ANALYSIS OF STRESS CONCENTRATION AND DEFLECTION IN PLATES UNDER STATIC LOADING

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SUMMARY:

The effect of stress concentration and deflection in plates with circular holes subjected to concentrated load is studied. Different hole sizes and distance from the plate center (x) are tested experimentally and compared with a reference plate without hole. The specimens are classified into two groups, the first represents specimens containing hole leis in the x-axis of the plate group (A) , and the second group represents the specimens containing two half hole leis at the edge of plate group (B). The results are analyzed using finite element method (FEM), which gives good agreement with the experimental deflection data. The specimens which have central hole group (A) or side two half hole with the same diameter group (B) give lower deflection than that the plate without hole for the same cross sectional area. Increasing hole diameter gives a reduction in the deflection values for each specimen. Group (B) give a higher deflection value for a wide range of (x) as comparing with those of hole specimens group (A). The maximum stress (σx) is higher in groups as comparing with the reference plate for wide range of (x). When this distance (x) increased, the value of maximum stress is reduced for groups. The same behavior is found when increasing the hole diameter.

Key words: Stress Concentration and Deflection, Plates under static loading.

تحليل تمركز الأجهاد والأنحراف في الصفائح المسلط عليها حمل متمركز

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المستخلص:

تمت دراسة تأثير تمركز الأجهاد والأنحراف في الصفائح ذات الفجوة الدائرية المسلط عليها حمل متمركزعلى أنحرافها وأقصى أجهاد فيها. في هذا العمل تم أختبار أحجام فجوات ومسافات مختلفة عن مركز الصفيحة ومقارنتها مع صفيحة أساسية لاتحتوي على تجويف. تم تصنيف العينات الى مجوعتين الأولى (A) تحوي فجوة واقعة على المحور السيني للعينة ، والثانية (B) تحوي نصفي الفجوة واقعة عند حافات الصفيحة . تم تحليل النتائج بطريقة العناصر المحددة، والتي أعطت نتائج جيدة مقارنة مع النتائج العملية . المجموعة الأولى والثانية من العينات أعطت مقدار أنحراف أقل مقارنة مع الصفيحة الأساسية والتي لاتحتوي على تجويف. زيادة قطر الفجوة أدى الى نقصان مقدار الأنحراف لكلا المجموعتين . المجموعة الثانية أعطت مقدار أنحراف أعلى مقارنة مع الأولى لمدى واسع من المسافات (x). كما لوحظ أن أقصى أجهاد (σx) يكون أعلى في المجموعتين مقارنة مع تلك

بدون فجوة لمدى واسع من المسافات (x). وعند زيادة تلك المسافة فأن أقصى أجهاد يقل، كما تمت ملاحظة نفس التصرف عند زيادة قطر الفجوة.

1. INTRODUCTION:

In order to link the concept of stress concentration with the elasticity theory, it is necessary to determine the stress field around the hole in an infinite plate. The analysis of stress concentration factor (SCF) of adjacent holes in a spherical pressure vessel can be approached by considering a thin plate undergoing hydrostatic stresses [1].

The von Misses stress is considered to determine the SCF, various arrangements of adjacent holes are investigated i.e., two, three, four, and five adjacent holes are taken into account. The SCF curves with respect to the ratio of the distance between adjacent holes to the diameter of hole, (L/d), and for a certain ratio of the diameter of hole to the plate thickness, (d/t), are then plotted. The results show that the decreasing of (L/d) will affect the increasing of SCF, while for the case of five adjacent holes configuration, the increasing of (d/t) doesn't make any significant effect to the increasing of SCF [2].

Examines the efficiency of an adhesively bonded reinforcement patch in reducing the stress concentration around a hole in a plate, as a function of hole size. A stress concentration factor is defined as the tangential stress in the plate at the hole boundary, compared to that far away in the plate but still under the reinforcement [3].

The distributions of stresses and deflection in rectangular isotropic and orthotropic plates with central circular hole under transverse static loading have been studied using finite element method (FEM). The (D/A) ratio (where (D) is the hole diameter and (A) is plate width) is varied from (0.01-0.9). The analysis is done for plates of isotropic and two different orthotropic materials. The results are obtained for three different boundary conditions. The variations of SCF and deflection with respect to (D/A) ratio are presented in graphical form and discussed. The finite element formulation is carried out in the analysis section of the package [4].

In the case when an anisotropic plate contains a triangular, oval, or square opening, the only solution available in the literature is an approximate solution for orthotropic plates with openings. The solutions presented here have only one simple unified expression for various openings such as the ellipse, circle, crack, triangle, oval, and square. Two special loading conditions are considered form. The results show that the effect of an isotropy on the stress concentration is totally determined through the fundamental elasticity matrices [5].

2. MATERIAL DESCRIPTIONS AND SPECIMENS PREPARATION:

The material used in this work is pure Aluminum (AA1050) where the chemical composition is listed in **Table (1)**. A tensile test specimen is machined as in **Figure (1)** to achieve the mechanical material properties.

The dimensions of reference plate used in this work is made from a sheet of plate have a thickness of (t = 1mm); a width (w = 21mm) and a length of (L = 90mm). The cross sectional area of this plate is (21 mm^2). The value of cross sectional area will be assumed as a reference to compare the results. Two groups of holed plate are prepared such that the cross sectional area remains the same as in the reference plate.

2.1 Group (A):

To explain the effect of central hole on the values of stress and deflection, the plate is drilled with central hole along the longitudinal center line. Hence the width of reference plate (W=20mm). Specimens are made such that the net width remains the same and results in equal cross sectional area. The center of hole is the same that the center of plate, that means the distance (x) in **Figure (2)**, (x=0 mm). The net sectional area of this group (A) is shown schematically in **Figure (3)**. Therefore, the width and hole diameter values of specimens are assumed as in **Table (2)**.

2.2 Group (B):

The same specimen dimensions mentioned in group (A) are made for group (B). but the hole is divided in two half circle at the edges of plate to predict and compare the effect of side half holes with that the same of central hole, as shown in **Figure (4)**. The cross section area of this group (B) is shown schematically in **Figure (5)**.

3. EXPEREMENTAL WORK:

A concentrated force is applied along the center line of plate parallel to the width of plate. This force will give a maximum deflection in the center line of plate, **Figure (6)**. The concentrated load is increased gradually from zero value until reach the value of (F=10N) where the deflection of plate is record.

4. FINITE ELEMENT MODEL:

The stress and deflection of plates are analyzed with finite element method. The following steps are done for each plate [6]:

- Define the element type (elastic 4 nodes 63).
- Define the real constant for the above element (using thickness t = 1mm).
- Define the material property (E=70000 N/mm^2, ν = 0.3).
- Molding area (drawing the specimen groups and the reference plate).
- Meshing the specimen with fine mesh.
- Applying the boundary conditions.
- Applying the concentrated force (F=10N).
- Solve the current model.
- Plot the results of stress and deflection for each specimen.
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5. RESULTS AND DISCUSSIONS:

The results of this work can be classified into:

- Central deflection results include the experimental and the FEM results.
- Results of maximum stress in plate (σx).

To compare the results between all specimens with the reference plate, the same cross sectional area, the applied concentrated load (F=10N) and the boundary conditions are used as mentioned in

the experimental work. **Figure (7)** represents the variation of central deflection with the horizontal distance for five widths of specimens (W=27-35mm), group (A).
As comparing with the reference plate, the deflection of plates for group (A) is lower than that for the reference plate. That means; making a central hole in the plate will result in decreasing the deflection (for the same cross sectional area, force and boundary conditions). Also for the same hole diameter, the deflection will decrease as the horizontal distance (x) increase for each specimen. Increasing the hole diameter for the same value of (x) results in decreasing the value of central deflection.

Figure (8) represents the behavior of deflection with the distance (x) for five specimen widths (w=27-35mm), group (B). Where the deflection for all specimens is lower than that of the reference plate and decrease with increasing hole diameter for the same distance (x). It has been shown that the deflection increases gradually for each specimens width with increasing the distance from (x=0–5) mm, and reach maximum value at (x=5mm).After this, the deflection decreases with increasing (x).

A sample specimen is taken to show the results of stress distribution in the x-axis (σx) for all nodes of plate specimen. The specimen is from group (A) with the dimensions of (W=35mm, d=14mm), where the distance have a range of (x=0, 5, 10, 15, 20, 25 mm) in **Figures (9-14)** respectively. It has been observed that the maximum stress decreases from (σx=82MPa) found around the hole, **Figure (9),** and (σx=45 MPa) found at the center of plate.

The maximum stress found around the hole has a small amount as shown in **Figures (9 -11)**, (x=0, 5, 10 mm). This is due to the effect of stress concentration in the curved area of hole circle. This effect reduces gradually as the distance (x) increases and the amount of maximum stress will appear in the center of plate as in **Figure (12)**, (x=15mm). The amount of maximum stress will be larges in the plate center than that around hole, **Figure (13)**, (x=20mm).

When the value of (x) reaches (x=25mm), **Figure (14)**, the maximum stress is appears at the center of the plate, where the effect of the curved area is diminished. That means the effect of concentration of stress around hole is reduced as the distance (x) increases.

6. CONCLUSIONS:

The following conclusions are presented:

1- The specimens which have central hole group (A) or side hole group (B) gives small deflection than that the plate without holes, the value of central deflection is decrease with increasing the distance (x) for groups.

2- Increasing hole diameter gives a reduction in the deflection values for each specimen of groups.

3- The maximum stress (σx) is higher in groups as compared with the reference plate for wide range of (x). Increasing the distance (x) reduce the value of maximum stress for groups.

4- Maximum stress is at the center of specimens for the ranges (x=0 -15mm).and the maximum stress is found only at the center of specimens for the value of (x=25mm).

5- The amount of maximum stress transfers from the location of hole surrounding to the plate center as the distance (x) increases.

7. REFERENCES:

[1] (Fuad1 Kh., et al, 2007) "Stress Concentration Factors of Various Adjacent Holes Configurations in a Spherical Pressure Vessel" 5th Australasian Congress on Applied Mechanics, ACAM, Brisbane, Australia.

[2] (Pickthall C. and Rose L.F., 1998) "Stress Concentration around a Patched Hole in an Axi-Symmetrically Loaded Plate" Aeronautical and Maritime Research Laboratory Commonwealth of Australia.

[3] (Nitin Kumar Jain, 2009) "Analysis of Stress Concentration and Deflection in Isotropic and Orthotropic Rectangular Plates with Central Circular Hole under Transverse Static Loading" World Academy of Science, Engineering and Technology.

[4] (Chyanbin Hwu, 1990) "Anisotropic Plates with Various Openings under Uniform Loading or Pure Bending" Transactions of the ASME Vol. 57.

[5] (Rao K.P., 2001) "stress concentration and stability studies in composite ribs with flanged cutouts", CAE group, Infosys Technology limited, Bangalore, India.

[6] (James Doyle, 2004) "Finite element methods", John Wiley & Sons, Ltd.

Table (1) Chemical compositions of Aluminum specimens (AA1050).

Al	Si	Fe	Cu	Mg	Mn	Cr	Ni	Zn	Ti	Ag	B	Bi	Be
99.5	0.173	0.225	0.0125	0.0045	0.0215	0.0043	0.0051	0.0113	0.0163	0.00062	0.0028	0.001	0.0028

Ca	Cd	Co	Hg	La	Li	Na	P	Pb	Sn	Sr	V	Zr
0.00045	0.00035	0.001	0.0021	0.0005	0.0002	0.00099	0.001	0.0027	0.001	0.0001	0.005	0,0003

Table (2) Dimensions of group (A) specimens.

Specimen No.	1	2	3	4	5
w(mm)	27	29	31	33	35
d(mm)	6	8	10	12	14
t(mm)	1	1	1	1	1
A=(w-d)*t	21	21	21	21	21

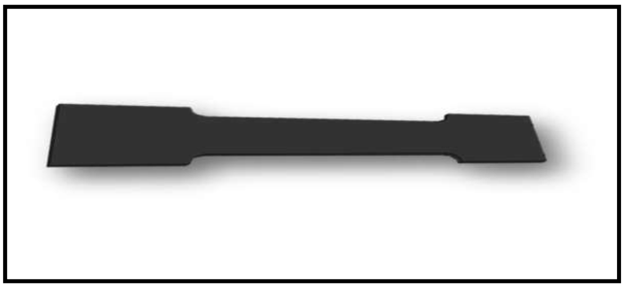

Figure (1) Tensile test specimen.

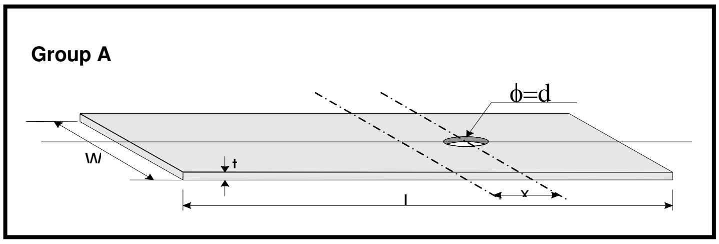

Figure (2) Shape of group (A) specimens.

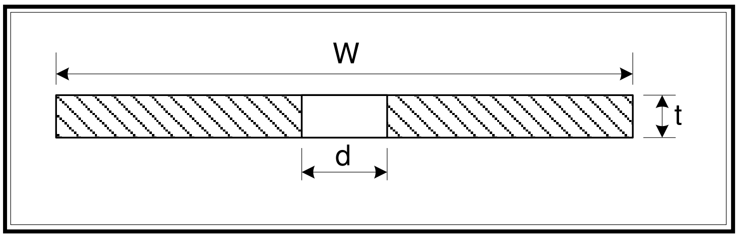

Figure (3) Cross sectional area of group (A) specimens.

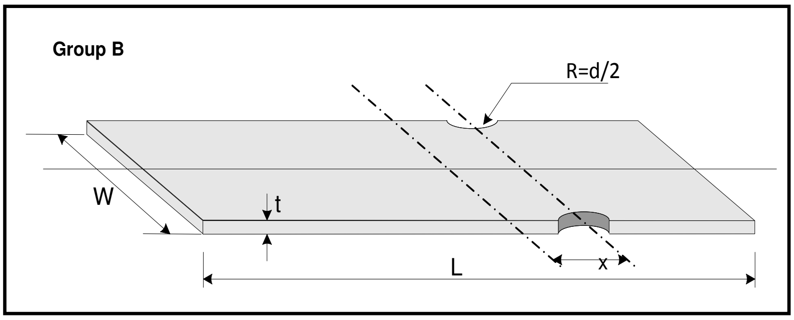

Figure (4) Shape of group (B) specimens.

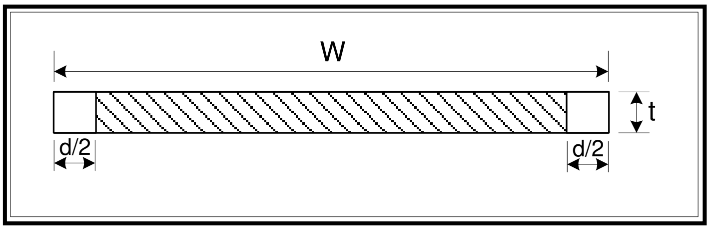

Figure (5) Cross sectional area of group (B) specimens.

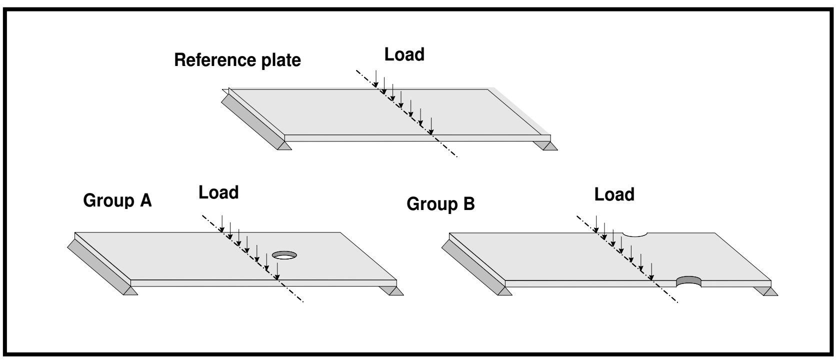

Figure (6) Boundary conditions and concentrated load of specimens.

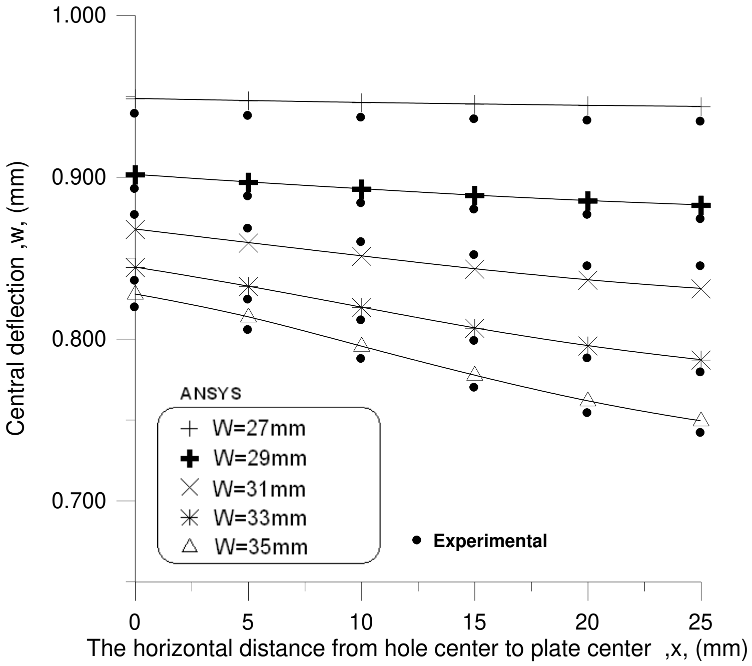

Figure (7) Variation of central deflection with the distance for group (A).

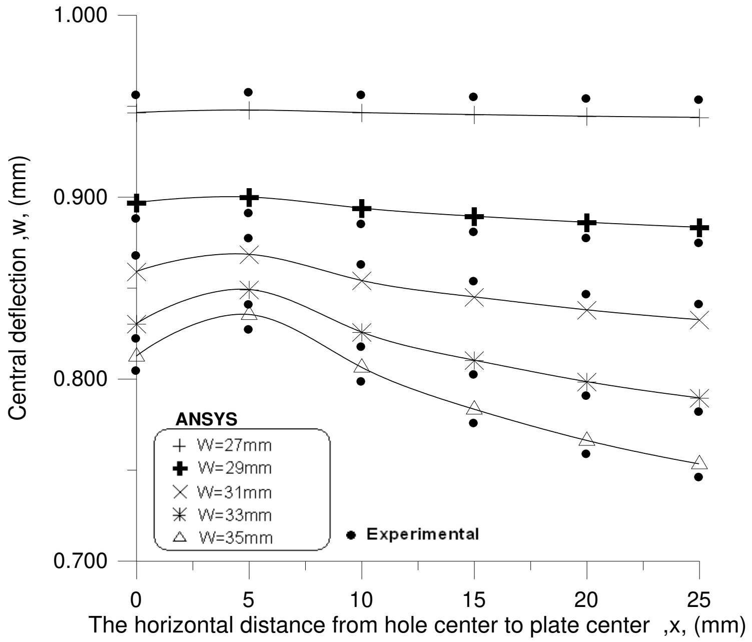

Figure (8) Variation of central deflection with the distance for group (B).

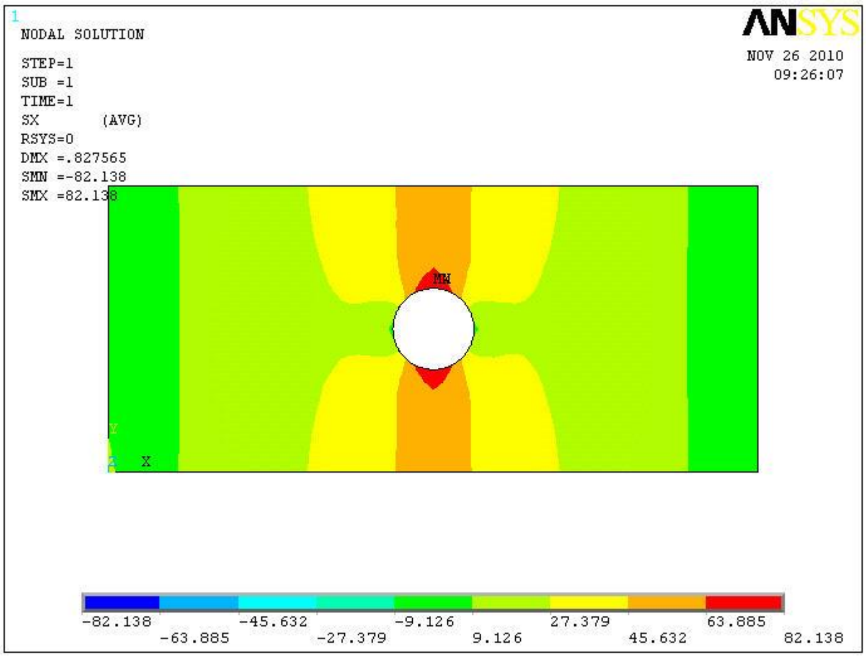

Figure (9) Variation of stress (σx) for the distance (x=0 mm).

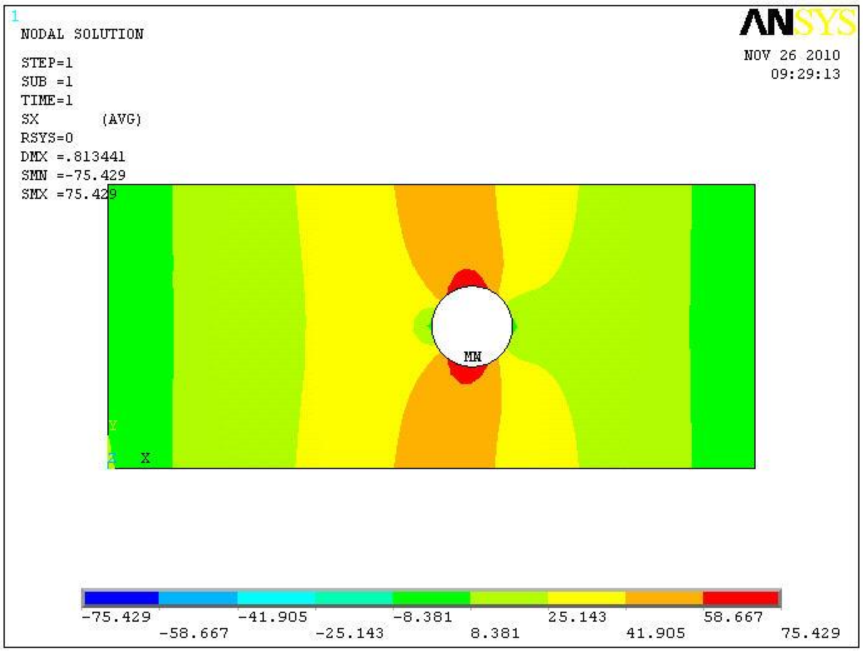

Figure (10) Variation of stress (σx) for the distance (x=5 mm).

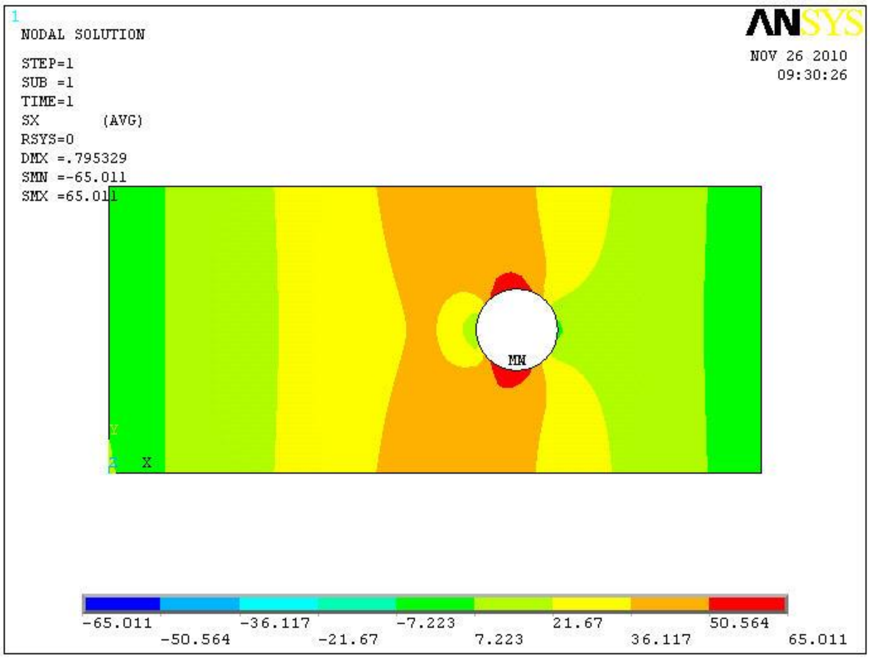

Figure (11) Variation of stress (σx) for the distance (x=10 mm).

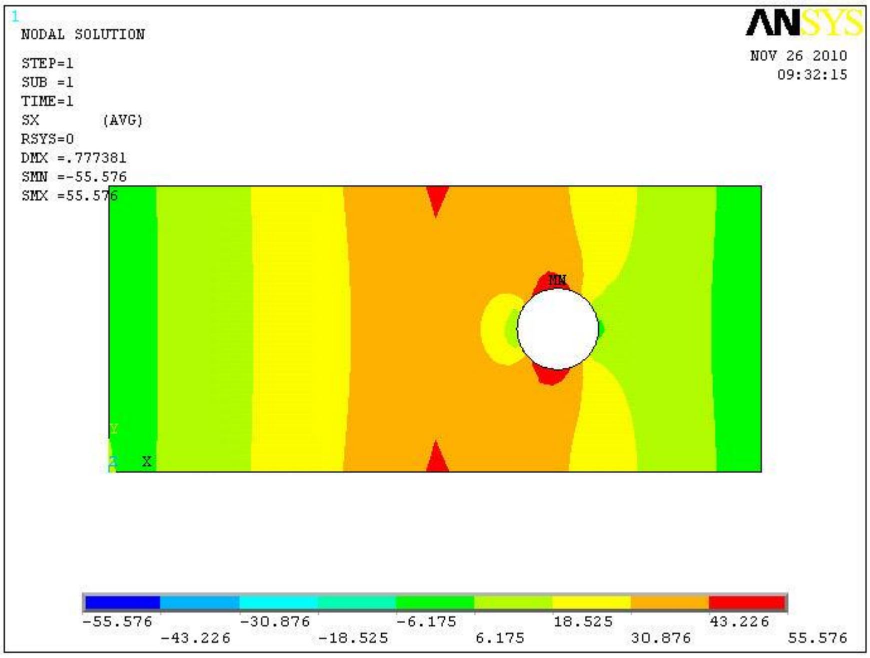

Figure (12) Variation of stress (σx) for the distance (x=15 mm).

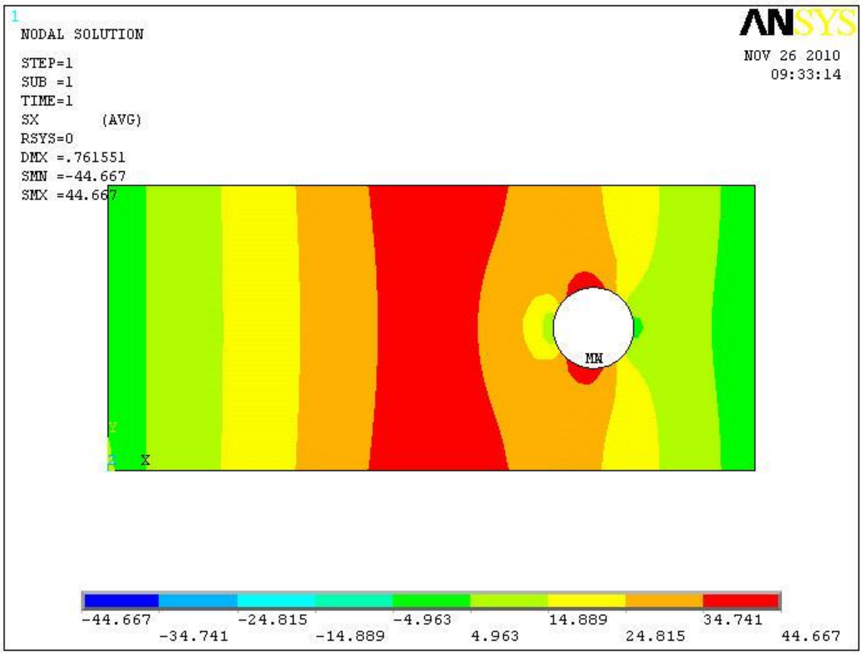

Figure (13) Variation of stress (σx) for the distance (x=20 mm).

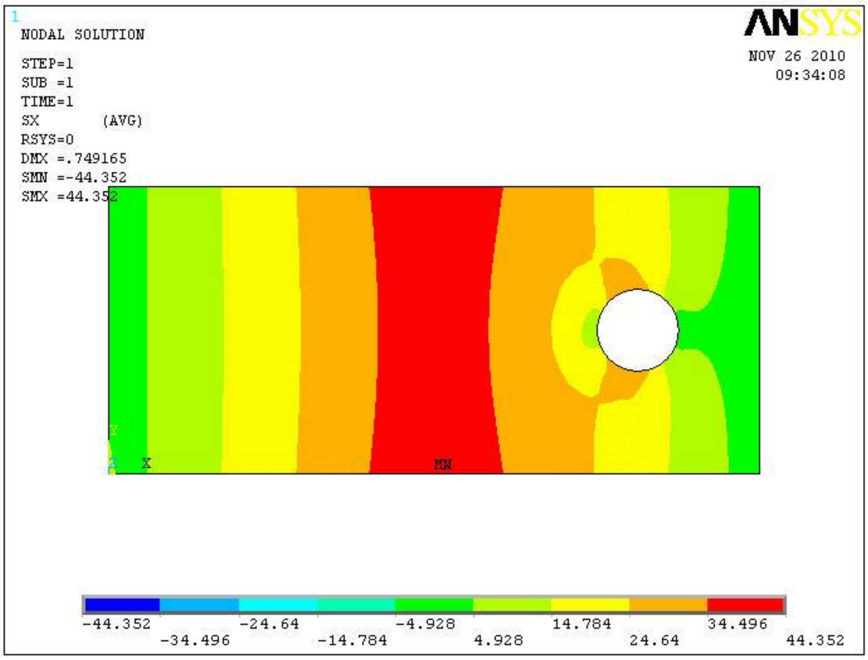

Figure (14) Variation of stress (σx) for the distance (x=25 mm).