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Numerical evaluation of material type on topology optimization of thin square plates

Savaş Evran[a*], Mustafa Kurt[b]

[a]*Marmara University, Faculty of Applied Sciences, Department of Jewelry and Jewelry Design, 34865 Istanbul, Türkiye*
(ORCID: 0000-0002-7512-5997), sevran@marmara.edu.tr
[b]*Marmara University, Faculty of Technology, Department of Mechanical Engineering, 34865 Istanbul, Türkiye*
(ORCID: 0000-0001-8714-977X), mkurt@marmara.edu.tr

Abstract

This numerical paper including topology optimization method deals with the investigation the impact of the material type on final mass as topology density and the total deflection of thin square plates under clamped-free boundary conditions. The clamped boundary condition was employed at the bottom edge of each plate, whereas the other edges were considered as free. Various compressive forces such as 5kN and 7 kN in numerical analyses were applied to top edge of square plates. Numerical determinations were conducted by the static structure and topology optimization in ANSYS WORKBENCH commercial software. The final mass results for square plates in topology optimization were found in accordance with von Mises stress data calculated. The numerical results show that the lowest final mass and highest deflection data of thin square plates were found in accordance with Magnesium Alloy, Aluminum Alloy, Copper Alloy, and Structural Steel, respectively. The highest and lowest mass reduction results in the topology optimization were obtained utilizing Magnesium Alloy and Structural Steel, respectively.

Keywords: Deformation; Finite Element Method; Material; Stress; Topology optimization

Nomenclature

MT	Material type
CF	Compressive force
σ	von-Mises stress
δ	Deformation
GPa	Gigapascal
kg	kilogram
Δm	Mass reduction

1. Introduction

Topology optimization approach in many fields of the manufacturing engineering may be employed as an important tool in the design of parts which have the optimum material properties. This technique can be utilized in the plan of structures with reduced weight. Some of the engineering fields including topology optimization approach are thermodynamic analysis [1, 2], fluid analysis [3, 4], electro mechanic analysis [5], acoustic analysis [6], multiphysics analysis [7], additive manufacturing [8-11], heat exchanger [12, 13] etc. In the many analyses, the density-based approach [14-16] has been used. Besides the density-based approach, there are various approachs such as bubble method [17, 18], topological derivative [19-21], level-set method [22-24], phase filed method [25-27]. Different finite element software such as ANSYS [28-32] and ABAQUS [29, 33-35] has been

* Corresponding author
E-mail addresses: sevran@marmara.edu.tr
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utilized in several studies. Additionally, many scientists have presented different studies with topology optimization approaches in the open literature. Xia, et al. [36] reported the operating technique consisting of topology design to reduce stress by applying an BESO approach and they employed the finite element approach in solutions. Zhu, et al. [37] observed the enhancements the topology optimization methodology for aircraft structures and they decided the density-based methodology. Abdulkerim [38] studied the topology optimization solutions by operating various optimization techniques and used MATLAB software in analyses. Also, the Interior-Point method was determined to be the best effective method. Demircioğlu, et al. [39] emloyed the topology optimization technique to reduce the mass of the mobile transportation robot and utilized ANSYS software. They determined the safety factor of structure with the final mass. Ramesh, et al. [40] used the topology optimization approach to reduce the mass of the excavator Lower Arm. They utilized the CATIA Software in design. Karaçam and Arda [41] determined the topology optimization method to provide the lowest mass and the extreme stiffness for the load-carrying element. Bayram and Köse [42] evaluated the topology optimization to decrease the mass of structure made of steels utilized in the assembly of solar panels. There are numerous studies consisting of topology optimization method, but studies consisting of numerical methodologies are very limited. In this study, impact of material type on the total deformation and final mass of thin square plates were mathematically examined by employing the finite element approach.

2. Material

One of the aims of the numerical paper including topology optimization approach is to determine the ideal designs of the plates to find the lowest final mass data. Various metal materials were discussed to carry out this aim. Metals in the modelling of plates were used as materials. Each metal material consists of different properties such as Young’s module and density. Therefore, influence of the metal material properties for topology optimization approach, the stress and total deflection data of thin square plates were studied mathematically. Metal materials utilized in numerical calculations were described in Table 1 [43].

Table 1. Properties of metals [43]

Properties	Units	Materials			
		Structural Steel	Aluminum Alloy	Magnesium Alloy	Copper Alloy
Young's Modulus	GPa	200	71	45	110
Poisson's Ratio	(-)	0.3	0.33	0.35	0.34
Density	kg/m^3	7850	2770	1800	8300

As exhibited in Table 1, the maximum Young’s modules of the metal materials were reported to be Structural Steel, Copper Alloy, Aluminum Alloy, and Magnesium Alloy, respectively. Additionally, the highest densities were determined to be Copper Alloy, Structural Steel, Aluminum Alloy, and Magnesium Alloy, respectively.

3. Numerical Topology Optimization

To carry out the topology optimization analysis of thin square plate, two techniques such as static structure and topology optimization approach were employed by ANSYS WORKBENCH commercial software. In the first stage, static analysis was conducted under compressive forces such as 5 kN and 7 kN. Thus, different von Mises stress and total deflection data were numerically obtained. In the second stage, the von Mises stress data calculated using static structure analysis were applied to determine the final mass of thin square plates. In the numerical approaches, the plates with width and length of 200 mm were considered. Additionally, each plate had the thickness of 0.5 mm. In the mesh design, the edge sizing for each edge of the plates was applied and number of divisions was assumed to be 80. To perform the homogeneous mesh operations, face meshing proses was utilized. Clamped boundary condition was applied to the bottom edges of the plates, whereas other edges were considered to be free boundary conditions. Plate dimensions, boundary conditions, and mesh size were exhibited in Figure 1.

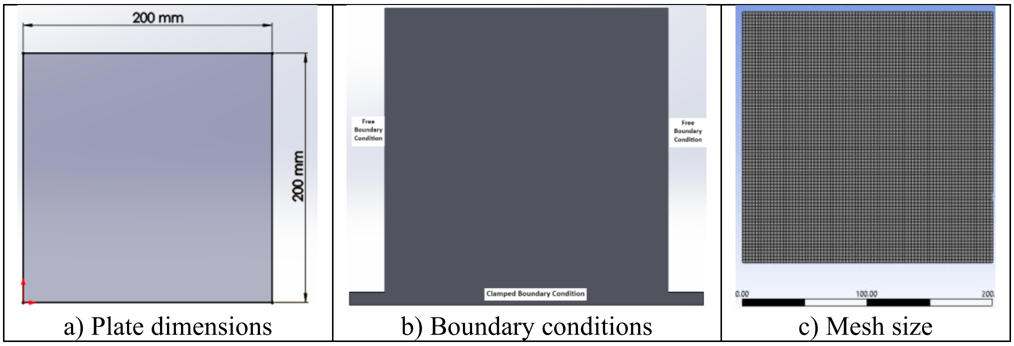

Fig. 1 a) Dimensions, b) boundary conditions, and c) mesh size

For mesh operations, target quality in skewness model was selected as 0.05 and meshing was carried out at values lover than data (0.05). Compressive forces such as 5 kN and 7 kN were employed to the upper edge of the plates to obtain the von Mises stress data. The mass data was chosen to be the response type, while global von Mises stress was assumed to be response constraint.

4. Results and Discussions

In this numerical paper consisting of topology optimization approach, the impact of the material type and von Mises stress obtained by compressive forces on total deformation and topology density such as mass remove for thin square plates made of different metal materials was numerically evaluated by ANSYS WORKBENCH commercial software. In the modeling for static structure, von Mises stress and total deformations of the plates were calculated and numerical results were listed in Table 2.

Table 2. Numerical data for von Mises stress and total deformation

Test	Deciding Factors		Results	
	Material Type MT, (-)	Compressive Force CF, (kN)	von Mises Stress σ, (MPa)	Deformation δ, (mm)
1	Structural Steel	5	115.97	0.050
2	Structural Steel	7	162.36	0.070
3	Aluminum Alloy	5	122.71	0.142
4	Aluminum Alloy	7	171.80	0.198
5	Magnesium Alloy	5	127.21	0.223
6	Magnesium Alloy	7	178.10	0.313
7	Copper Alloy	5	124.96	0.091
8	Copper Alloy	7	174.95	0.128

As can be realized from Table 2, outcomes for the highest von Mises stress were found utilizing thin square plates made from Magnesium Alloy, Copper Alloy, Aluminum Alloy, and Structural Steel, respectively. In addition, outcomes for the lowest total deformation of thin square plates were completed utilizing Structural Steel, Copper Alloy, Aluminum Alloy, and Magnesium Alloy, respectively. The total deformation and von Mises stress of thin square plate increase by increasing of the compressive forces. In the topology optimization analysis, von Mises stress data obtained from static structural analyses under different compressive forces were utilized. The numerical results for final mass and mass reduction of thin square plates were listed in Table 3.

Table 3. Results of final mass and % mass reduction

Test	Deciding Factors	Results		
	Material Type MT, (-)	von Mises Stress σ, (MPa)	Final Mass m, (kg)	Mass Reduction Δm, (%)
1	Structural Steel	115.97	0.092	41.48
2	Structural Steel	162.36	0.092	41.48
3	Aluminum Alloy	122.71	0.031	43.92
4	Aluminum Alloy	171.80	0.031	43.90
5	Magnesium Alloy	127.21	0.019	46.93
6	Magnesium Alloy	178.10	0.019	46.15
7	Copper Alloy	124.96	0.089	46.13
8	Copper Alloy	174.95	0.089	46.11

As displayed in Table 4, the maximum % mass reduction was found utilizing thin square plate made from Magnesium Alloy under the von Mises stress of 127.21 MPa, whereas the minimum % mass reduction was detected utilizing thin square plate made of Structural Steel under the von Mises stress of 41.48 MPa. Thus, the highest and lowest mass reduction data were calculated to be 46.93% and 41.48%, respectively. In other words, the maximum and minimum mass reduction results were detected using Magnesium Alloy and Structural Steel materials. Additionally, variation of von Mises stresses of the plates had very limited impact on the mass reduction. Visual numerical results for topology optimization and total deformation were exhibited in Figure 1 and Figure 2, respectively.

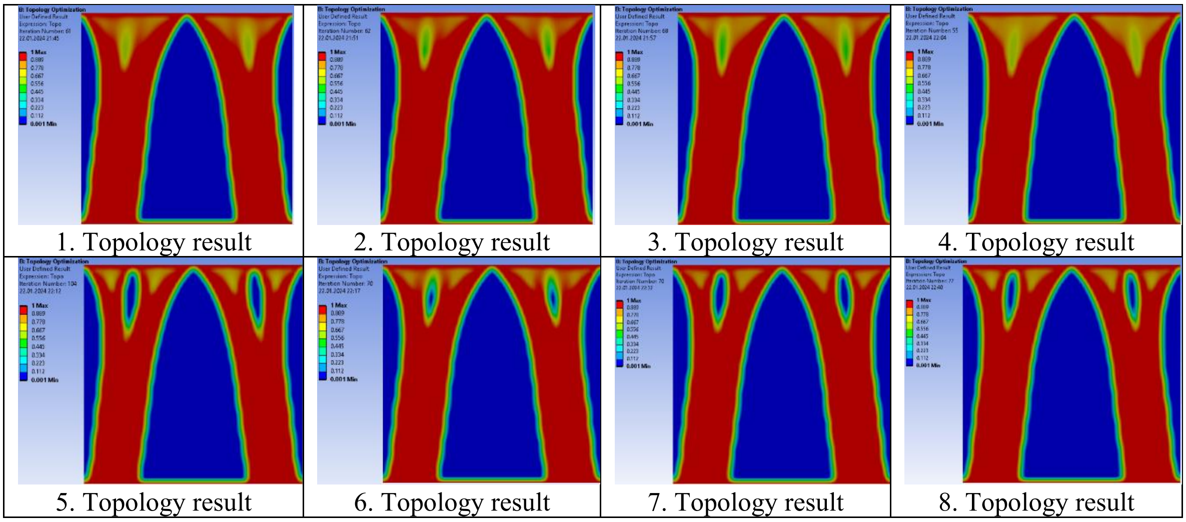

Fig. 2 Visual topology optimization results

As monitored from Figure 2, the red areas exhibit the final mass, whereas the blue areas expression the reduced mass in thin square plates.

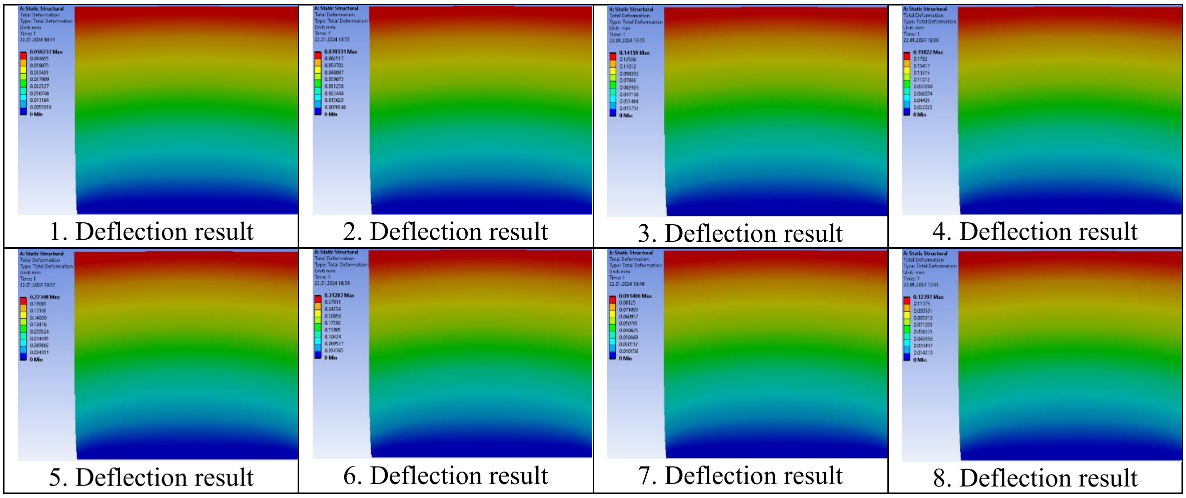

Fig. 3. Visual total deflection results

As exhibited in Figure 3, the highest total deformations were monitored in area close to the edge where compressive force was employed, whereas the lowest total deformations were observed at the edge close to clamped boundary condition.

5. Conclusions

In the paper, impacts of material type on total deflection and final mass as topology density for thin square plates were numerically examined utilizing finite element software ANSYS WORKBENCH. Static structure and topology optimization were operated in the finite element approach. Material type and von Mises stress occurred under compressive force were considered to be deciding factors. The first deciding factor were expected to be materials such as Structural Steel, Aluminum Alloy, Magnesium Alloy, and Copper Alloy, whereas the second deciding factor were assumed to be von Mises stress occurred by compressive forces of 5 kN and 7 kN, respectively. The following conclusions may be summarized:

- The maximum von Mises stress of thin square plates was obtained utilizing Magnesium Alloy, Copper Alloy, Aluminum Alloy, and Structural Steel, respectively.
- The minimum total deformation data were achieved utilizing plates made from Structural Steel, Copper Alloy, Aluminum Alloy, and Magnesium Alloy, respectively.
- The total deformation and von Mises stress of thin square plate increase with increasing compressive forces.
- The maximum and minimum mass reduction data for topology optimization were calculated utilizing Magnesium Alloy and Structural Steel, respectively.
- The highest and lowest total deformations were monitored in the zones close to the edge where compressive force was applied and the edge where clamped boundary condition, respectively.

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