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Fixture Layout Optimization of Sheet Metals by Integrating Topology Optimization into Genetic Algorithm

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Abstract: Manufacturing process accuracy is obtained by proper arrangement of fixture elements known as fixture layout. A N-3-2-1 method is used for sheet metals which requires (N + 3) fixture elements to constrain deformation normal to surface. Genetic Algorithm (GA) is used for fixture layout optimization, but it requires high computational effort due to large number of populations. A new method for fixture layout optimization is proposed by integrating topology optimization into GA. In this method, topology optimization reduces the population for GA. The objective function is to reduce the population for GA and minimize total deformation normal to the plane of workpiece. The proposed approach comprised three stages. In the first stage, the initial number of clamps are determined. In the second stage, the population is reduced for GA and the feasible area of clamps are identified using the topology optimization technique. In the third stage, the number and position of clamps, earlier identified in stage one, are optimized using GA. Two different case studies are solved by varying applied load position and magnitude. The proposed method results 47.5% and 65% decreases in the population for subcase 1 and subcase 2, respectively. However, in subcase 3 and subcase 4 the population reduced was 90% and 80%, respectively. The 25% of reduced population is used as the convergence criteria. Similarly, total deformation normal to the plane is reduced in each subcase, with the highest reduction of 86.31% in subcase 1 and lowest of 59.85% in subcase 4. The experiment is performed on the first case study to validate results. This concludes that the proposed method is valid and that optimal results are found.

Keywords: fixture layout; genetic algorithm; topology optimization; fixture elements

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1. Introduction

The manufacturing system comprises many components; fixture is considered to be the most important component. The purpose of fixture is to hold the work piece at a specific position and orientation in the assembly, manufacturing, and verification process [1]. Fixtures restrain workpieces in such a way that the deformation is minimized during the manufacturing process. They also reduce the deformation due to the weight of the workpiece under the effect of gravity. A fixture comprises locators and clamps. Locators are used to determine the position and orientation of a work piece. On other hand, clamps exerts clamping force to hold a workpiece against the locators [2].

Fixture design and fabrication cost is quite high and it comprises almost 10–20% of the cost of the manufacturing system. Product cost also depends on fixture cost. Fixture eliminates frequent checking, individual marking, positioning and non-uniform quality in manufacturing process. This results in a reduction in operation time and an increase in productivity. As defined by Prabhaharan et al. [3]: fixture layout is to arrange fixture elements within the fixture, and optimized fixture layout is the arrangement of fixture elements that results in the minimum deformation of a workpiece.

Different techniques of fixture layout optimization are used. The most popular are genetic algorithms, simulated annealing, mathematical programming methods, and ant colony algorithms. Due to the flexible nature of the sheet metal's rigid body, fixturing methods are not applicable to sheet metals. The research work on sheet metal is very limited in the literature and many researchers are focusing on sheet metal due to its many applications. In this research, the flexible workpiece is considered. First, the literature review regarding rigid body is explained, and later sheet metals.

Meyet et al. [4] proposed a method to optimize fixture layout, considering dynamic conditions. Minimize deflection was set as the objective function and was achieved in terms of clamping force. Tao et al. [5] worked on arbitrarily shaped workpieces while applying a computational geometric approach. Amaral et al. [6] developed a technique to find optimal support locations using FEA. Workpiece stability and minimization of maximum deformation is set as the objective function. Tan et al. [7] proposed a method by combining the force closure method, optimization technique, and Finite Element Method (FEM) for optimal fixture modelling design and validation. Kashyap et al. [8] optimized the fixture design using FEM. This research targets deformation and minimizes it during drilling and milling operations. The case study used involved the reduction of deformation up to 30% from initial deformation. Krishna Kumar et al. [9] optimized the machining fixture layout using the Genetic Algorithm (GA). Authors modified GA to optimize six locators using the 3-2-1 method. It was found that modified GA results in better stability and quality of the workpiece [10].

Most researchers are focusing on sheet metal fixture; the literature review regarding sheet metals is described below. Li et al. [11] were the first to consider fixture elements' number and position to optimize the fixture layout of sheet metal assembly used in laser welding using GA. Li et al. [12] developed a method known as the fixture configuration method for laser welding form on a newly suggested locating scheme. Authors verified the proposed method by applying it to an automotive assembly. Cai et al. [13] developed the fixture optimization method to reduce variations in assembly undergoing welding gun variations. It was found that by using the welding gun variation model need of the Monte Carlo simulation was eliminated, because assembly variation simulation is converted into the deterministic assembly model. Xing et al. [14] developed the N-2-1-1 fixture layout optimization method with integrating genetic algorithm and FEM. Xing et al. [15] proposed a two-stage method for the fixture layout of sheet metal to reduce the deflection of sheet metal normal to surface. This method is applied to the rear bracket plate and results showed it has higher prediction accuracy and good simulation effect. Lu wang et al. [16] proposed the N-2-1 locating scheme for the positional variation analysis of sheet metal workpieces. Ahmad et al. [17] proposed a new N-3-2-1 method for sheet metal fixture layout optimization and found the best optimal position for the multipoint respot welding of sheet metals. Optimization is performed using GA. The spacer grid case study is performed to validate results.

Different techniques have been used to reduce computational effort in fixture layout optimization. Hallam et al. [18] proposed three methods: adaptive, exponential, and linear reduction methods, to reduce population size for GA. It was found that the adaptive method outperformed the other two methods. Besides GA, some other optimization methods are also used in structural optimization. Kaveh and Talatahari [19] developed the Big Bang–Big Crunch (BB–BC) algorithm for truss structure optimization. Authors compared the BB–BC algorithm to other optimization algorithms including the ant colony algorithm, GA, particle swarm optimization (PSO), and harmony search. Numerical results indicate that the BB-BC algorithm has better performance than other heuristic algorithms. Chen et al. [20] adopted a graphical method and PSO to produce optimal origami patterns. Numerical experiments were performed and it was concluded that the proposed PSO method results in high accuracy, as well as low computational cost.

Kaveh and Zolghadr [21] proposed the Democratic PSO algorithm to overcome premature convergence phenomena in the original PSO. The proposed algorithm is validated by solving four numerical problems. Chen et al. [22] proposed the PSO for developing flat–foldable origami patterns with degree -4 vertices. Authors concluded that the presented method is better than the analytical approach and GA because both trivial and non-trivial flat–foldable solutions are found using less computational effort. Zhang et al. [1] identified the symmetry order and symmetry group of planar structures using two Convolutional Neural Networks (CNNs). A short summary of currently existing methods, characteristics, and limitations are described in Table 1.

Table 1. Summary of currently existing fixture layout optimization methods.

Author	Characteristics and Methods	Limitations
Menassa et al. [23]	Fixture support positions were identified using Broyden–Fletcher–Goldfarb–Shanno (BFGS) method.	Only applicable on rigid body. Only optimizes position of clamps.
Kulankara et al. [24]	Developed iterative method based on GA to optimize fixture layout.	Only applicable on rigid body. Very high population for GA. Only optimizes position of clamps.
Cai et al. [25]	Find optimal position of fixture elements considering sheet metal using Multi Point Constraint (MPC) feature.	Number of fixture elements cannot be optimized.
Cheng et al. [26]	Genetic algorithm–ant algorithm (GAAA) was used to reduce assembly variations.	Requires High computational effort.
Xing et al. [27]	Fixture layout optimization by non-dominating sorting social radiation algorithm (NSSRA).	It optimizes only positions of clamps; number of clamps were not optimized.
Bo et al. [28]	Fixture layout optimization based on N-2-1 locating scheme by combining cuckoo search algorithm.	Objective function is achieved after many evolutionary generations, which increases computational cost.

In this research, the topology optimization technique is used to reduce the population for GA. Topology optimization is generally applied in the early stages of design. The main purpose of topology optimization is to get an optimized structured layout. In topology optimization some material is removed and a new layout is obtained [29]. At present, different FEM softwares (Altair Optistruct, MSC Nastran, Simulia Tosca, etc.) are available that provide an optimization module to obtain lighter-weight structures. However, different researchers have developed [22,23] their own codes using programming languages. General two methods are used for the topology optimization method: the homogenization method and density method. Bendsoe and Kikuchi [30] proposed the homogenization method, but it is computationally expensive. To overcome this issue later, a density method was proposed by Bendsoe [31] and called the solid isotropic material with penalization method (SIMP); it was further developed by Zhou and Rozvany [32]. Csebfalvi [33] solved two-dimensional problems considering the displacement-constrained, volume-minimizing topology optimization model. The density method considers isotropic material [34]. The MSC Nastran solver is based on the density method. Ahmad et al. [35] proposed a method for the topology optimization of nonlinear response using equivalent static loads (ESL). ESL are calculated from the analysis domain results. These calculated loads are used in linear response optimization. Gebremendhen et al. [36] performed topology optimization by considering stress constraints in 3D models with regards to the SIMP method. Yunfei et al. [37] performed topology optimization of robots' upper arm using the SIMP method. Xue et al. [38] proposed a hybrid method for topology optimization by combining the SIMP and GA algorithms, called the SIMP–GA method. If the number and position of fixture elements are not optimal they may result in lower geometric accuracy [39]. Authors combined the Kriging surrogate model and multi-objective bat algorithm (MOBA) to reduce FEA calculations for multi-objective optimization in sheet metal fixtures [40]. Authors combined FEA and the whale optimization algorithm to minimize the overall strain energy of thin-walled parts by optimizing the number and position of locators [41].

The proposed methodology, including problem formulation and stages of fixture layout optimization using topology optimization, is discussed in Section 2. The flat plate and spacer grid case study is solved using the proposed method in Section 3. Linear static analysis is used to solve the problem, because fixture layout optimization problems are solved within the elastic limit range by defining the constraints in the problem formulation or by checking the failure criteria limits. The optimal results of case studies are discussed in Section 4. In Section 5, the experiment is performed to verify and compare the results of the flat plate case study with simulation results. Conclusions are explained in Section 6.

2. Proposed Methodology

The proposed method comprised three stages, shown in Figure 1. In the first stage, the initial number of clamps are determined. The second stage objective is to reduce the population for GA by a identifiying feasible region for clamps using the topology optimization technique. The third stage objective is to optimize the number and position of clamps using GA. This is done such that workpieces should have minimum number of clamps. Maximum allowed deformation is set to 2 mm, to get high stiffness of work piece. For stage 1 and stage 3, geomtry constraint of elements such as axis symmetry, same element type, and same material is used. For stage 2, axis geomteric symmetry constraint is not used because in this research the main purpose of topology optimization is to reduce the population for GA. So, axis symmetry will only increase computational effort and is not more useful.

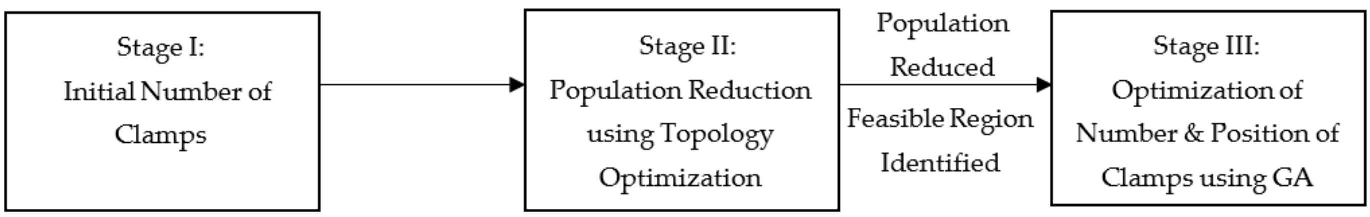


Figure 1. General procedure of proposed method.

2.1. Problem Formulation of Fixture Layout and Topology Optimization

The objective function of this research is to minimize the total deformation normal to the plane of the workpiece, while maintaining individual nodes deformation up to 2 mm. This research does not include clamping force and area as parameters in minimizing deformation in sheet metals. The following Equation (1) represents the objective function for Fixture layout optimization. Equations (2) and (3) represent the constraining condition and clamp, ranges respectively. The problem formulation of fixture layout optimization is represented as:

$$\text{Minimize } \sum \delta_i \tag{1}$$

$$\delta_{max} \leq \ 2\text{ m} \quad i = 1,2,3\ldots,n \tag{2}$$

$$\begin{array}{c} \text{Subject to } a_j \leq x_j \leq b_j \qquad j = 1,2,3\ldots,t \\ c_j \leq y_j \leq d_j \\ g_j \leq z_j \leq k_j \end{array} \tag{3}$$

where δ_i: nodal deformation

n: number of finite elements

t: primary plane clamps

a, b, c, d, g, k: Limit of clamps *in* x, y, z direction

Minimizing compliance, as shown in Equation (4), is the objective function [38]. Equation (5) represents the law of elasticity. Equation (6) shows displacement constraint, whereas Equation (7) represents mass constraint. Equation (8) indicates volume constraint. Equation (9) represents the density range of elements [35]. The problem formulation of topology optimization is represented as:

$$\text{Minimize } \mathrm{C}(\rho_i) = \mathrm{F}^T\mathrm{U} \tag{4}$$

$$\text{Subject to } \mathrm{F} = \mathrm{K}(\rho)\mathrm{U} \quad i = 1, 2, \ldots, n \tag{5}$$

$$\mathrm{u} \leq \bar{\mathrm{u}} \tag{6}$$

$$\mathrm{m} = \bar{\mathrm{M}} * \mathrm{m_o} \tag{7}$$

$$\sum v_i\, \rho_i \leq \mathrm{V} \tag{8}$$

$$0 < \rho_{min} \leq \rho_i \leq 1 \tag{9}$$

where C: compliance of structure
F: global load vector
ρ_i: density of ith element
U: global displacement vector
K: global stiffness matrix
n: number of finite elements
u: displacement value at point of interest
$\bar{\mathrm{u}}$: presetting max allowable value
m: mass after topology optimization
$\mathrm{m_o}$: initial mass
$\bar{\mathrm{M}}$: mass fraction constraint
v_i: volume of ith element
V: total volume of structure

2.2. Fixture Layout Optimization Using Topology Optimization

The proposed method comprises of three stages.

2.2.1. Stage 1—Initial Number of Clamps

Workpiece geometry is divided into four hypothetical quadrants after determining its geometric center. Maximum deformation in each quadrant is determined through LSA. Maximum deformation in a workpiece must be less than or equal to 2 mm. Any maximum deformation criteria can be set for this proposed method, depending on design requirements. In this research, 2 mm maximum deformation criteria is used just to validate the proposed method. None of the clamps are placed next to each other. Secondary and tertiary plane locators are fixed. After each step, LSA is performed and when maximum deformation is below 2 mm stage 1 is stopped. If the maximum deformation node is not at the edge then clamps are placed on the node at the edge, which is in line with the node of maximum deformation. This stage consists of following steps:

Step 1 The primary plane clamps are placed at the four corners of the workpiece and locators at their respective positions.
Step 2 Clamps are rearranged and moved to the new position of maximum deformation.
Step 3 Additional clamp is placed on node at the edge, which is in line with the node to which load is being applied.
Step 4 Clamp along force node is fixed and remaining 4 clamps are rearranged.
Step 5 An extra clamp is added to the node of maximum deformation. Total clamps in this step are 6. Clamps are added until it satisfies the maximum allowed deformation criteria. Flow chart of Stage 1 for finding initial number of clamps using maximum deformation is shown in Figure 2.

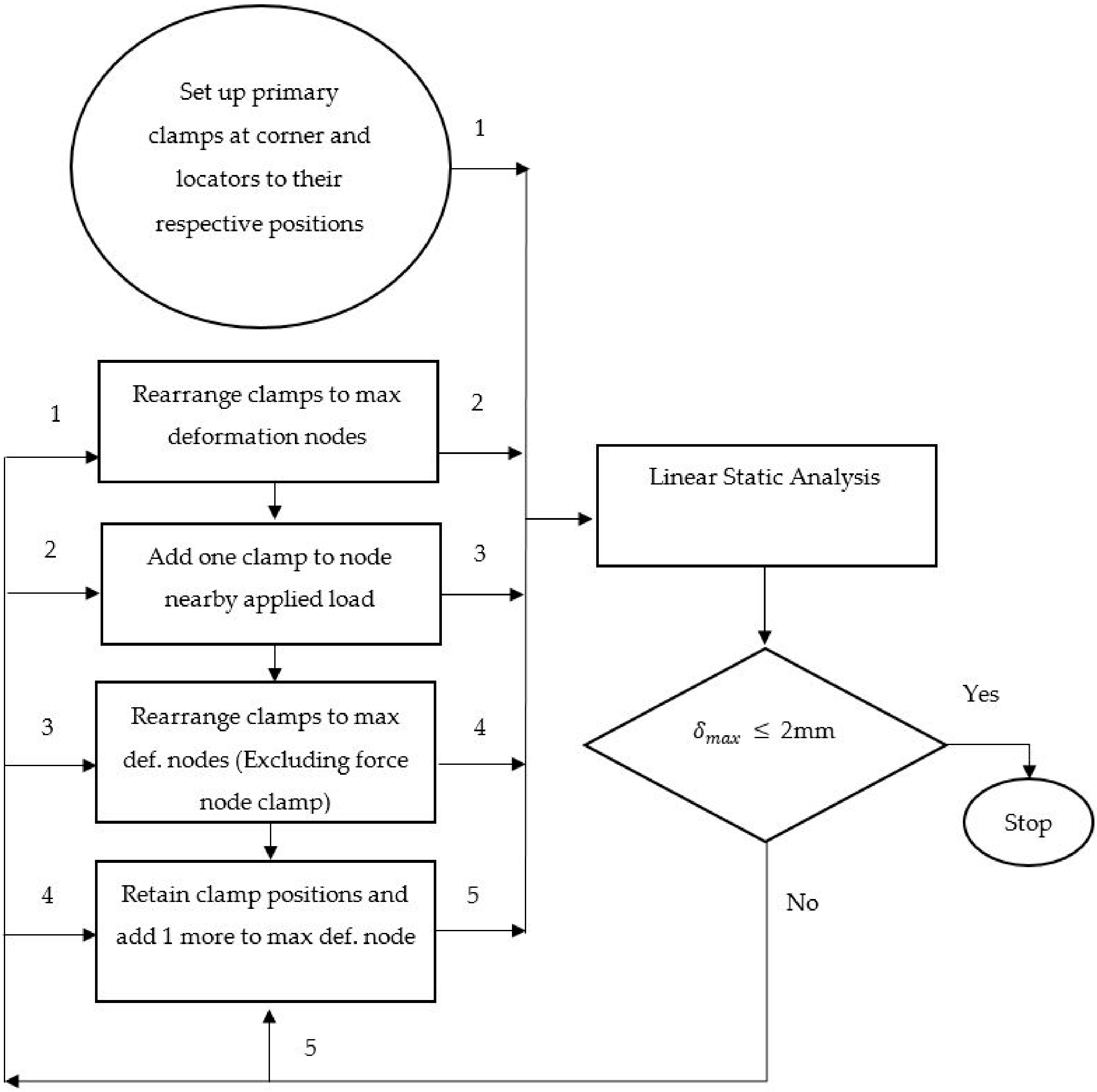


Figure 2. Stage 1 flowchart for finding initial number of clamps by using maximum deformation point data.

2.2.2. Stage 2—Population Reduction Using Topology Optimization

Step 1 To reduce computational effort, two quadrants with highest maximum deformation are taken as the design domain and another two as the non-design domain for topology optimization. Topology optimization is performed only on the design domain.

Step 2 Objective function is set to minimize compliance of the workpiece. Displacement constraint is maximum deformation; must be below or up to 2 mm at load node.

Step 3 Initially, mass constraint is set to 10% (mass removed 90%) and FEA is performed.

Step 4 Mass constraint is increased by 10% until maximum deformation of the workpiece reaches below or up to 2 mm.

Step 5 Workpiece geometry obtained after topology optimization has intermediate density elements. Geometry is imported in hypermesh and refined. Feasible range of clamps in each quadrant is identified. Flowchart to reduce population for GA using topology optimization is shown in Figure 3.

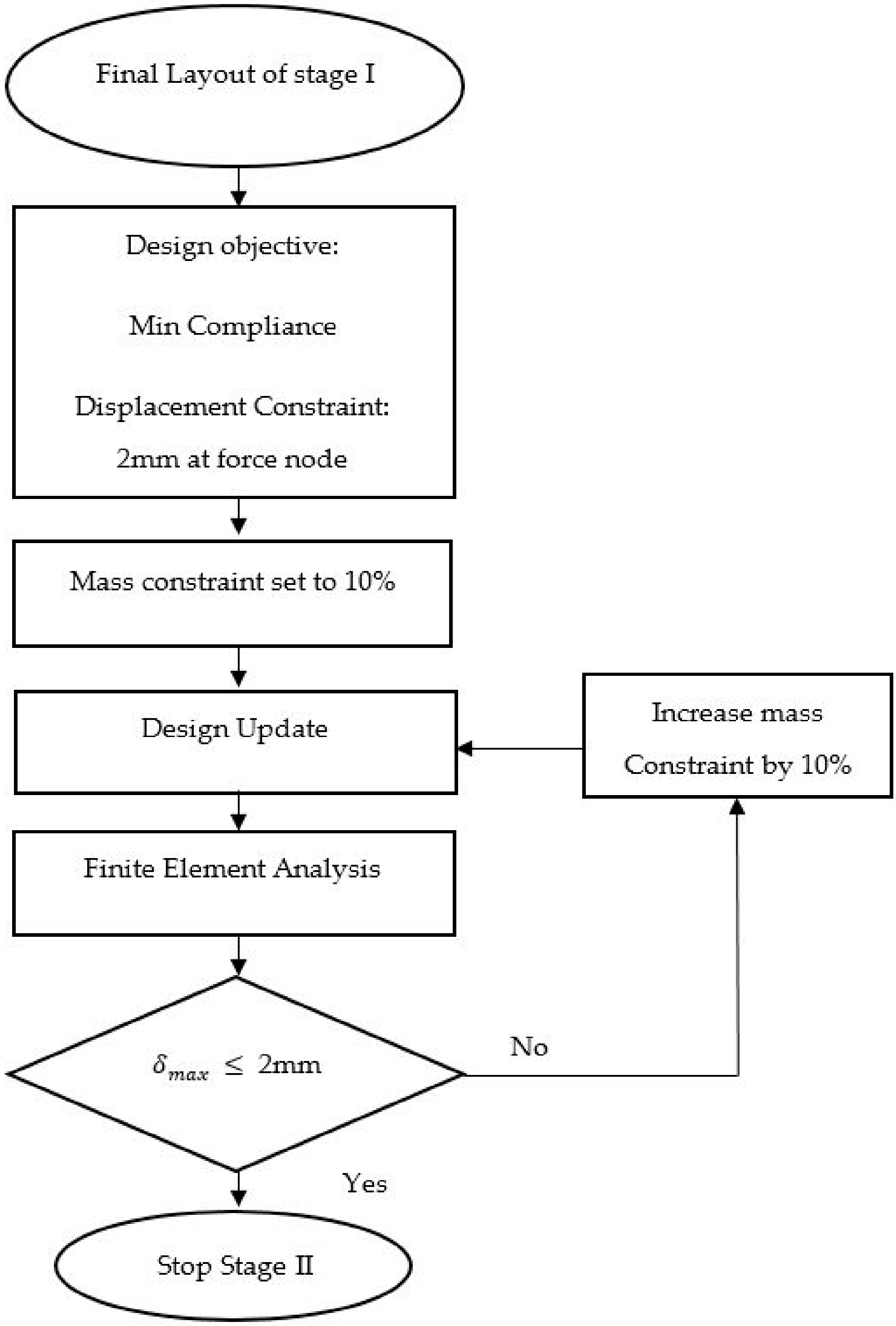


Figure 3. Stage 2 flowchart to reduce population by using topology optimization.

2.2.3. Stage 3—Optimization of Number and Position of Clamps

All possible combinations are generated within the feasible area of clamps, as found in stage 2. Clamps are removed methodologically while deformation is kept below or up to 2 mm. The final layout obtained in each subcase is regarded as the optimal layout, with the optimized number and position of clamps. According to N-3-2-1, the fixturing principle minimum number of clamps in the primary plane is 4. When the number of clamps reaches 4, the allowable maximum deformation criteria is rechecked and the process to reduce the number of clamps is stopped. A total of 25% of the reduced population, after topology optimization, is tested by using GA. When 25% of the reduced population is tested GA is terminated.

This stage comprises of following steps:

Step 1 Non-design region clamps are kept fixed because their position and number have very little effect on the reduction of deformation.
Step 2 One clamp is removed from the design quadrant, which has the least effect on deformation.
Step 3 All possible combinations of initial clamps in the design quadrant are generated. This process is just like population generation in the genetic algorithm. All clamps and locators are combined to generate the complete layout.
Step 4 Each combination of clamps and locators on the workpiece are contained in a separate subcase. The generated subcases are analyzed using MSC Nastran. The subcase with least maximum deformation is selected for the next step.
Step 5 Clamps are removed from the design quadrant until maximum deformation remains below 2 mm.
Step 6 Once the optimal number of clamps is found, the selection process is executed and population is generated.
Step 7 In the crossover process, the population selected from the selection process is split into two groups. The first half of the first group is paired with the second half of the second group, and vice versa.
Step 8 In mutation one or more clamps' position is changed in some combinations to gain diversity in the population.
Step 9 New population is generated which is different and more diverse than the initial population.
Step 10 Population is analyzed in MSC Nastran.
Step 11 The fitness is evaluated. When maximum deformation is below 2 mm the optimization process is terminated. If not, the procedure is recommenced until convergence criterion is fulfilled. Proposed GA is used for static load. This proposed algorithm may be modified to accommodate the requirements of dynamic load. Flow chart of Stage 3 for fixture layout optimization using GA is shown in Figure 4.

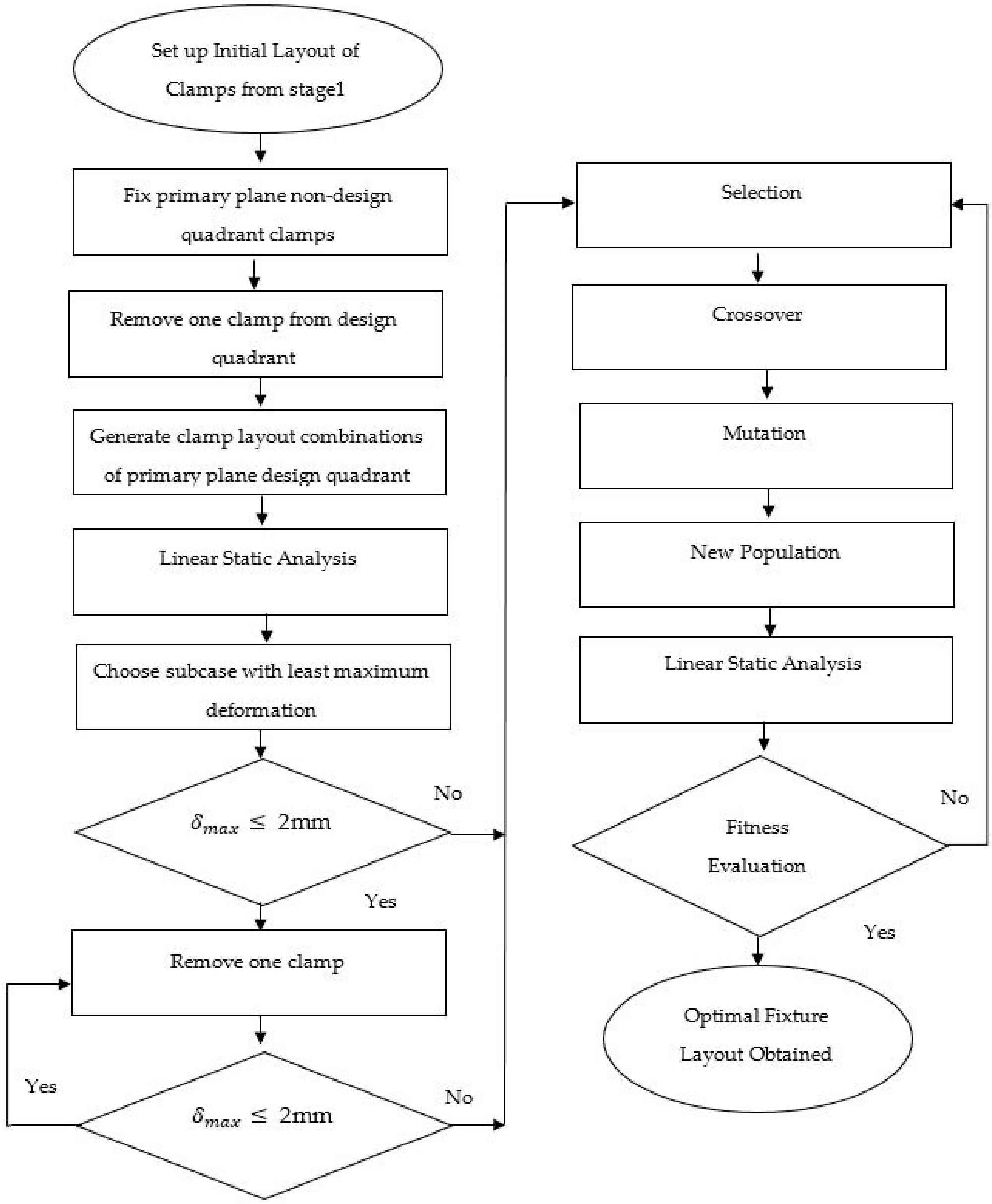


Figure 4. Stage 3 flowchart for fixture layout optimization using genetic algorithm.

3. Numerical Modelling

Two case studies are solved as per the proposed method. The preprocessing is done in Hypermesh, analysis in MSC Nastran, and optimization in Matlab. In MSC Nastran, for design sensitivity and optimization the SOL 200 command is used. CQUAD4 is used for quadrilateral plate element connection and the PSHELL property is assigned, which defines the membrane and bending properties of thin-shell elements. Membrane thickness of 1 mm is used. The density threshold used is 0.3, which means elements with density less than 0.3 are removed from the structure for topology optimization. The TOPVAR command is used, which defines the topology design region. DRESP1 defines the set of structural responses used in design either as objectives or constraints. The DCONSTR command is used to define displacement and mass constraints. The material used for optimization is steel with modulus of elasticity 210 GPa and a Poisson ratio of 0.3, which is defined using the MAT1 command. According to N-3-2-1 principles, two secondary plane locators are placed along the long edge at a 100mm distance from both corners. One tertiary plane locator is placed at the center of the short edge. The clamps on the secondary and tertiary planes were kept at their respective positions throughout both case studies. According to the N-3-2-1 fixturing principle, the N value must be greater than or equal to one. The clamps on the primary plane at the start are 4. Therefore, the initial fixturing principle is 1-3-2-1.

3.1. Case Study 1—Flat Plate

In this case study, a flat-sheet metal plate is considered; the dimensions of the sheet metal are 800 mm × 600 mm × 1 mm in the x, y, and z axes, respectively. Primary plane clamps are placed at the long edge of the workpiece. The finite element model of the flat plate is shown in Figure 5. Two subcases were considered in this case study. In subcase 1, 20 N load is applied at (600, 450, 0); in subcase 2, 30 N load is applied at (660, 510, 0) in Z-direction (downward).

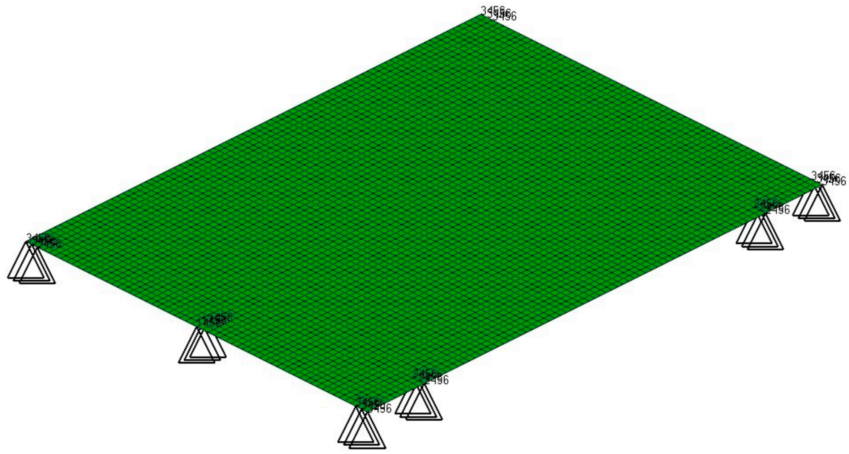


Figure 5. FEA model of flat plate.

3.2. Case Study 2—Spacer Grid

In this case study, a spacer grid is considered and the dimensions of the spacer grid are 800 mm × 640 mm in Z and X direction, respectively. The case study is solved in three stages. The workpiece has inclined long edges; due to this geometric constraint, the clamps cannot be placed at long edges. Therefore, only the short edge of the spacer grid is considered for placing clamps. The finite element model of the spacer grid is shown in Figure 6. Two subcases are considered in this case study. In Subcase 1, 200 N load is applied at (160, 45, 360); in subcase 2, 250 N load is applied at (180, 45, 400) in Y-direction (downward).

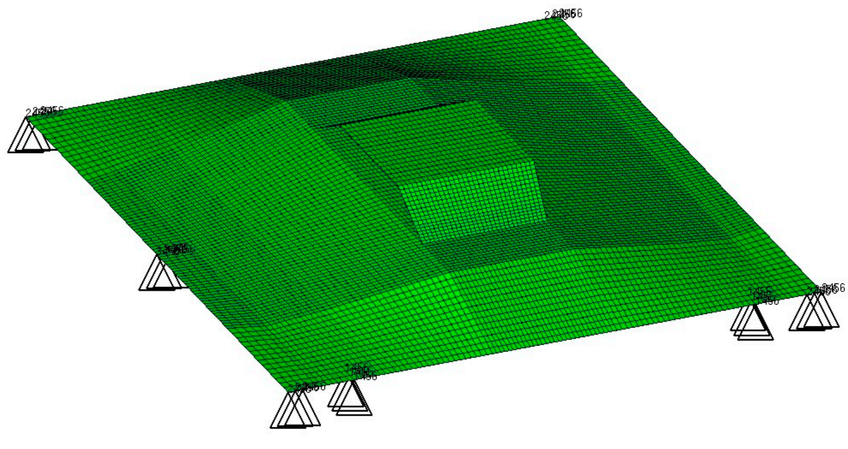
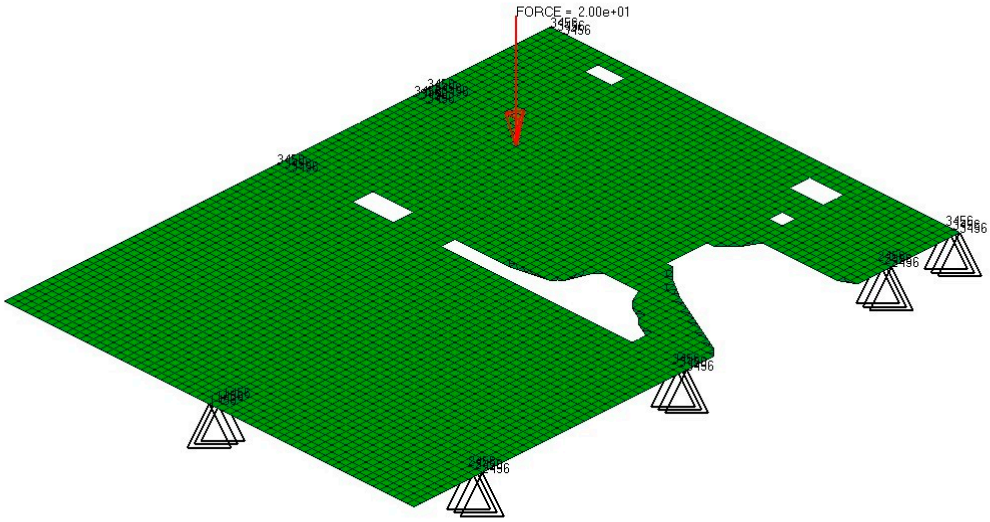


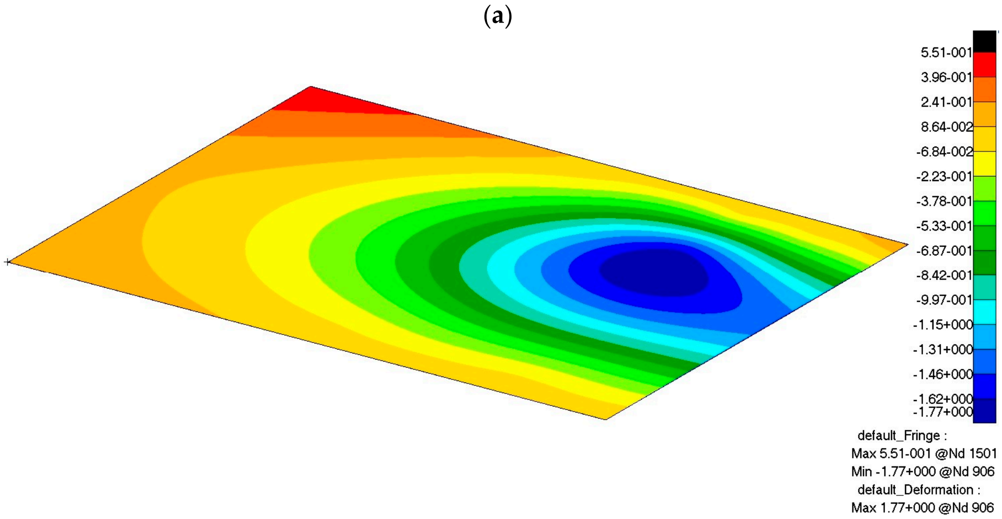
Figure 6. FEA model of spacer grid.

4. Analysis of Results

In this flat plat case study, the short edge has less impact on deformation. Clamps are only applied on the long edge of the workpiece. However different sheet metal materials are used by researchers. Bo et al. [28] used workpiece material with a density of 2.8×10^{-6} kg/mm^3. Ahmad et al. [17] and Vinosh et al. [42] used workpiece material with a density of 7.85×10^{-6} kg/mm^3; the same material is used in this research. In subcase 1 and subcase 2, the first and fourth quadrants have the highest maximum deformation, so these were considered as the design quadrant. In stage 1 of subcase 1, six clamps were found as the initial number of clamps. In stage 2 of subcase 1, the design quadrants' population was reduced from 1600 to 840. In stage 3 of subcase 1, five clamps were found as the optimal number of clamps. Similarly, for subcase 2 the initial number of clamps was determined to be 5. The design quadrants' population was reduced from 1600 to 560. In stage 3 of subcase 2, the optimal number of clamps was found to be 4. The workpiece, after topology optimization, and the final optimum results of subcase 1 and subcase 2 are shown in Figures 7 and 8, respectively.

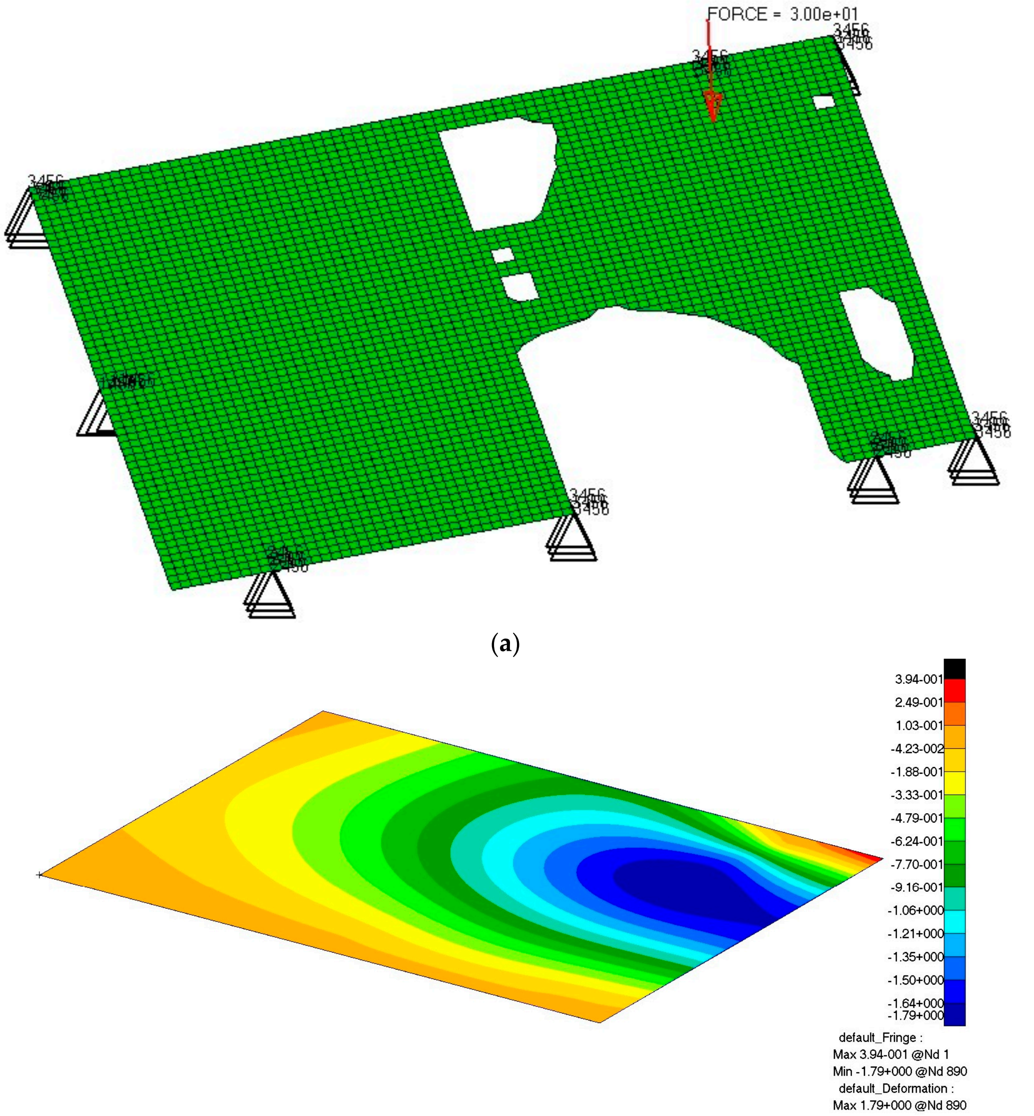


(**a**)



(**b**)

Figure 7. (**a**) Subcase 1: population reduction after topology optimization, (**b**) Subcase 1: optimum layout maximum deformation.

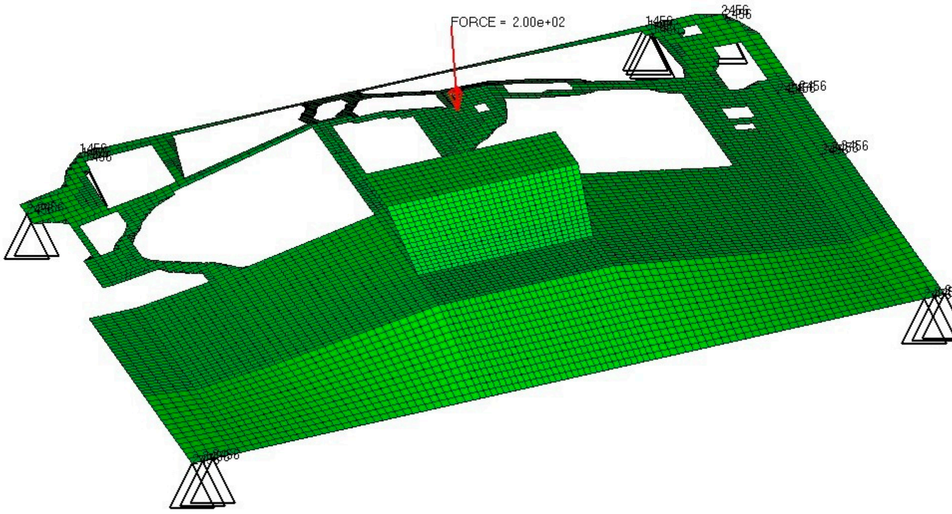


(**a**)

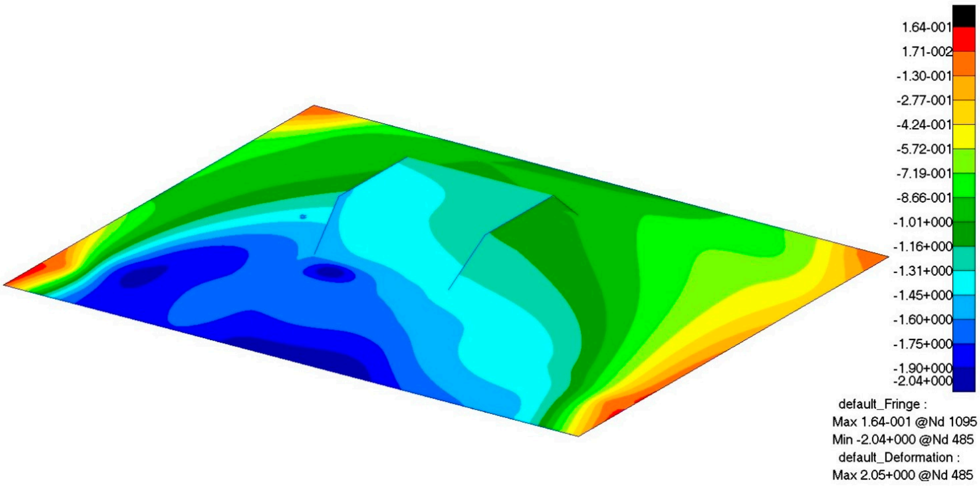
(**b**)

Figure 8. (**a**) Subcase 2: population reduction after topology optimization, (**b**) Subcase 2: optimum layout maximum deformation.

The spacer grid has inclined long edges, so clamps cannot be placed on long edges due to geometric constraint. Therefore, only the short edge of the spacer grid was considered for placing clamps. In subcase 3 and subcase 4, the second and third quadrants have highest maximum deformation after stage 1. Therefore, these quadrants were taken as the design domain for topology optimization. Subcase 3, stage 1 results eight clamps as the initial number of clamps. In stage 2, the population was reduced from 2025 to 195. Stage 3 results four as the optimal number of clamps for subcase 3. In subcase 4, ten clamps were determined as the initial clamps in stage 1. The population was reduced from 2025 to 390 in stage 2. Stage 3 results in 5 clamps as the optimal number of clamps. Figure 9 illustrates the workpiece after topology optimization and maximum deformation obtained from fixture layout optimization in the spacer grid case study.



(a)



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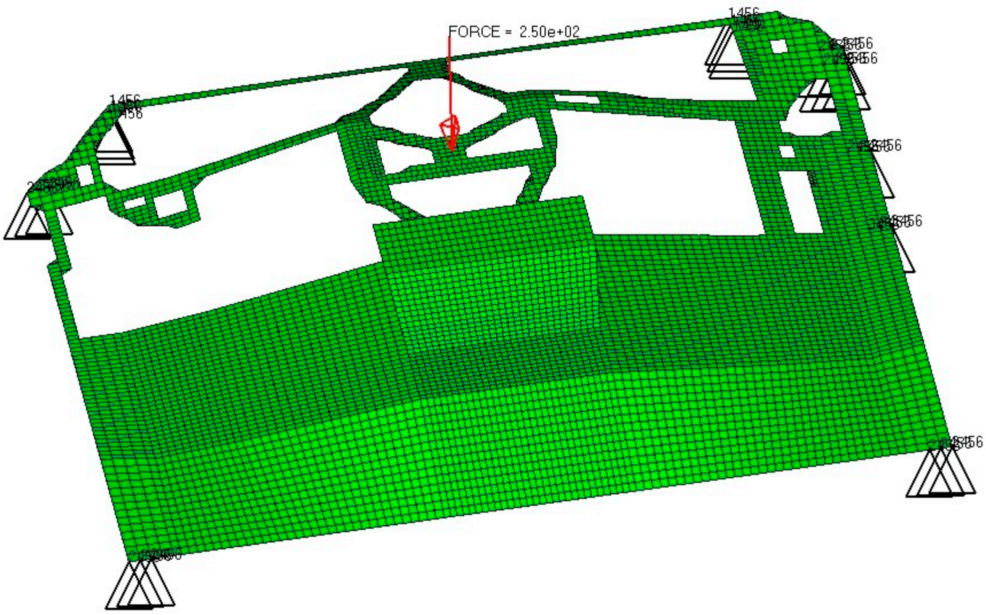
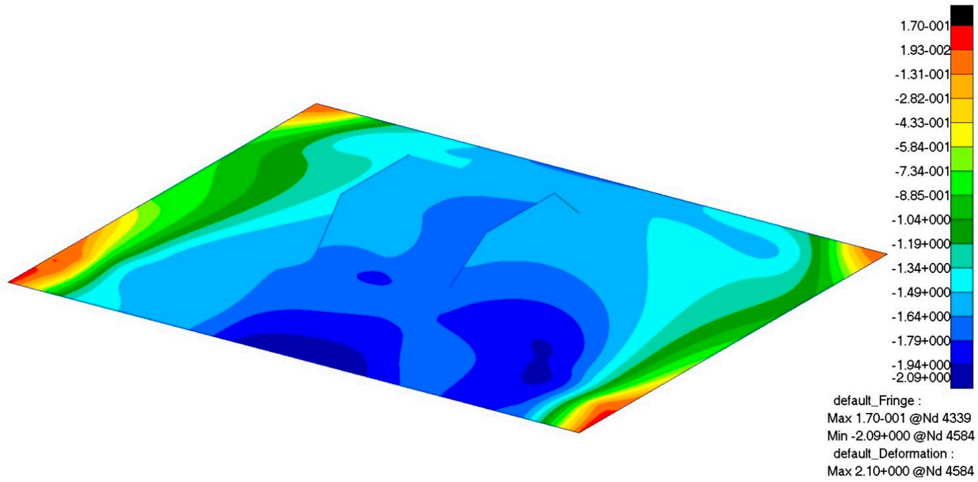


(c)

Figure 9. *Cont.*



(**d**)

Figure 9. (**a**) Subcase 3: population reduction after topology optimization, (**b**) Subcase 3: optimum layout maximum deformation, (**c**) Subcase 4: population reduction after topology optimization, (**d**) Subcase 4: optimum layout maximum deformation.

No. of clamps, maximum deformation, total deformation, and population reduction of both case studies is presented in Table 2.

Table 2. Results of all stages of case study 1—flat plate and case study 2—spacer grid.

Case Studies	Sub-Cases	Initial	Stage 1		Stage 2	Stage 3		
		Total Deformation (mm)	No. of Clamps	Maximum Deformation (mm)	Population Reduction (%)	No. of Clamps	Maximum Deformation (mm)	Total Deformation (mm)
Case Study 1—Flat Plate	1	17,010.1	6	−1.89	47.5	5	−1.77	2328.5
	2	17,857.9	5	1.57	65	4	−1.78	3091.3
Case Study 2—Spacer Grid	3	31,222.1	8	−1.82	90	4	−2.04	12,433.8
	4	39,297.4	10	−1.96	80	5	−2.09	15,775.6

The total deformation value in the final stage is optimum, which is less than the initial total deformation value. Similarly, the maximum deformation value in the initial layout and optimum layout is lowered. The number of clamps in both case studies are also optimized from stage 1 to stage 3. Maximum deformation is occurring in the design region, which indicates that topology optimization is accurate and that the criteria of the design region identification is validated. The topology optimization technique has proved to be helpful in reducing computational effort for GA.

The maximum deformation values of each subcase, in the flat plate and spacer grid case studies, are shown against each iteration in Figure 10.

The iteration number is represented on the x-axis and maximum deformation against each iteration on the y-axis. As shown in Figure 10a,b, optimum results of subcase 1 and subcase 2 were obtained on the 64th and 46th iterations, respectively. Similarly, as shown in Figure 10c,d, optimal results of subcase 3 and subcase 4 were obtained on the 4th and 14th iterations, respectively.

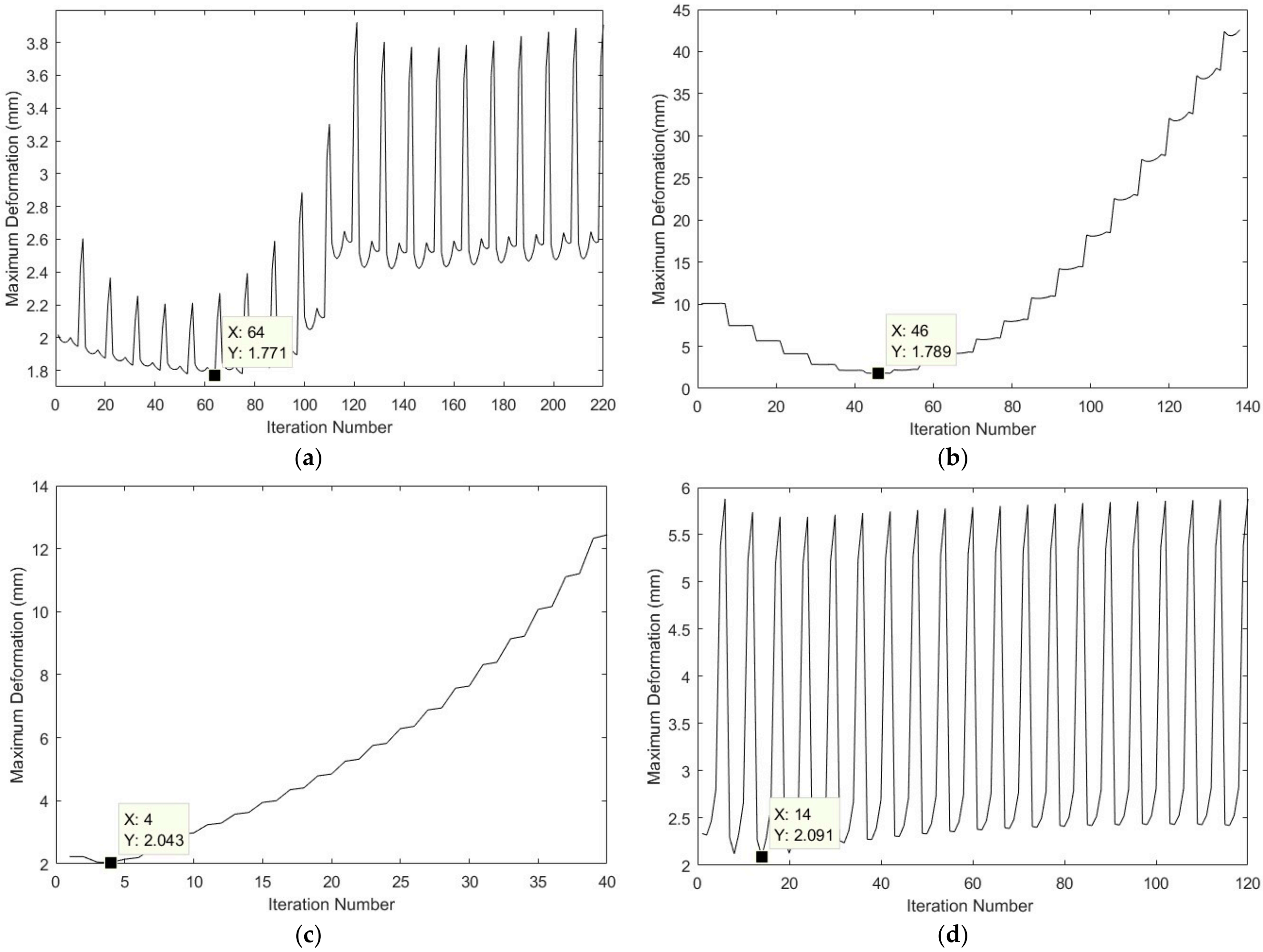


Figure 10. (**a**) Subcase 1: graph of maximum deformation, (**b**) Subcase 2: graph of maximum deformation, (**c**) Subcase 3: graph of maximum deformation, (**d**) Subcase 4: graph of maximum deformation.

5. Experimentation

A practical is performed to verify the results of the flat plat case study. The experimental setup consists of clamp mounting assembly, sheet metal of the same dimensions as in simulations, load applying apparatus, and clamps and deflection gauge. Clamps, applied load, and maximum deformation points are marked on the sheet metal. The deflection gauge is set below the sheet metal to measure maximum deformation; load is applied and clamps are clamped on the sheet metal as layout obtained from simulation. Maximum deformation is measured.

5.1. Experiemntal Procedure

The procedure to perform the experiment consists of the following steps:

1. Use the coordinates obtained from the simulated layout to mark the clamps, locators, and load positions on the sheet metal workpiece.
2. Adjust the clamp positions on the guide channels according to the markings on the sheet metal.
3. Mark the position where maximum deformation occurred in simulations.
4. Place sheet metal in the assembly and clamp it.
5. Place the load applying apparatus over the sheet metal and put weight over the load applying apparatus.

6. Place the dial indicator at the marked position of maximum deformation below the sheet metal.
7. The deformation value is now measured and is compared with the simulation results.

Details of the experimental components used in this research are shown in Figure 11.

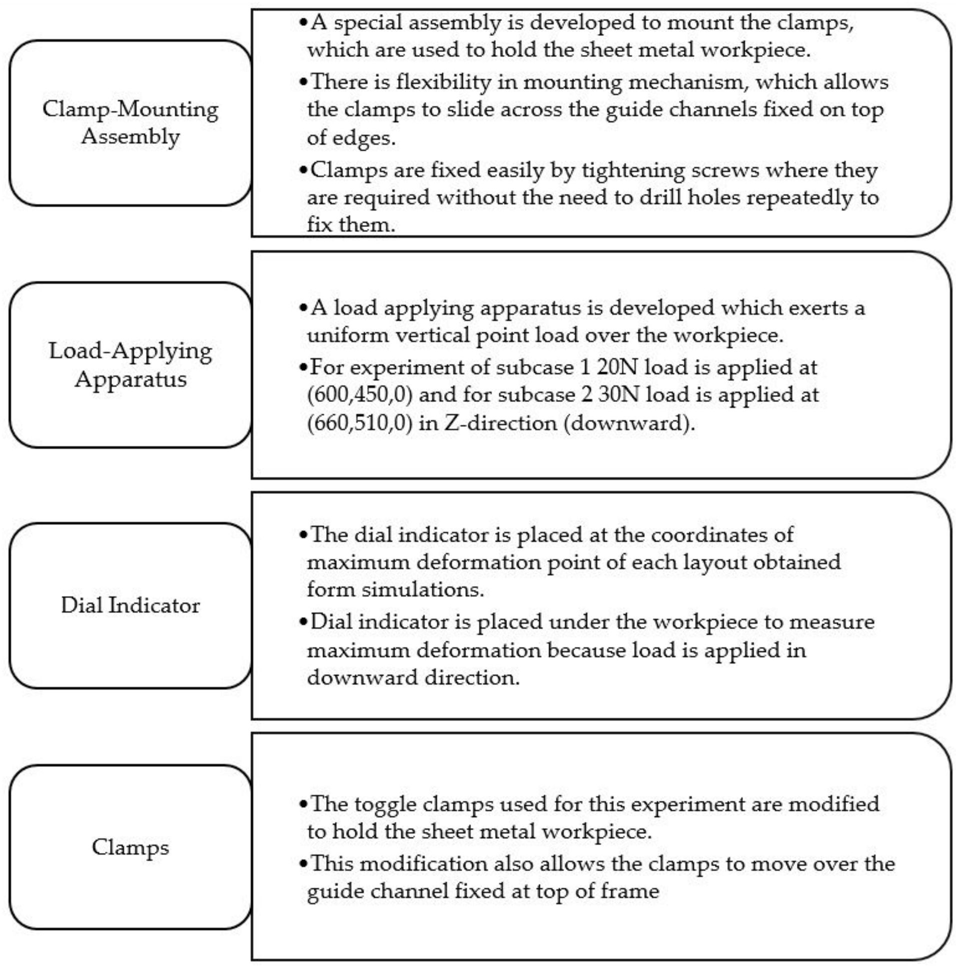


Figure 11. Block diagram containing details of all experimental components.

Experimental setup with all its components is shown below in Figure 12.

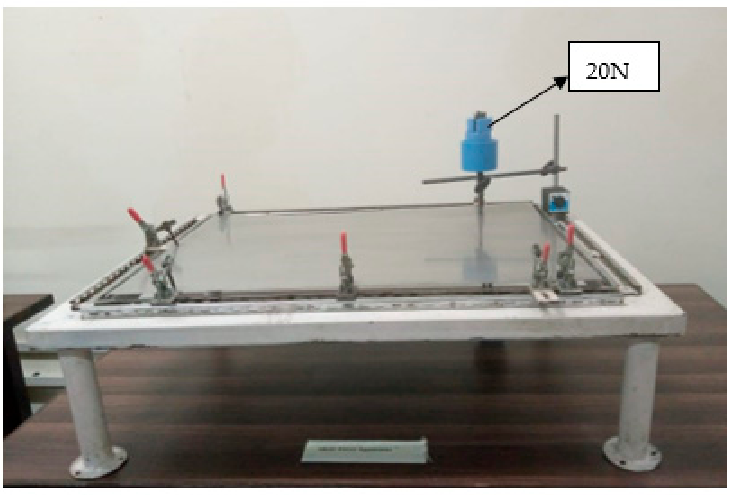


Figure 12. Experimental Setup of Case Study 1—Flat Plate.

5.2. Experiemntal Results Dicussions

The coordinates of clamp positions and node with maximum deformation at completion of stage 1 and stage 3 of subcase 1 and subcase 2 are given in Table 3.

Table 3. Coordinates of clamp positions and maximum deformation point case study 1—flat plate.

Subcase	Load (N)	Distance from Origin (0,0,0)			Maximum Deformation Point		
		Initial	Stage 1	Stage 3	Initial	Stage 1	Stage 3
1	20	0, 0, 0	400, 0, 0	400, 0, 0	470, 600, 0	610, 380, 0	610, 390, 0
		800, 0, 0	800, 0, 0	640, 0, 0			
		800, 600, 0	800, 600, 0	700, 600, 0			
		0, 600, 0	400, 600, 0	600, 600, 0			
			600, 600, 0	400, 600, 0			
			620, 600, 0				
2	30	0, 0, 0	400, 0, 0	400, 0, 0	510, 600, 0	670, 390, 0	650, 400, 0
		800, 0, 0	800, 0, 0	740, 0, 0			
		800, 600, 0	800, 600, 0	0, 600, 0			
		0, 600, 0	660, 600, 0	680, 600, 0			
			0, 600, 0				

The end results of both initial and final stages of simulations are compared with the experimental results. The difference between the experimental and simulation values is due to some factors like human error, clamping force, etc. The deformation values obtained from the experimentation are still within the maximum deformation allowable limit (2 mm). Comparison of the simulation (Sim.) and experimental (Exp.) values of initial and final maximum deformations of the flat plate case study are shown in Table 4.

Table 4. Comparison of simulation (Sim.) and experimental (Exp.) results of case study 1—flat plate.

Subcase	Maximum Deformation (mm)					
	Initial			Final		
	Sim.	Exp.	% Diff	Sim.	Exp.	% Diff
1	−8.53	−9.2	−7.6	−1.77	−1.86	−4.5
2	−10.5	−11.5	−8.3	−1.79	−1.91	−6.5

6. Conclusions

A workpiece is constrained by the proper arrangement of fixture elements, known as fixture layout. The flexible nature of sheet metal requires the N-3-2-1 fixturing method, which requires at least four clamps normal to the plane to restrain workpiece excessive deformations. The genetic algorithm requires high computational effort for fixture layout optimization due to the large number of the population. In this research, a new method for fixture layout optimization of sheet metals is proposed. The proposed method combines topology optimization and GA. Topology optimization is used to reduce populations for GA. The objective function is to reduce populations for GA and minimize total deformation normal to plane of the workpiece, while maintaining maximum deformation of individual nodes up to 2 mm. The proposed method consists of three stages. The initial number of clamps are determined in stage 1. In stage 2, the population is reduced using topology optimization. In stage 3, the number and position of clamps, earlier identified in stage 1, are optimized using GA. The proposed method is implemented on two case studies: flat plate and spacer grid. Convergence criteria for GA is to solve 25% of the reduced population in each subcase. The results show that in subcase 1 and subcase 2 the population was reduced by 47.5% and 65%, respectively. Whereas, in subcase 3 and subcase 4, 90% and 80% of the population is reduced using proposed method. Total deformation normal to the plane was also reduced in each subcase. The experiment is also performed on case study 1—flat plate and results are compared with simulation results. It concludes that the optimal number and position of clamps are determined using less computational effort by integrating topology optimization into GA. The proposed algorithm can also be used in different industrial scenarios to find optimum positions, especially for respot welding operations of sheet metals.

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