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Thermal-Static Structural Analysis of Isotropic Rectangular Plates

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Abstract: *Static and thermal analysis of isotropic rectangular plate made up of various materials with various types of load applications and different boundary conditions is analysed in this research. Both numerical and by finite element formulation are carried out in the analysis and the FEM formulation is done in the analysis section of the ANSYS package. In this study, flat rectangular plates without cut-out which can be assumed as prefect platesand plates with a central rectangular cut-out that is considered as imperfect plates which are made up of steel, aluminium and invar materials are analysed. Finally comparison has been done between the results obtained from numerical analysis and ANSYS results for isotropic rectangular plate without cut-out. A study on the structural properties such as deflections and thermal behaviour of different materials has been conducted during the analysis which will be helpful in various fields of engineering.*
Keywords:*ANSYS, Boundary conditions, Deflections, Isotropic rectangular plate, Static analysis, Thermal analysis.*

I. Introduction

In many constructions and industrial areas such as buildings, ships, bridges, railway coaches, aircrafts and automobiles the plate structures are widely being used. The failure of the plates can leads to catastrophic disasters. Generally these failures are occurred due to bending and excess stress on it. Due to the functional requirements, to produce lighter and efficient structures it is necessary to provide cut-outs for structural components. Therefore it is necessary to study the behavior of these kinds of plates properly. Traditionally, the material used for the plate construction is steel. Steel is the most economical material from a pure manufacturing point of view. But when the cost of operations and maintenance during its usage comes into account, the interest of cost in a life cycle perspective has increased. The use of alloys or composites has increased considerably as to reduce the maintenance costs and acquisition. It also helps to improve the structural and operational management. When changing traditional steel into alloy or composite design there is a remarkable reduction of structural weight and it is the major added advantage. The structural weight reduction was about 50% compared to the steel version. Therefore, a detailed comparison on the structural behavior of aluminum and invar material with steel is incorporated with this study.

The deflections and stresses of rectangular plate with different boundary conditions are subjected to the action of uniformly distributed loads is studied, which is a major problem because of its technical importance. This study analyzes the deflections of isotropic rectangular plate with different boundary conditions and varying aspect ratios. When the plate thickness is at least one order of magnitude less than the span of the plate, then it is called as a thin plate. It is found that the rectangular isotropic plate with a central rectangular cut-out under uniform load, have widespread applications in various engineering fields. The accurate knowledge in the properties like deflections, stresses and stress concentrations are required for the design of plates with imperfections like cut-out and any abrupt change in the geometry of the plate under loading results in the stress concentration.

Thermal analysis of plate structures is very important, especially in thin-walled members, since structural components of high-speed machines like ships, aircrafts and space vehicles are usually subjected to non-uniform temperature distribution due to solar radiation, heating and aerodynamic structure. Thermal stresses can be termed as the stress generated by the restriction of thermal expansion and contraction. When the plate experiences non-uniform temperature field and if the displacement of the plates are prevented from occurring freely because of the restriction induced on the plate boundaries, then thermal stresses will occur. However the atmospheric temperature is increasing day by day it is essential to conduct thermal analysis. Therefore a study on thermal behavior of plates with different material is conducted.

Weicheng Cui, Yongjun Wang, PrebenTerndrup Pedersen presented simplified analytical method generalized to deal with combined load cases. The simplified analytical method is able to determine the ultimate strength of unstiffened plates with imperfections in the form of welding induced residual stresses and geometric deflections subjected to combined loads [1].JeomKee Paik, JuHye Park, Bong Ju Kim examined the metal plates of offshore structures at sea often subjected to non-uniformly distributed loads. This study showed that current practice of the marine industry that is with an average magnitude of loads, results in a great underestimation of lateral deflection calculations when the non-uniformity of lateral pressure loads becomes more significant[2]. Vanam B. C. L, Rajyalakshmi M, Inala R analyzed the static analysis of an isotropic rectangular plate with various boundary conditions and various types of load applications. Numerical results showed that, the results from finite element analysis and ANSYS simulation results are in close agreement with the results obtained from exact solutions from classical method. The optimal thickness of the plate has been obtained when the plate is subjected to different loading and boundary conditions during the analysis[3].William L. Kopresented the thermal analysis of rectangular plates with central circular or square cut-outs. To study the effects of plate support conditions, plate aspect ratio, cut-out geometry, and cut-out size on the mechanical and thermal-buckling strengths of the perforated plate method of finite element structural analysis was used [4]. K. C. Deshmukh*et al.*considered a thin simply supported rectangular plate and the temperature distribution function subjected to heat supply is determined. Due to thermal bending moments, the thermal stress components are evaluated. The results are plotted in the form of series solutions[5].

The analysis of the study is carried out both numerically and the finite element formulation is done by using ANSYS software. In this work, flat rectangular plate without and with cut-out are analyzed. The materials considered for the structure are steel, aluminum and invar. The work is carried out for bending analysis and thermal analysis in detail under various types of load applications and different boundary conditions. Later comparison has been done between the results obtained from numerical analysis and ANSYS results for isotropic rectangular plate without cut-out. After validating the results of numerical approach with results obtained from software analysis for regular rectangular plate without cut-out the analysis is further carried out using FEM software for a rectangular plate with a central rectangular cut-out. During the analysis studies on the structural properties such as deflections and thermal behavior of different materials has also been conducted. It is essential for the proper knowledge about the properties like deflections, stresses and stress concentrations required for the design of plates especially with imperfections like cut-out. The results obtained will be compared by varying the aspect ratio with respect to plate dimensions and to fix the suitable material for the design of plates.

II. Theory and Formulations

A structural engineer deals with the analysis anddesign of load bearing structures in the field of civil engineering. It can be a simple beam, column or plate to complete structures. The analysis of an isotropic rectangular plate element under various boundary conditions and loadings are conducted in the present work using ANSYS. The Euler-Bernoulli beam theory which is a simplification of the linear theory is also known as the Engineers beam theory provides the load carrying and deflection characteristics of beam. After the Euler-Bernoulli beam theory was proposed, many plate theories were formulated. The two widely accepted plate theories are:

- Kirchhoff-Love plate theory (classical plate theory)
- Mindlin-Reissner plate theory (shear deformation theory)

2.1 Kirchhoff Plate Theory

The classical Kirchhoff's plate bending theory [7] is identical to the Euler-Bernoulli beam theory assumptions and these basic assumptions being considered for the analysis. With the Kirchhoff theory, the following assumptions are also considered:

- The transverse shears strain is equal to zero. However transverse shear strainΥ_{xy} does not equal to zero. After loading right angles in the plane of the plate may not remain right angles. The plate may twist in the plane. This implies that a normal remains normal.
- $\epsilon_x = 0$ means that change in plate thickness can be neglected and normal undergoes no extension.
- In-plane strains ϵ_x and ϵ_y in the stress-strain equations is negligible and normal stress σ_z has no effect on in-plain strains.
- The calculated stress can be higher than the yield stress of the material since no yielding is taken into account in the analysis.
- The plate is initially flat. Therefore, the in-plane deflections in x and y directions at the mid-surface are assumed to be zero.
- The material of the plate is elastic, homogeneous and isotropic.

The assumptions will results in the reduction of a three-dimensional plate problem into a two dimensional problem.

2.1.1 Governing equation for deflection

The governing equation of plate is derived by assuming that the plate is subjected to lateral forces by using the three equilibrium equations.

$$\sum M_x = 0, \sum M_y = 0, \sum P_z = 0 \quad (1)$$

Where M_x and M_y, are bending moments of the plate and P_z is external load applied into it. The theory of plates is necessary to deal with the internal forces and moments.

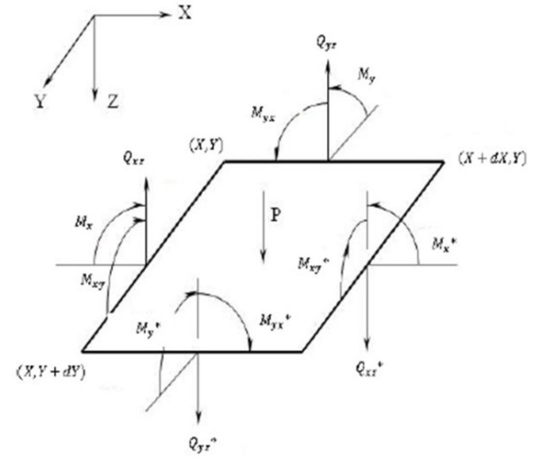

Fig 1: Differential plate with stress resultants

$$\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2\,\partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{P}{D} \quad (2)$$

The equation (2) is termed as the differential equation of the plate subjected to lateral loads.

2.1.2 Analytical solution for rectangular thin plate

Consider an isotropic homogeneous elastic rectangular plate subjected to uniformly distributed load q. The governing equation of the plate is:

$$\Delta^4 w = \frac{q}{D} \quad (3)$$

The following expression is a solution of a rectangular plate, Deflection w:

$$\frac{4qa^4}{\pi^5 D} \sum_{m=1,3,5,..}^{\infty} \frac{1}{m^5}\left(1 - \frac{\alpha_m \tanh\alpha_m + 2}{2\cosh\alpha_m}\cosh\frac{2\alpha_m y}{b} + \frac{\alpha_m}{2\cosh\alpha_m}\frac{2y}{b}\sinh\frac{2\alpha_m y}{b}\right)\sin\frac{m\pi x}{a} \quad (4)$$

Accordingly, the maximum deflection for a plate is obtained from the series in this expression converges very rapidly and sufficient accuracy is obtained by taking only the first term. Then it can represent the maximum deflection of a plate in the form.

$$w_{max} = \alpha\frac{qa^4}{D} \quad (5)$$

The maximum values of bending moments ,

$$(M_x)_{max} = \beta qa^2 \quad (6)$$

$$(M_y)_{max} = \beta_1 qa^2 \quad (7)$$

Where α,β and β_1 is a numerical factor depending on the ratio b/a of the sides of the plate. q is the Load Intensity on the plate.

III. Ansys Modeling

A finite element based software ANSYS which gives good results is used for the analysis of structural elements. SHELL-63 is used as a modeling element for the static analysis and PLANE-55 element is used for thermal analysis.

3.1 Static Analysis

SHELL-63[6] element is used in the analysis. It has both bending and membrane capabilities. SHELL-63 usually has a smaller element formulation time. The element permits normal loads and in-plane loads. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z- axis.

3.1.1 Boundary Conditions

a. Simply Supported Edge Conditions - Plate boundaries that is prevented from deflecting but free to rotate about a line along the boundary edge such as a hinge is defined as a simply supported edge.

b. Mixed Edge Conditions - Consider the plate to be simply supported on two opposite sides and clamped on the other two sides.

3.1.2 Problem Specification

Throughout the static analysis, simply support and mixed boundary conditions are applied for the considered rectangular plate without and with cut-out subjected to uniformly distributed load of 20MPa. The detailed description of the problem is described in Figure 2.

Fig 2: Rectangular plate having SSSS and SSCC boundary conditions

3.2 Thermal Analysis

Plane 55 [6]can be used as a plane element with 2-D thermal conduction capability. The element has a single degree of freedom, temperature at each of its four nodes. The element can be applied to a 2-D, steady state or transient thermal analysis. The element can also compensate for mass transport heat flow from a constant velocity field. The model is plotted in Figure 3.

In Transient thermal analysis, an ambient initial temperature of 20^0C is applied to the structure. The load step time considered for the analysis is 300 seconds. At time T = 0 the temperature will begin to flow from the area where the maximum temperature of 100^0C is applied into the plate structure where some of the heat energy is stored and for the same reason there is a need to apply the specific heat and density of the material. And some of the thermal energy will be released due to convection. The transient solutions require a new solution for each of the individual time step while the steady state solutions requires that the system of equations defining the model be solved only once. Solution accuracy of the analysis will be a function based on the size of the load step time as well as the mesh density and its characteristics. The analysis is done for both the rectangular plate without cut-out and plate with a central rectangular cut-out at center.

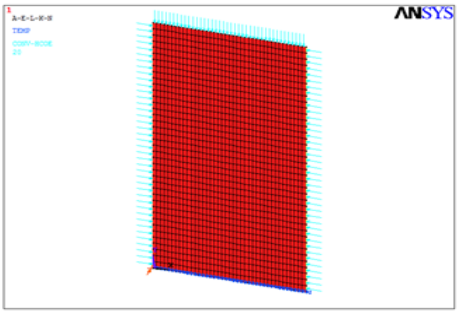

Fig 3: Rectangular plate having thermal boundary condition

IV. Results and Discussions

4.1 Static Analysis Results

4.1.1 Rectangular plate simply supported along all sides (SSSS) andRectangular plate with two edges simply supported & other two edges clamped (SSCC)

Throughout the static analysis, uniformly distributed load of 20MPa is applied on an isotropic plate. The analysis is done for steel, aluminum and invar. All the plates had a length equal to 500mm, but the width of the plate was varied to cover aspect ratios equal to 1, 2, 3 and 4. The corresponding plate widths become 500mm, 250mm, 165mm and 125mm. The variation of deflections and bending moments of the rectangular plate with boundary condition simply supported along all edges and rectangular plate with two edges S.S & other two edges clamped are illustrated in Table I and Table II. The result for deflection of plates with aspect ratios 2, 3 and 4 for different materials gives a close agreement compared to aspect ratio 1. The plate structures modeled with steel and invar material gives better results for deflected profile compared to the aluminum plate.

The effect of aspect ratio on deflected profile of the plate is plotted on Fig. 4 and Fig.5. Considerable decrease in deflection is shown as the aspect ratio increase for all the materials and the models with aspect ratios 2, 3 and 4 shows better results. Results shows plates with mixed edge condition shows the better deflected profile as compared to the simply supported (SSSS) plates.

Table I Rectangular plate simply supported along all sides (SSSS)

Specimen	Width of plate (mm)	Max. Theoretical Results			FEM Results		
		Deflection W_{max} (mm)	Moments(N.mm)		Deflection W_{max} (mm)	Moments(N.mm)	
			M_x	M_y		M_x	M_y
S1	500	17.734	239500 127125 64741 38594	239500 58000 22106 12000	17.734	238849	238849
S2	250	2.765			2.764	126802	58084
S3	165	0.634			0.635	24219	25337
S4	125	0.219			0.218	38510	13832
A1	500	48.917			48.917	244361	244361
A2	250	7.628			7.624	127454	61495
A3	165	1.747			1.752	64812	25654
A4	125	0.603			0.603	38530	14642
I1	500	25.31			25.318	237012	237012
I2	250	3.950			3.946	126585	56980
I3	165	0.904			0.907	64697	23746
I4	125	0.312			0.312	38511	13561

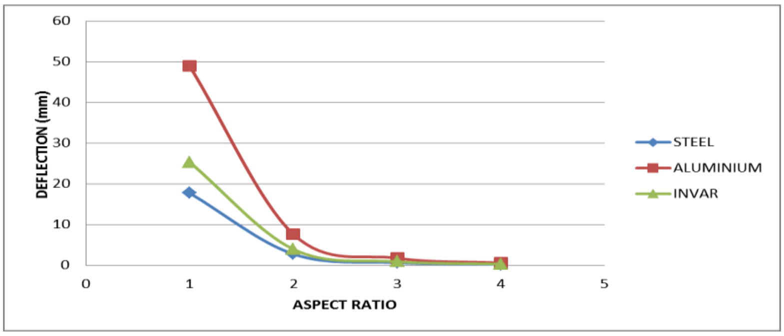

Fig 4: Effect of aspect ratio on deflection in rectangular plate having SSSS boundary condition

Table II Rectangular plate with two edges S.S & other two edges clamped (SSCC)

Specimen	Width of plate (mm)	Max. Theoretical Results			FEM Results		
		Deflection W_{max} (mm)	Moments(N.mm)		Deflection W_{max} (mm)	Moments(N.mm)	
			M_x	M_y		M_x	M_y
S1	500	8.387	122000 108625 62291 39063	166000 59250 22815 11719	8.376	121648	165684
S2	250	2.304			2.306	108333	59063
S3	165	0.605			0.608	62375	23472
S4	125	0.222			0.216	38140	13307
A1	500	23.133			23.105	125907	168056
A2	250	6.356			6.362	109210	62051
A3	165	1.669			1.677	62511	25094
A4	125	0.613			0.596	38164	14210
I1	500	11.973			11.958	120228	164893
I2	250	3.289			3.292	108041	58068
I3	165	0.864			0.868	62330	22955
I4	125	0.317			0.309	38133	13003

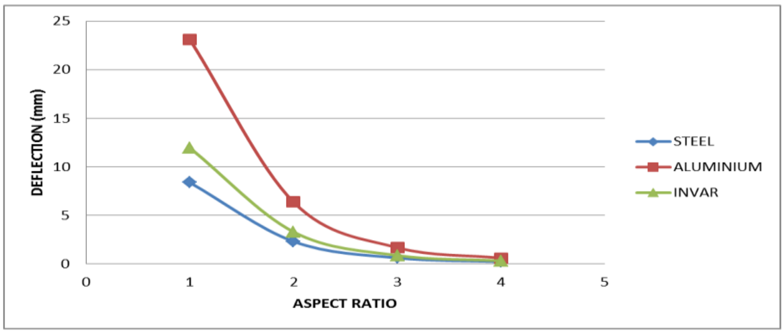

Fig 5: Effect of aspect ratio on deflection in rectangular plate having SSCC boundary condition

4.1.2 Rectangular platesimply supported along all sides (SSSS) with cut-out and Rectangular plate simply supported alongtwo edges& other two edges clamped (SSCC) with cut-out

Static analysis is done for isotropic plate with an UDL of 20MPa having SSSS and SSCC boundary conditions. In this case a rectangular cut-out is provided at the mid-section of the plate. As the aspect ratio varies the area of opening to the area of the plate also varies from a range as (a/A) 0.02, 0.04, 0.06 and 0.08. The variation of deflections and bending moments of the plate with the boundary conditionsare illustrated in Table III andTable IV. The result for deflection of plates with aspect ratios 2, 3 and 4 for different materials gives a close agreement compared to aspect ratio 1.The imperfection accounted influenced the deflected profile across the plate. The plate structures modeled with steel and invar material gives a better deflected profile compared to the aluminum plate. The effect of aspect ratio on deflected profile of the plate is plotted on Fig. 6 and Fig.7. Considerable decrease in deflection is shown as the aspect ratio increases for all the materials and the models with aspect ratios 2, 3 and 4 shows better results. Due to the presence of cut-out in plate with SSSS boundary condition deflection are increased compared to simply supported plates (SSSS) without cut-out. It is clear that the plates with mixed edge condition shows the better deflected profile results as compared to the simply supported (SSSS) plates with cut-out from Table IV. Due to the presence of cut-out deflection are increased as compared to plates having mixed edge condition (SSCC) without cut-out.

Table III Plate with cutout having SSSS condition

Specimen	Width of plate (mm)	Deflection w_{max} (mm)	Max. Moments(N.mm)	
			M_x	M_y
S1	500	20.651	375042	758806
S2	250	3.640	167431	325503
S3	165	0.896	70559	151706
S4	125	0.322	46278	77157
A1	500	57.757	384278	779884
A2	250	10.248	169514	329497
A3	165	2.532	71283	153415
A4	125	0.906	46455	78079
I1	500	29.354	371967	751832
I2	250	5.163	166729	324175
I3	165	1.272	70317	151136
I4	125	0.456	46218	76849

Table IV Plate with cutout having SSCC condition

Specimen	Width of plate (mm)	Deflection w_{max} (mm)	Max. Moments(N.mm)	
			M_x	M_y
S1	500	9.437	175296	369648
S2	250	2.976	137056	268343
S3	165	0.850	67345	144688
S4	125	0.315	45321	76114
A1	500	26.366	180995	381396
A2	250	8.384	138999	272184
A3	165	2.406	68062	146419
A4	125	0.889	45514	77040
I1	500	13.419	174225	365734
I2	250	4.220	136401	267064
I3	165	1.204	67105	144111
I4	125	0.447	45255	75805

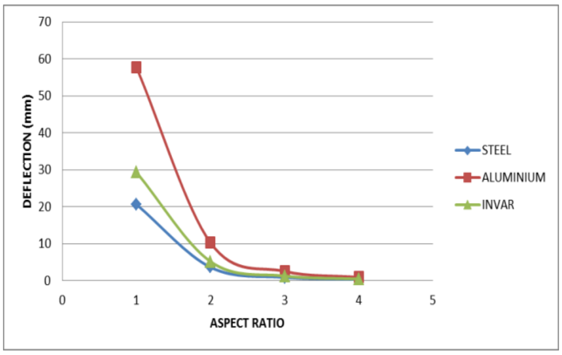

Fig 6: Effect of aspect ratio on deflection in plate with cut-out having SSSS condition

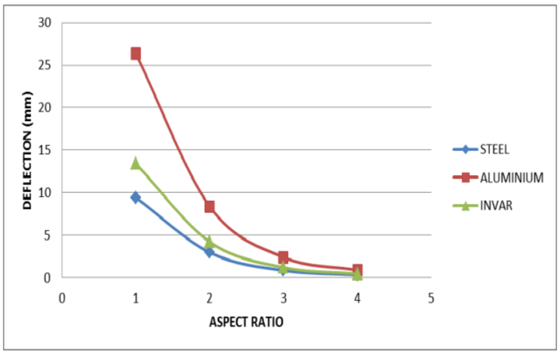

Fig 7: Effect of aspect ratio on deflection in plate with cut-outhaving SSCC condition

4.2 Thermal Analysis Results

As the atmospheric temperature is increasing day by day it is essential to conduct analysis to determine the effect of temperature on the material which is exposed to thermal conditions. The transient thermal analysis is carried over by the FEM software ANSYS and it is usually done to determine the temperature and the other thermal quantities that varies over time. The temperature that a transient thermal analysis calculates as an input to structural analyses for thermal stress evaluation is most commonly used by the engineers. The steady state thermal analysis and transient thermal analysis basically follows the same procedure. The main difference between the two analyses is that in transient thermal analysis most applied loads are in a function of time. Plane-55 can be used as a plane element for the analysis with a two-dimensional thermal conduction capability.

4.2.1 Heat flow for different plate materials with varying aspect ratios

Transient thermal analysis is done for the isotropic plate without and with central rectangular cut-out. In this case plate withaspect ratio (A.R) 1, 2, 3 & 4 is considered for different material steel, aluminum and invar. For the same aspect ratio a plate with cut-out is also analyzed as the area of cut-out to area of plate as (a/A) 0.02, 0.04, 0.06 & 0.08.The dimensions of the plate considered is 0.5m x 0.5m, 0.5m x 0.25m, 0.5m x 0.165m, 0.5m x 0.125m. The heat flow with respect to distance in the material is summarized in Table V–Table XII and Fig. 8 –Fig. 15 shows the comparison among different materials. In both cases the plate made with invar material exhibits better thermal resistance results compared to the steel plate and aluminum plate.

Table V Effect of heat flow on different plate materials with aspect ratio (A.R) - 1

Distance (m)	Temperature (^{0}C)		
	Steel	Aluminum	Invar
0	100	100	100
0.05	74.086	86.804	36.043
0.10	52.288	74.174	20.974
0.15	36.853	62.609	20.02
0.20	27.641	52.478	20
0.25	22.998	44.005	20
0.30	21.016	37.263	20
0.35	20.297	32.211	20
0.40	20.075	28.736	20
0.45	20.017	26.709	20
0.50	20.006	26.029	20

Table VI Effect of heat flow on different plate materials with aspect ratio (A.R) - 2

Distance (m)	Temperature (^{0}C)		
	Steel	Aluminum	Invar
0	100	100	100
0.05	74.021	86.704	36.043
0.10	52.204	74.01	20.974
0.15	36.788	62.421	20.02
0.20	27.604	52.298	20
0.25	22.981	43.85	20
0.30	21.009	37.138	20
0.35	20.295	32.115	20
0.40	20.075	28.662	20
0.45	20.017	26.649	20
0.50	20.006	25.974	20

Table VII Effect of heat flow on different plate materials with aspect ratio (A.R) - 3

Distance (m)	Temperature (^{0}C)		
	Steel	Aluminum	Invar
0	100	100	100
0.05	73.902	86.592	36.036
0.10	52.068	73.838	20.973
0.15	36.694	62.236	20.02
0.20	27.554	52.128	20
0.25	22.959	43.706	20
0.30	21.002	37.024	20
0.35	20.293	32.027	20
0.40	20.074	28.595	20
0.45	20.017	26.595	20
0.50	20.006	25.925	20

Table VIII Effect of heat flow on different plate materials with aspect ratio (A.R) - 4

Distance (m)	Temperature (^{0}C)		
	Steel	Aluminum	Invar
0	100	100	100
0.05	73.78	86.488	36.009
0.10	51.942	73.684	20.97
0.15	36.611	62.072	20.02
0.20	27.511	51.976	20
0.25	22.941	43.577	20
0.30	20.995	36.921	20
0.35	20.291	31.948	20
0.40	20.074	28.535	20
0.45	20.017	26.546	20
0.50	20.006	25.88	20

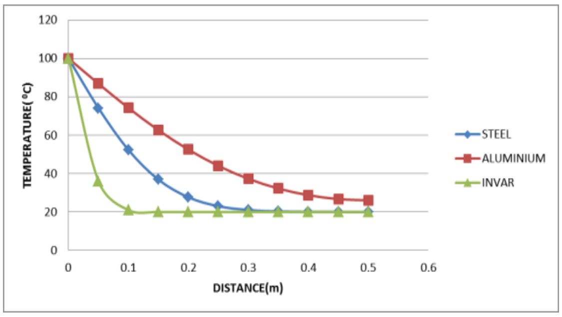

Fig 8: Effect of heat flow for different plate material with aspect ratio (A.R) - 1

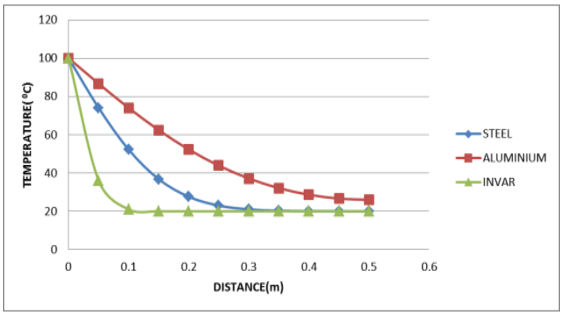

Fig 9: Effect of heat flow for different plate material with aspect ratio (A.R) - 2

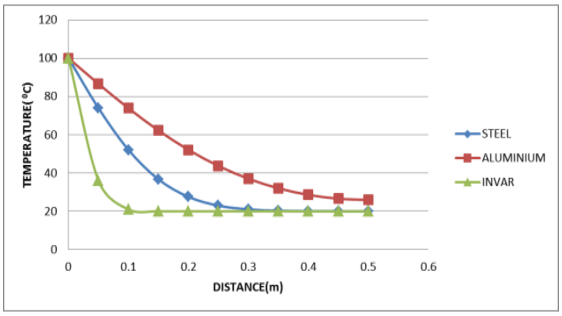

Fig 10: Effect of heat flow for different plate material with aspect ratio (A.R) - 3

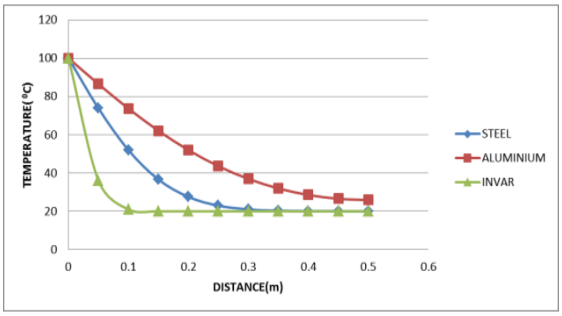

Fig 11: Effect of heat flow for different plate material with aspect ratio (A.R) - 4

Table IX Effect of heat flow on different plate materials having cut-out with aspect ratio (A.R) - 1

Distance (m)	Temperature (^{0}C)		
	Steel	Aluminum	Invar
0	100	100	100
0.05	77.299	88.98	41.179
0.10	53.216	75.91	21.06
0.15	37.532	64.981	20.015
0.20	29.959	57.169	20
0.25	23.246	44.763	20
0.30	20.789	35.476	20
0.35	20.222	31.174	20
0.40	20.057	28.143	20
0.45	20.012	26.248	20
0.50	20.005	25.728	20

Table X Effect of heat flow on different plate materials having cut-out with aspect ratio (A.R) - 2

Distance (m)	Temperature (^{0}C)		
	Steel	Aluminum	Invar
0	100	100	100
0.05	73.909	87.384	35.726
0.10	52.26	75.553	20.861
0.15	37.493	65.252	20.014
0.20	29.475	56.751	20
0.25	23.226	44.934	20
0.30	20.783	35.5	20
0.35	20.218	31.09	20
0.40	20.058	28.07	20
0.45	20.013	26.218	20
0.50	20.005	25.615	20

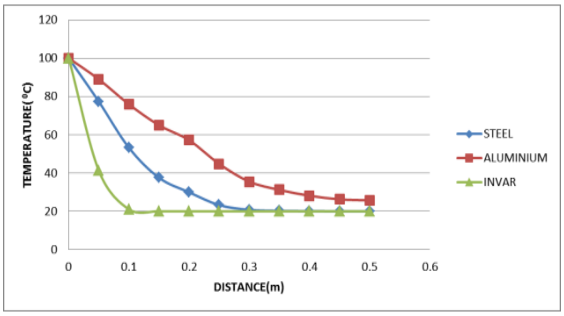

Fig 12: Effect of heat flow for different plate material having rectangular cut-out with A.R-1

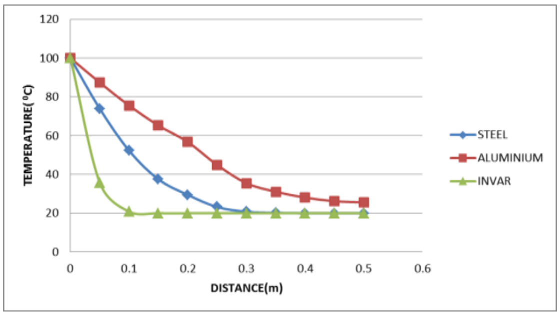

Fig 13: Effect of heat flow for different plate material having rectangular cut-out with A.R-2

Table XI Effect of heat flow on different plate materials having cut-out with aspect ratio (A.R) - 3

Distance (m)	Temperature (^{0}C)		
	Steel	**Aluminum**	**Invar**
0	100	100	100
0.05	75.742	88.59	38.574
0.10	54.164	77.255	21.289
0.15	36.492	65.145	20.012
0.20	29.902	58.113	20
0.25	23.27	45.314	20
0.30	20.794	35.423	20
0.35	20.186	30.42	20
0.40	20.065	28.052	20
0.45	20.012	25.917	20
0.50	20.005	25.389	20

Table XII Effect of heat flow on different plate materials having cut-out with aspect ratio (A.R) - 4

Distance (m)	Temperature (^{0}C)		
	Steel	**Aluminum**	**Invar**
0	100	100	100
0.05	77.258	89.628	41.207
0.10	52.966	77.23	21.067
0.15	38.212	67.523	20.025
0.20	29.633	58.488	20
0.25	23.366	45.726	20
0.30	20.801	35.138	20
0.35	20.223	30.579	20
0.40	20.057	27.549	20
0.45	20.012	25.701	20
0.50	20.004	25.123	20

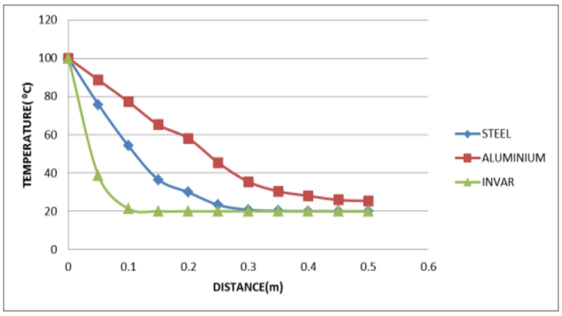

Fig 14: Effect of heat flow for different plate material having rectangular cut-out with A.R-3

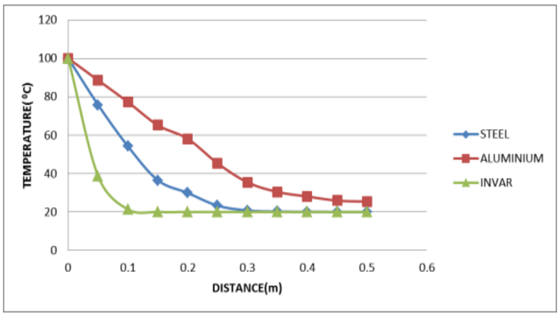

Fig 15: Effect of heat flow for different plate material having rectangular cut-out with A.R-4

4.2.2 Effect of Thermal Flux

Thermal flux or heat flux is the transfer rate of heat energy through a particular surface per unit surface. The variation of heat rate for different materials for varying aspect ratios is summarized in the table XIII. The results are plotted for plate without and with cut-out. In this case a rectangular plate with rectangular cut-out is provided at the mid-section of the plate is also analyzed. As the aspect ratio varies the area of opening to the area of the plate also varies from a range as (a/A) 0.02, 0.04, 0.06 and 0.08. Invar plate materials show less conductivity across the body compared to steel and aluminum plate. So from the transient thermal analysis results it is clear that invar material will be the best material to withstand thermal effect than steel or aluminum.

Table XIII Effect of thermal flux for varying aspect ratios for different materials without and with cut-out

Specimen	Width of plate (m)	Thermal Flux ($x\ 10^3 W/m^2$)	
		Plate Without Cut-out	Plate With Cut-out
S1	0.500	44.434	44.434
S2	0.250	44.499	44.472
S3	0.165	44.554	44.473
S4	0.125	44.640	44.509
A1	0.500	65.413	114.763
A2	0.250	65.601	115.512
A3	0.165	65.893	116.261
A4	0.125	65.238	117.010
I1	0.500	18.209	18.197
I2	0.250	18.272	18.361
I3	0.165	18.286	18.385
I4	0.125	18.291	18.410

V. Conclusion

In this study, the conventional finite element method is used and it is done by using FEM software ANSYS. Using the FEM software, the static and thermal analysis of plates made up of different materials without and with cut-outs having different boundary conditions by varying the aspect ratio is done. The numerical study is done and discussed in above. The detailed conclusions on the structural behavior of plates that can be plotted from the present study are summarized as follows:

(1) When there is no cut-out in the plates as the aspect ratio (l/b) increases above unity the deflection decreases considerably for all the materials having SSSS and SSCC boundary conditions.
(2) When there is a rectangular cut-out at the mid-section of the plates as the aspect ratio (l/b) increases above unity the deflection decreases considerably for all the materials having SSSS and SSCC boundary conditions.
(3) When the static analysis results are observed, the steel plate got better results for deflection compared with the aluminum and invar plates. But the deflected profile obtained for plate made up invar material is very much comparable with steel plates and hence invar plate design can be recommended as an alternate for a steel design.
(4) From the thermal analysis carried out by using the FEM software ANSYS clearly shows that the plate manufactured with invar material is best suitable under thermal conditions than steel or aluminum design. The heat rate per unit area for invar plates are twice less than the steel plates.

The major advantage of changing the traditional steel design for plates to alloy or composite design is the considerable reduction in the strength to weight ratio. Light weight material is a better alternate in the engineering industry where strength and stiffness is required and comparable to steel design. The main advantage of the invar material that is an example for alloy design is the thermal resistance much better than traditional steel design.

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