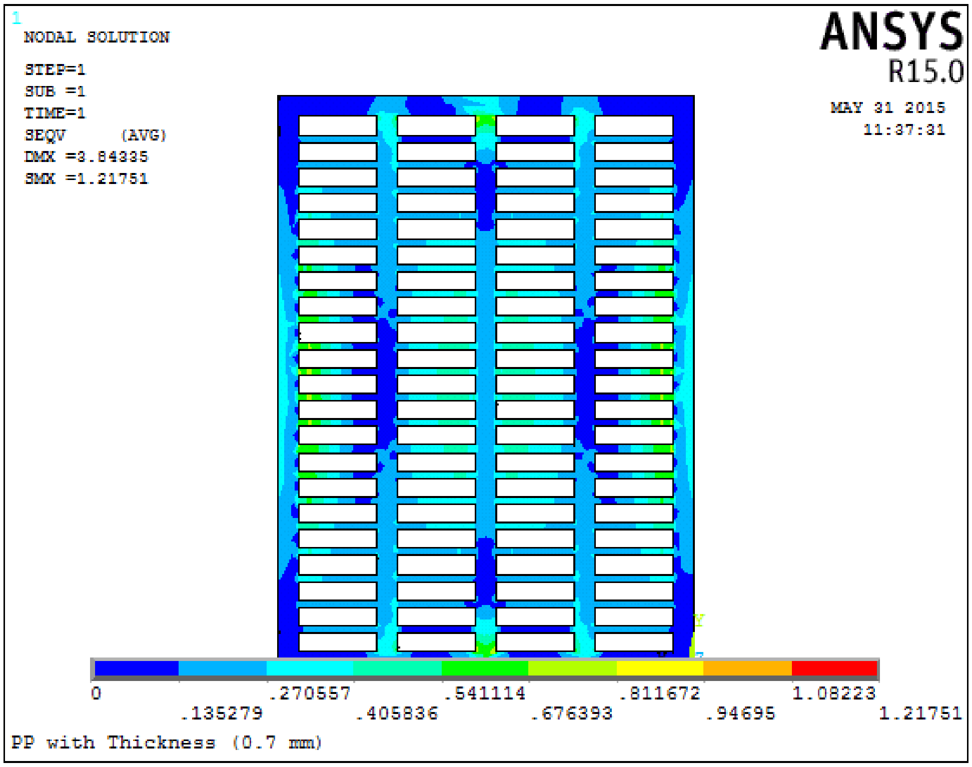

1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =2.13698
SMX =2.13698
ANSYS
R15.0
MAY 31 2015
13:34:03
0
.237442
.474883
.712325
.949767
1.18721
1.42465
1.66209
1.89953
2.13698
PP with Thickness (1 mm)


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =2.13698
SMX =.808362
ANSYS
R15.0
MAY 31 2015
13:33:55
0
.089818
.179636
.269454
.359272
.44909
.538908
.628726
.718544
.808362
PP with Thickness (1 mm)


NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =2.13698
SMX =.808362
ANSYS
R15.0
MAY 31 2015
13:33:49
0
.089818
.179636
.269454
.359272
.44909
.538908
.628726
.718544
.808362
PP with Thickness (1 mm)


NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =2.13698
SMX =2.13698
ANSYS
R15.0
MAY 31 2015
13:33:35
0
.237442
.474883
.712325
.949767
1.18721
1.42465
1.66209
1.89953
2.13698
PP with Thickness (1 mm)


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =3.84335
SMX =3.84335
ANSYS
R15.0
MAY 31 2015
11:37:39
0
.427038
.854077
1.28112
1.70815
2.13519
2.56223
2.98927
3.41631
3.84335
PP with Thickness (0.7 mm)


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =3.84335
SMX =1.21751
ANSYS
R15.0
MAY 31 2015
11:37:31
0
.135279
.270557
.405836
.541114
.676393
.811672
.94695
1.08223
1.21751
PP with Thickness (0.7 mm)