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Experimental and numerical study of hammering process on stress concentration factor for different hole shapes

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The stress concentration factor (Kt) in (holes, notch, streamed, etc.) regions of mechanical parts is regarded as a significant and frequent issue that needs to be addressed since raising it in response to large strains and deformations in mechanical elements may fail. The current study examines stress concentration, its factor influence, and various hole shape types using mild steel plates with various hole shapes (circle, triangle, square, and elliptical). A theoretical equation can be used to calculate in (Kt) and all results are practical to kt. The mechanical characteristics and applied tensile stress on a mechanical element. The Auto Desk Inventor program is used to recreate the earlier states, and all of the results follow the same trend, with the triangle hole possessing the highest value (Kt). The Auto desk inventor program is used to simulate the previous states and all results refer to the same trend, where the maximum (Kt) is for a triangle hole (4.8, 7.9), while the minimum is for an ellipse hole whose major axis is perpendicular on longitudinal axis plate (2.26, 1.79, 2.1). The reduction of stress concentration and its factor by using the hammering process on hole edges produces residual stress due to strain hardening in a metal plate. The (Kt) results reduce because of bearing in a circle hole, while compression force on the internal surface of holes (triangle, square, and ellipse). The result in the direction of the hammering process succeeds in producing resist force against the tensile process during the operation of the mechanical element. The stress concentration is increased in a circle hole, the greater the stress concentration to prevent fatigue, avoid abnormalities, and use rounder fillets whenever possible. Surface modification: Because machining leaves behind scratches and grooves, polishing a machined surface will lengthen its fatigue life. Compressive residual stress can be added to the surface layer to extend fatigue life.

Keywords: Stress concentration; Stress Concentration Factor; Hammering process; Strain hardening.

1. INTRODUCTION

The increase in internal stresses that take place in a loaded structural part with a circular opening is measured by the stress concentration factor at a hole, which is a dimensionless constant. Currently, nanotechnology is widely used in many applications of mechanical engineering. The influence of nanoparticles can impact positive effects due to their unique properties such as high reactivity, and large surface area. The work of one researcher is the numerical analysis of stresses in the plate has holes, which are drilled along the plate diametrical. The plate is subject to a leveler load. The plate is subjected to biaxial loading in Y direction (Fy = +/- 100KN) and in the Z direction (Fz = +/_ 100KN). The stress concentration is reduced in the plate which has one hole and two holes respectively. In another study, plate steel (45C8) in square shape with dimensions (50*50 mm) and thickness (10mm), which have different shapes of holes such as; square, circular, rectangular, and triangular. One side of the plate is fixed and the other sides are subjected to it tensile force. The nominal stress can be calculated with the help of finite element analysis (FEA) by software and then calculate stress concentration factor (Ft) for every hole of different shapes contrasts with each other. In another paper, the goal is exemplified by stress concentration by simulation approach, where the results converge with practical results. The accuracy of simulation results gives seizure numerical data that can be used in applications to reduce the cost. The practical curves of (Kt) can be regarded reference for workers in this field, where it contains very small errors. The different shapes of holes are selected and designed in the ANSYS program on condition, these shapes are similar to mechanical models. The three types of loadings are subjected to edges of shapes; axial forces, elastic moment, and torsional torque to get maximum normal force which is related to stress concentration factor calculation.

2. BACKGROUND

The mechanical behavior of a material reflects the relationship between its response or deformation to an applied load or force. The study focused on the effect of the different apertures mentioned above on the properties of the concentration factor (Kt). The stress concentration is increased with an increase in hole number [1, 2]. The simulation by solid works program is used to know the shape best of the hole which has less stress concentration and (Kt) to use this approach in varied applications [3,4]. The results from the simulation have the same reliability and can be used to achieve low cost [5,6]. The factor of safety is regarded as very important to avoid unnecessary loss in material life because of the high degree of stress in mechanical elements. If the maximum stress is increased anent nominal stress is in (groove, notch, holes … etc.), therefore stress concentration factor is also increased. The present research discusses different ways to calculate stress concentration factors [7-9].

The steel alloy GH4169 is used to investigate residual stress that is produced from tensile deformation and uses a micro mechanism to show tensile deformation. The residual stress hasn't constant density in the alloy as in test X-ray for residual stress, X-ray diffract meter (XRD), and electron backscatter diffraction. The results in research show that any increasing about 3% in tensile deformation due to increasing for maximum value of residual stress reaches about 90%. One of the common ways to relieve residual stress is heat treatment at specified temperatures in the furnace, then the residual stress is reduced and distributed uniformly in the alloy. In multiplication don't regard residual stress in mechanical elements although is very important to avoid failure [10, 11, 12]. Many materials, when in experiments, are subjected to forces or loads; examples include the mild steel plates from which the holes work constructed. In such situations, it is necessary to know the characteristics of the material and to design the member from which it is made such that any resulting deformation will not be excessive and fracture will not occur. The amount of deformation on the surface of the hole inside and outside and the amount of failure while maintaining the mechanical properties of the metal surface mentioned above. [13-18]. To assess the level of stress concentration in a mechanical part, the stress concentration factor

(Kt) is a dimensionless factor. The higher stress ratio in a part compared to the reference stress is what is referred to by this term. The structural stress concentration factor (Kt) used in engineering applications is available in many hole shapes (circle, triangle, square, and elliptical) sections. The stress concentration factor (Kt), is a dimensionless factor that is used to quantify how concentrated the stress is in a material. It is thus defined as a ratio of the highest stress in the element to the reference stress.

Scope of Study: The scope of this research is to clearly define and ensure the achievement of the analysis process by examining the mild steel plates to estimate stress concentration for various geometric shapes with different types of holes shape using different methods to find the main influencing factors

3. MATERIALS AND METHODS

3.1 Theoretical Stress Concentration Factor

The Von Mises theory is used as a principle in the present study, where the tensile load is subjected to the square shape of a mild steel plate in dimensions (200, 60, and 5mm). The cross-section of the plate is depending to calculate of nominal stress according to tensile force which is a constant value (1000N) to all states. The Von Mises theory is used in theoretical and simulation. The prediction of "actual" stress resulting from different geometry holes, a

The theoretical stress concentration factor is applied to the nominal stress. For a part fixed from one end subject to a nominal stress, the true stress in real-time adjacency of the geometric discontinuity is calculated as:

$$\sigma_{max.} = K_t \cdot \sigma_n \text{ , } so \; K_t = {}^{\sigma_{max.}}/_{\sigma_n} \tag{1}$$

Similarity, also estimates the highly localized amplification of shear stress in the vicinity circumference of different geometric.

$$\tau_{max.} = K_t \cdot \tau_n \tag{2}$$

$$\sigma_{nominal} = \frac{F}{b * t} \tag{3}$$

The stress concentration factor (Kt) is obtained experimentally and numerically in the present work, and regarding geometric property is very important. (Kt) is very important in brittle material, but in ductile material, where (Kt) is important in fatigue calculation, if safety is critical, localized yielding hardness material (strain hardening) and redistribution stress concentration.The present research specifies areas of different shapes as the same calculations and subjected to tensile load in constant value, while the nominal stress of apart around cross-section, and typically assumes a linear elastic, homogenous, and isotropic. The shape of the cavity in mild steel plate taken (circular, square, ellipse, hexagon, rectangular, triangle). The mechanical and physical properties of mild steel plate as shown in Table 1.

Table 1 The mechanical and Physical properties of mild steel plate.

Name	Mild steel	
General	Density	7.86 g/cm^3
	Yield Strength	207 MPa
	Ultimate Tensile Strength	285 MPa
Stress	Young Modulus	220 GPa
	Poiesso s' ratio	0.275
	Shear Modulus	86.274 GPa
Thermal Stress	Expansion Coff.	0.000012 ul/c
	Thermal Conductivity	56 W/m.k
	Specific heat	460 J/Kg.c

4. EXPERIMENTAL WORK

In the state of sheet steel metal has different hole shapes subjected to tensile load and these different holes have the same area and are located in the center of the plate, hence, these different hole shapes have an effect on the calculation of nominal stress as shown in figure 1. The tensile test for these plates is produced in universal tensile test equipment in the workshop of the mechanical department at Al-musaib Technical Institute as shown in figure 2. When the tensile test is performed, the results of maximum nominal loads have been recorded and calculate maximum nominal stress, whereas from characteristics of mild steel plate in Table, hence, (Ultimate tensile strength = 285MPa), and assume a factor of safety is 5, therefore the maximum normal stress is (σmax.=σultimate/F.O.S)=57MPa), and then can be calculated practical stress concentration factor value for every state of hole shape.

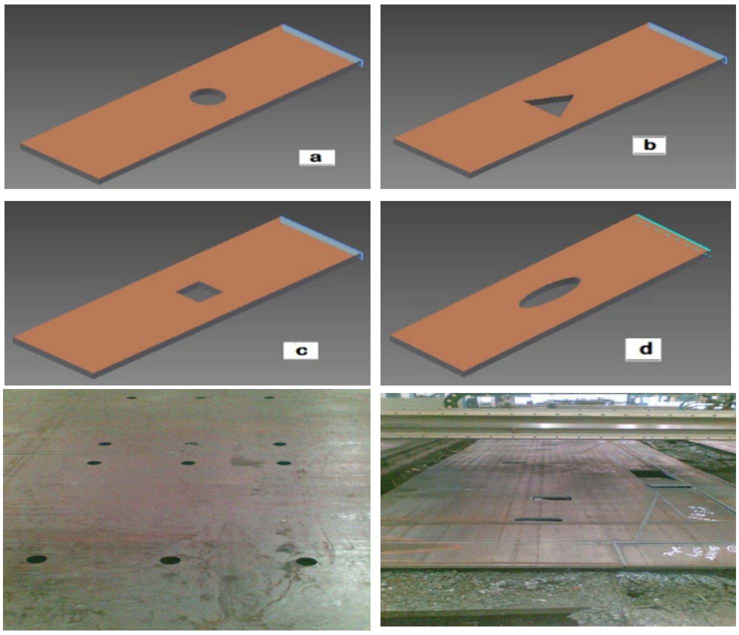

Figure 1 The different hole shapes in mild steel plate (Real samples).

Based on calculations, a safety factor of 5 is assumed. This indicates that the holes can support five times their Safe Workload (SWL) before breaking. Therefore, if an SWL of 5:1. The amount of excess load that a material surface will bear (or be required to sustain) over what is anticipated is what all calculations, at their core, quantify. Safety factor values can be viewed as a standardized method for evaluating the robustness and expendability of diverse systems. Depending on the availability of mild steel metal and its thickness, the size of the holes is not fixed.

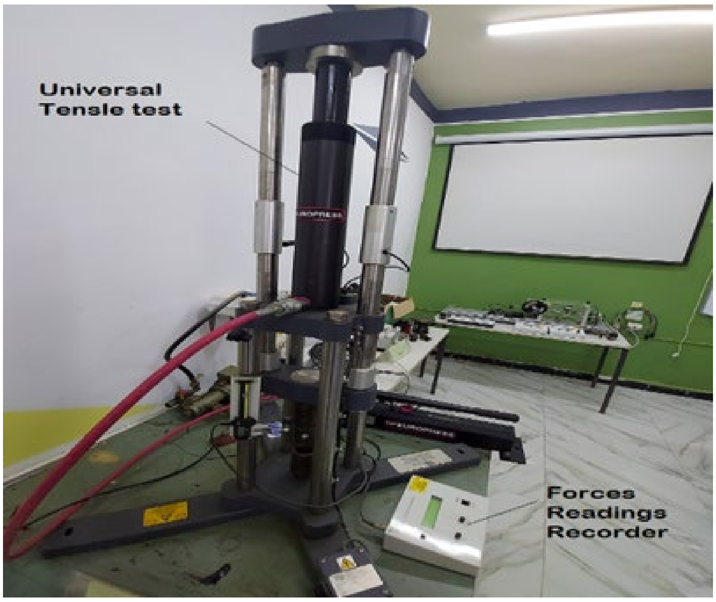

Figure 2 The universal tensile test equipment.

Table 2 Experimental results of tensile test.

Shape of hole in plate	Cross section of plate in hole region(mm)	Max. Tensile force (N)	Max. Nominal Stress (MPa)	Stress concentration Factor(K_t)
Plate with circular hole	(b-d) h=200	2225	11.25	5
Plate with Triangle hole	(b- triangle base)h=210	1520	7.2	7.9
Plate with Square hole	(b-t) h=210	1645	7.83	7.2
Plate with ellipse hole perpendicular on longitudinal axis	(b-4a) h = 160	4250	26.5	2.1
Plate with ellipse hole parallel with longitudinal axis	(b- 2a) h =230	2850	12.39	4.6

The hydraulic press is used in practical work press is used in practical work which existed in Almusaib Technical Institute workshop, its capacity is 5 tons as shown in figure 9. The press is used to hammer mild steel plates on the edges of different shapes holes to produce strain hardening in these regions and to resist stress concentration in hole edges by residual stresses in this region because of the hammering process. The previous samples are tested in universal tensile equipment after the hammering process to calculate (Kt) listed in Table 3.

Table 3 The experimental results of (Kt) at hammering process on plate holes.

Shape of hole in the plate	Max. Nominal stress(MPa)	(Kt)
Plate with circular hole	14.7	3.8
Plate with Triangle hole	11.8	4.8
Plate with Square hole	12.9	4.4
Plate with ellipse hole perpendicular on longitudinal axis	31.8	1.79
Plate with ellipse hole parallel with longitudinal axis	14.3	3.98

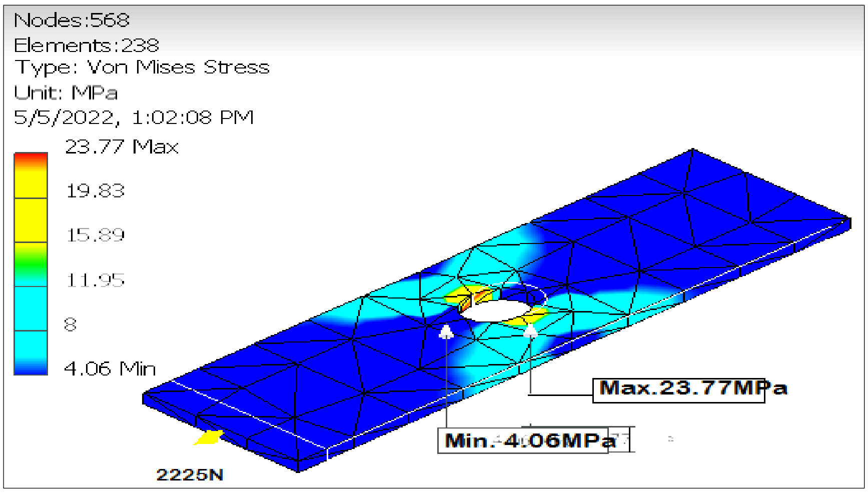

Figure 3 The hammering process by the hydraulic press on the plate.

5. SIMULATION WORK

The auto desk inventor program is used to draw mild steel plates that contain different shapes of holes (circular, triangle, square, and ellipse) as shown in previous figure 1, and is subjected to tensile force which equals practical tensile force as illustrated in the previous table 2. The results of nominal stress as shown in figures (4, 5, 6, 7, 8), and from □nominal value can be calculated (Kt) value. The strain hardening force affects on different whole region edge implications of the hammering process by hydraulic press. According to Von Mice theory, the same value of previous forces are subjected on plates, then the results are shown in figures (9, 10, 11, 12, 13). All the simulation results and (Kt) values are listed in Table 3.

Figure 4 Nominal stress at circular hole edge in mild steel plate.

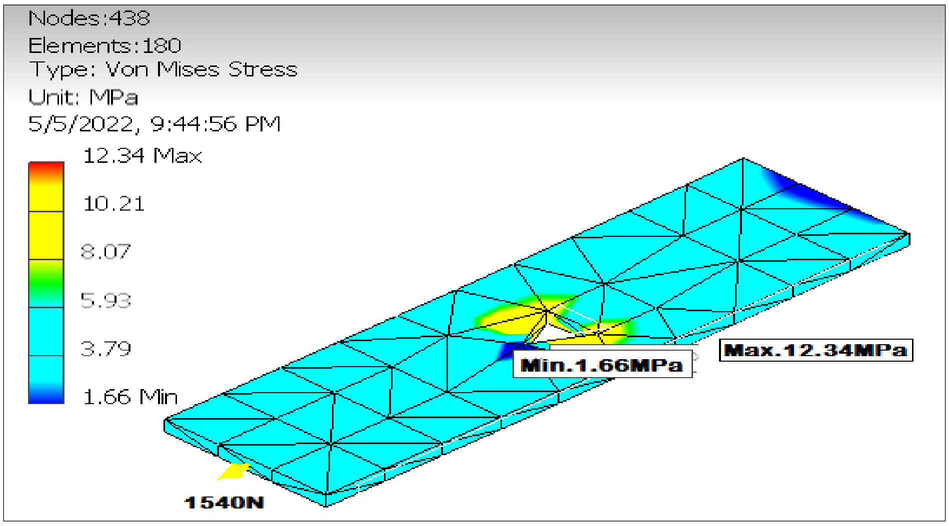

Figure 5 Show nominal stress at triangle hole edge in mild steel plate.

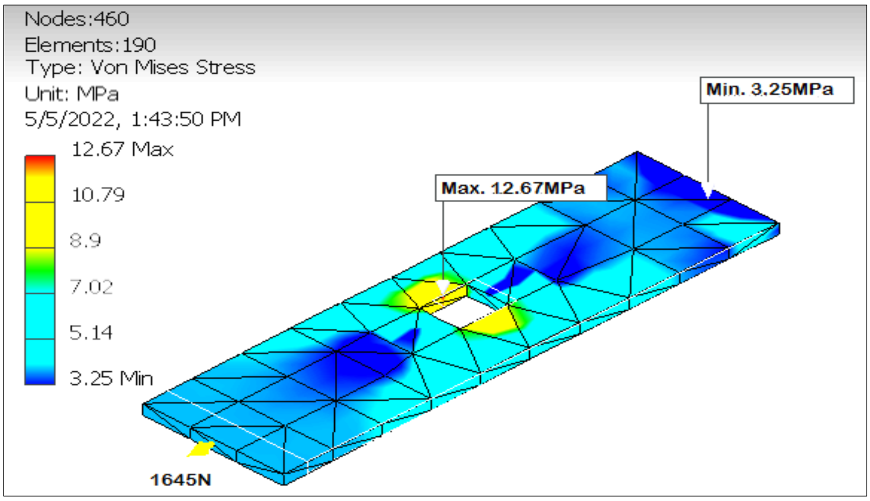

Figure 6 show nominal stress at square hole edge in mild steel plate.

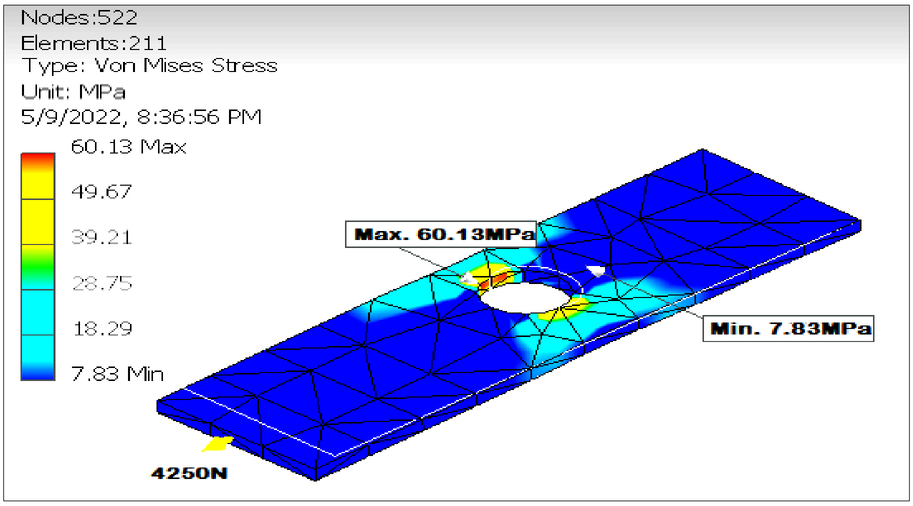

Figure 7 show nominal stress at ellipse hole edge in mild steel plate perpendicular on axis.

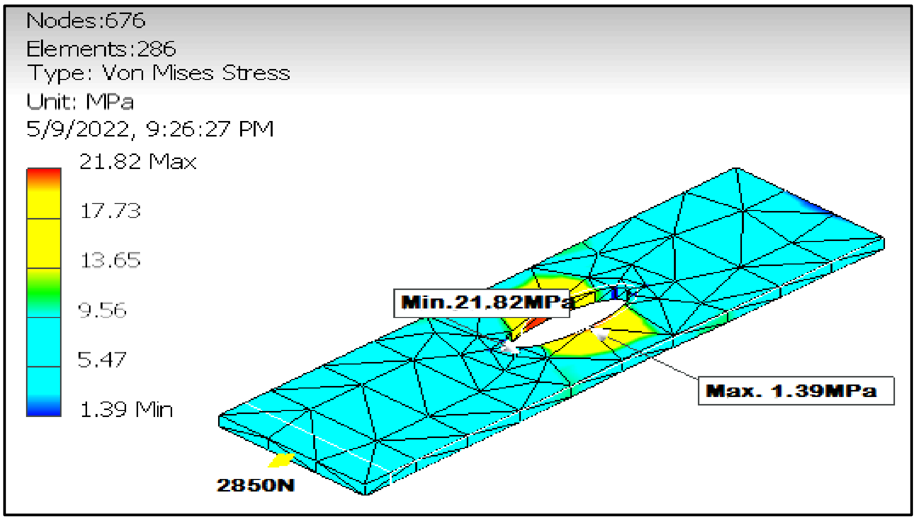

Figure 8 show nominal stress at the ellipse hole edge in mild steel parallel with the axis.

The Auto Desk inventor program is used to simulate samples with strain hardening due to the hammering process to calculate nominal values by (FEM) as shown in figures 9-12 and then calculate (Kt) in Table 4.

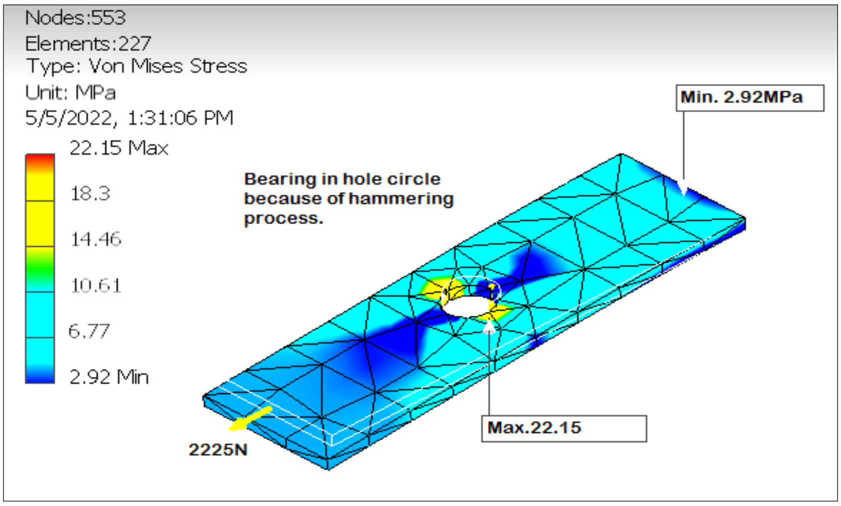

Figure 9 The simulation result of mild steel plate has circular hole after hammering process.

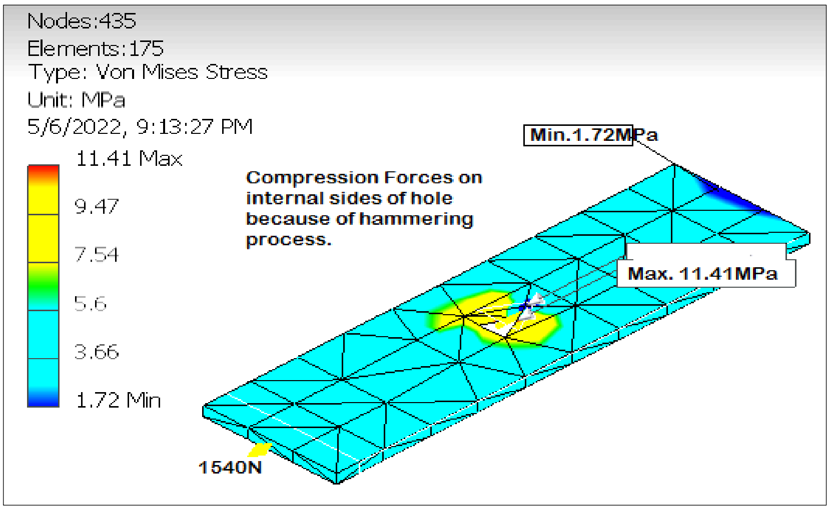

Figure 10 The simulation result of a mild steel plate has a triangle hole after the hammering process.

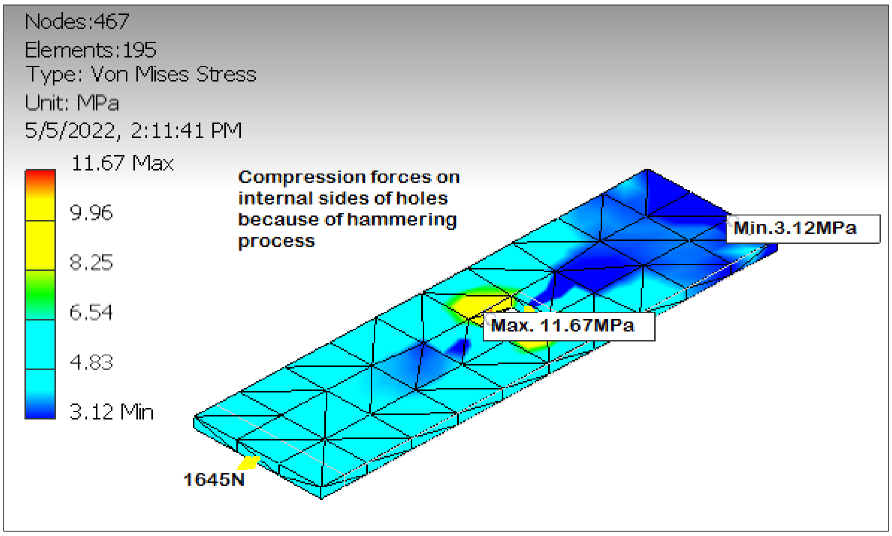

Figure 11 The simulation result of mild steel plate has triangle hole after hammering process.

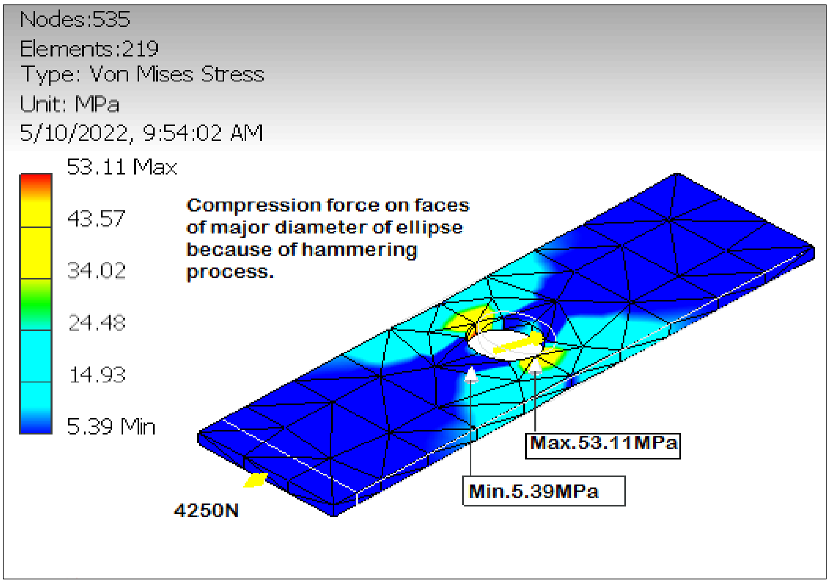

Figure 12 The simulation result of the mild steel plate has an ellipse hole perpendicular to plate longitudinal axis after the hammering process.

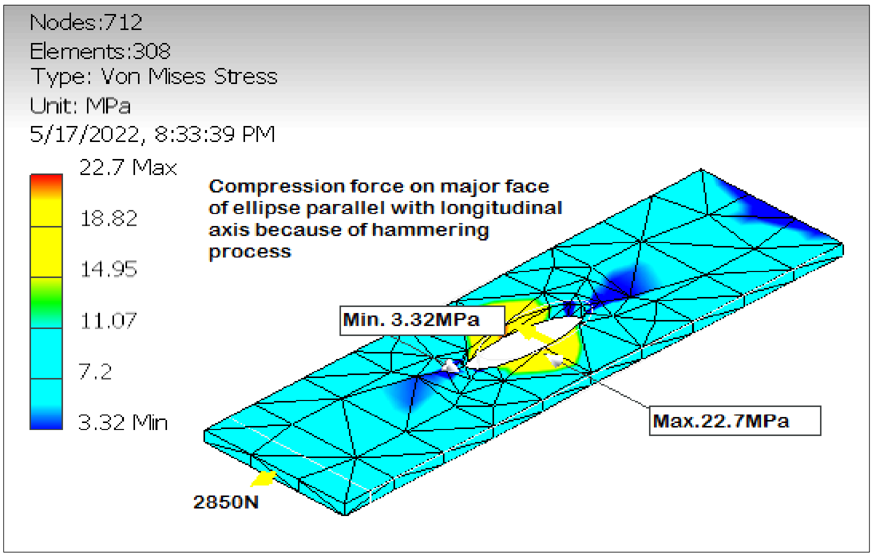

Figure 13 The simulation result of the mild steel plate has an ellipse hole parallel to the plate's longitudinal axis after the hammering process.

Table 4 Simulation results of (Kt) for different shapes holes in plates in two cases a and b.

Shape of the hole in the plate	(a) (Kt) without hammering process			(b) (Kt) with hammering process	
	$\sigma_{max.}$	$\sigma_{nominal}$	K_t	$\sigma_{max.}$	(Kt)
Plate with circular hole	23.77	11.25	2.11	22.15	1.96
Plate with Triangle hole	12.34	7.2	1.71	11.41	1.58
Plate with Square hole	12.67	7.83	1.61	11.67	1.08
Plate with ellipse hole perpendicular on longitudinal axis	60.13	26.5	2.26	53.11	2
Plate with ellipse hole parallel with longitudinal axis	21.83	12.39	1.76	22.7	1.88

6. DISCUSSIONS

The stress concentration is a very important state that must be avoided it in mechanical elements design because has interesting in deformations occur especially in different holes in metal plates, therefore the present research investigated of stress concentration in different holes for mild steel plates and then calculated the stress concentration factor (Kt) according to holes shapes in plates.

In practical work calculate the maximum stress on the base of ($\sigma_{ultimate}$) for mild steel plate and divide it by the safety factor, while failure maximum stress of mild steel plate at tension process is ($\sigma_{nominal}$) and then can be calculated stress concentration factor according to equation 1. Practical Table 1 shows that the maximum stress concentration factor (F_t =7.9) for a triangle-shaped hole is because there are sharp edges in triangle rips with angles (60°). In contrast (Kt) value for a square-shaped hole is less because of rips angles are (90o) and it is a closed circular-shaped hole. In contrast, the minimum value of (K_t = 2.1) for an ellipse shape hole is when the hole is perpendicular to the longitudinal axis of mild steel plate, while is increased (K_t = 4.6) for the ellipse when the hole is parallel to plate axis.

The hydraulic press (5 tons) is used to hammer hole edges in mild steel plate, and then plate testing in tension after the hammering process and record maximum value of stress before deformation and regard it nominal stress value, while the maximum stress depending on mechanical properties for mild steel without holes. The values of (Kt) show reduction because of strain hardening which occurs around hole edges due to the hammering process. These processes are due to bearing in circular holes, while compression in triangles and squares concentrated in internal surfaces of them, pressure stress on internal surfaces of ellipse holes which parallel on longitudinal axis for mild steelin the same direction with simple differences in values only in ellipse hole shape which parallel with the longitudinal axis of mild steel.

Table 3 shows (Kt) practical value for different shapes of hole plates. The (Kt min.) for the ellipse hole perpendicular to the longitudinal axis of plate because of residual stress due o strain hardening bp hammering which resists the longitudinal tension process, while (Kt max.) for triangle hole (4.8) because of sharp edges in (60o) which led to increase of stress concentration although there is residual stress due to strain hardening. Figures 4, 5, 6. 7, 8 represent simulation results by Auto desk inventor program. The same values of previous tension forces are subjected and measure maximum stress according to Von Mices theory and from strains of different plates in holes due to hammering can be calculate residual stress on holes surfaces edges, and then simulate these values as bearing forces or compression pressure on internal surfaces of holes and simulate tensile process for plates to record maximum stress in state of strain hardening on holes edges results of hammering in Table 4. These results give indicators in the same direction with simple differences in values only in ellipse hole shape which parallel with the longitudinal axis of mild steel plate, hence, (Kt) is little increased and regard is equal. In experimental work, the (Kt) in two values (3.48, 4.6), are approximately equal, because of the location of strain gage at this state must be at more locations to record accuracy readings. Although the simulation process gives state accuracy approximately because the stress concentration is increased with side pressure force on the ellipse hole surface.

7. CONCLUSIONS

1. The stress concentration increases in sharp edges for hole shapes in mild steel plates which led to increases of stress concentration factor also.
2. The stress concentration reduces in the elliptical hole which is a major axis perpendicular to the steel plate axis.
3. Can be reduced stress concentration and its factor by using the hammering process on hole edges to produce residual stress due to strain hardening at the hammering region.

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