INFLUENCE OF STRESS RAISERS ON COPPER PLATE FRACTURE UNDER UNIAXIAL TENSION LOADING

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ABSTRACT

The influence of stress raisers on copper plate fracture under the uniaxial tensile static loading is investigated. The effect of axial distance between holes and hole diameter, number, row, and position on the strength, ductility and stress factor is discussed. Notched and unnotched specimens are used for the experiments. The notch effect on the mechanical properties is obtained. The Kahn tear test is carried out to detect the effect of the stress raisers on the material toughness. The stress concentration factor is predicted using the force line and the inelastic methods. The predicted stress concentration values are compared to previously published values and experimental results. The computational accuracy is found to be acceptable for practical purposes.

KEYWORDS

Stress raisers, stress concentration factor, hole numbers and diameters, axial distance between hole centers, notched and unnotched specimens.

INTRODUCTION

These days different testing methods are used to determine the suitability of sheet metals for forming processes, but they have limited use in predicting the behavior of sheet metal for a specific deformation process. The deformation behavior of sheet metals is affected by the mechanical properties. Mohamed (1995) showed that the major effect of obtaining highly homogeneous material is greater toughness. Both Kahn tear test with sheet and the compact tension indicate substantially higher toughness. Also, recent results (Mohamed, 1995a; Mohamed, 1994; Mohamed, 1994a; Bieler et al., 1993; and Mohamed, 1993a) discussed the effects of anisotropy in improving the plastic instability and texture analysis. Under severe operating conditions, the most damaged parts are the notched parts, and severe operating raises the possibility of drastic fatigue failure at the notched parts. Stress concentration results from the presence of discontinuities, holes, notches, grooves and slots. This affects workability of metals in different metal working processes, (Sing and Rao, 1993). The effect of stress concentration on workability is usually investigated using the tension test. Ang and Tan (1988) found that beyond the proportional limit, the stress distribution depends on the material ductility. Ductile materials can be subjected to considerable stretching beyond the yield point without a great increase in stress. Smith (1985) deduced that the specimens with machined grooves of various depths shaw an apparent increase in the ultimate stress. Mohamed (1995) showed that the unnotched or holeless specimens have higher strength compared to that having notched stress raisers. The author also showed that a single isolated notch or hole has a worse effect compared to a number of similar stress raisers placed closed together in agreement with previous publications, (Shimamoto and Takahashi, 1991; Kihara and Yoshii, 1991; Hasegawa et al., 1987). All the methods described for detecting the plastic zone at the edge of a round hole or the notch root under uniaxial tension are valuable and applicable within certain limitations but non can be applied with confidence to all situations, (Mohamed, 1995). The author (1990) used the FEM to discuss the feasibility of numerical analysis to the elasto-plastic metal behavior during the uniaxial testing of copper sheets, and also the author with others used the FEM as a tool for computing the Cu/Al duplex tubes flow stress,(Chaaban et al., 1988), and investigated the strain gauge usage in measuring the friction forces in the constrained forge upsetting with a higher accuracy, (El-Sheikh et al., 1990). Hasegawa et al. (1987) presented the body force method to compute the stress concentration factor of an elastic strip supplemented with stress raisers. Also, Shimamoto and Takahashi (1991) determined the strain concentration factor at a round-hole edge under the uniaxial stress field.

In the present work, the effect of the number, diameter and the axial distance between hole centers of a one sided notched specimens on the material strength, ductility and stress concentration is investigated. Also, for the unnotched specimens, the effects of the hole position with respect to the applied load position, hole rows, numbers and diameters, and the axial distance between hole centers are compared. The Kahn tear test is carried out to detect the effect of the stress raisers on the material toughness. The test stress concentration factor is compared with those obtained according to the force line method, inelastic method and the published results.

EXPERIMENTAL PROCEDURES

Copper plates with 2.5±0.05mm thickness are used. The material is the same as used by Mohamed (1995). The material is cut in prescribed shapes and planed down to the definite thickness with a 58±0.05mm gauge length and 36.5±0.05mm width. The specimens are polished with emery paper #600 before testing and divided into five groups. Triplicate specimens are used for each test. In group I, a shallow notch is created on one side at the mid length with a fixed depth of 11±0.05mm. The notched specimens are supplemented with holes of different numbers (N), diameters (d) and axial distance between holes centers (x). Group II describes the unnotched-one hole test specimens where the hole position and the load position are varied. Group III illustrates the effect of the (d) values on the unnotched-two equal diameter holes specimens. Group IV shows the effect of different values of the axial distance (x) on the material properties of the unnotched - four holes specimens. Group V illustrates the effect of (N) on the unnotched specimens with a fixed (x and d) values. The testing machine used is the universal screw gear testing machine (Type ZDM 10t/91 VEB) with a maximum load reading error of ± 1%. The specimen load and elongation measurements are recorded throughout each experiment up to failure.

THEORETICAL ANALYSIS

I. Force Line Method (F.L.M.).

If the tensile force is applied to the notched specimen shown in Fig. 1, the specimen will be elongated while the wedge of the material is attached to its original position. The material has to be attached in its original position. In order to do this, the material have to be stretched along the cut line so as to coincide with the elongated member. This requires tensile force with a magnitude that will depends greatly on the wedge width i.e., the notch depth. These relatively high forces must "flow" around the notch root. This causes a high local increase in the distributed force at the notch root. This effect is shown by the narrowing of the force lines adjacent to the notch. The stress is inversely proportional to the force line width. High shear forces must exist along the "cut" section. Any plastic slip in this region will have the effect of alleviating the stress concentration at the notch root. This method of analysis explains why it is possible to relieve stress concentration by making stress raisers. The object is obviously to remove or weaken the undesirable material and compute the stress factor (Mohamed, 1995).

II. Inelastic Stress Method (I.S.M.).

The inelastic stress factor is computed according to Mohamed, (1995). Whenever the stresses near the stress raiser enter the inelastic range, some residual stresses at the stress raisers will remain after unloading. The residual compressive stress will itself enter the inelastic range in compression and will therefore have a value on the order of the compressive yield stress that increases the material resistance to the tensile loads in the specimens that containing stress raisers, so the material strength increases.

RESULTS AND DISCUSSIONS

I. Notched Specimens with Four Equal Diameter Holes.

The effect of the axial distance between holes center (x) on the copper strength, ductility and stress concentration factor is investigated. It is clear that as x increases, the stress values (ultimate stress;σ_u ; rupture stress;σ_r'; and tear stress;σ_T) decreases. This occur due to the force stream line spaces increment that result in decreasing the material ability to resist the shear planes flow and slipping which decreasing the load carrying capacity and the resistance to cracks propagation, see Fig. 2.a. As the hole diameters and numbers increase, the material strength increases due to the decrement of the force line spaces and the holes mitigation (Mohamed, 1995), see Fig. 2.b. As (x) increases, the percentage elongation; δ %; increases and the percentage reduction in area; q%; and the percentage thickness variation; t %; decreases. The maximum δ% is at x = 4.5d as shown in Fig. 3.a. Figure 3.b shows that as (d) and (N) increases, the δ% increases with a maximum value at (d) = 12mm and (N) = 4 holes. The stress concentration factor is calculated according to Mohamed (1995), where; $K_{F.L.M.}$= Force line method stress concentration factor, $K_{I.S.M.}$ = Inelastic stress method stress concentration factor, K_A = Anderson stress concentration factor, and K = Actual stress concentration factor. Figure 4 shows that as (x) increases, $K_{F.L.M.}$, $K_{I.S.M.}$ and K increases and K_A decreases. The higher stress factors are at N = 4 and d = 12mm.

II. Effect of Hole Position on Unnotched Specimen Characteristics.

Four specimens with one hole of 8mm are used. The hole center position; O(x,y); is differed with the load position as follows; O1(0,0), O2(-14.5,+7.25) opposite to the load position, O3(-14.5,+7.25) nearer to the load position and that O4 (-14.5,0) nearer to the load position . The hole position have a greatest effect on the material strength as shown in Fig. 5.a. The hole position (O1) has the highest strength. The hole position (O3), the nearer to the load position has the highest σ_r and also has a higher σ_u and σ_T values compared to specimen O2. Figure 5.b shows that specimen O1 has the highest δ% and the lowest q% and t % compared to the other three specimens. Specimen O3 has a higher q % and t % values compared to specimen O2 due to the strength increment. Using Lipson and Juvinall (1963), K_{LJ} value is obtained instead of K_A of the notched specimens as;

$$K_{LJ} = [(Pu / (B\text{-}d)t) / \sigma_{AV}] \quad \text{for one hole specimens.}$$

$$K_{LJ} = [(Pu / (B\text{-}Nd)t / \sigma_{AV}] \quad \text{for more than one hole specimens.}$$

where; Pu = Ultimate load, (N); t = Plate thickness, (mm); B = Plate width, (mm); σ_{AV} = Average stress; d = Hole diameter,(mm); and N= Number of holes. Figure 5.c shows that specimen O3 has the highest factor values.

III. Effect of Hole Diameter Values on Unnotched-Two Equal Diameter Holes Specimen Characteristics.

The effect of the hole diameter values on the strength, deformation and stress concentration factor of the unnotched-two equal diameter holes specimens is shown in Fig. 6. Figure 6 shows that as the hole diameter increases, the material strength increases with an optimum value at d=6mm. Also, as (d) increases, δ% and the stress factor decreases due to the material strength increment with an optimum value at d=6mm, see Fig. 6.b,c.

IV. Effect of Holes center Axial Distance (x) on Unnotched Specimen Characteristics.

The effect of the axial distance between hole centers (x) of the two rows-four equal diameter holes (d=4mm) unnotched specimens on the material strength, deformation and stress concentration factor is shown in Fig. 7. As the (x) value increases, the material strength increases with a maximum value at x =3d as shown in Fig. 7.a. Figure 7.b shows that as (x) increases, the δ %, q % and t % decreases due to the material strength increment with a maximum value at x = 3d. As (x) increases, $K_{F.L.M.}$, $K_{I.S.M.}$, and K_{LJ} decreases and K increases due to the strength increment, (Hasegawa et al., 1987).

V. Effect of The Equal Diameter Holes Number (N) on Unnotched Specimen Characteristics.

As the holes rows decrease, the material strength increases due to the decrement of the spaces between the force stream lines that result in alleviating the stress concentration as shown in Fig. 8.a. Also, as the number of holes (N) increases, the material strength increases due to the holes mitigation, (Hasegawa et al., 1987). Figures 8.b and 8.c illustrate that as N increases, q % , t % and K increases due to the strength increment, while δ%

decreases due to the material volume consistancy, (Mohamed et al., 1995), with an optimum value at N=8 of the equal diameter holes (d=4mm) unnotched specimens.

CONCLUSIONS

According to the present investigation, the following conclusions are obtained;

1. For the notched specimens; as the hole numbers, diameters increases and the axial distance between hole centers (x) decreases, the material strength and ductility increases.

2. The hole position with respect to the load position has a greatest effect on the material strength, ductility and stress concentration factors.

3. For the unnotched specimens; as the hole diameter, number and (x) values increases, the material strength and concentration factors increases while the material ductility decreases. The hole rows decrement increases q%, t%, K values and the material strength but the material ductility increases.

4. The unnotched holeless specimens have the highest strength and ductility values.

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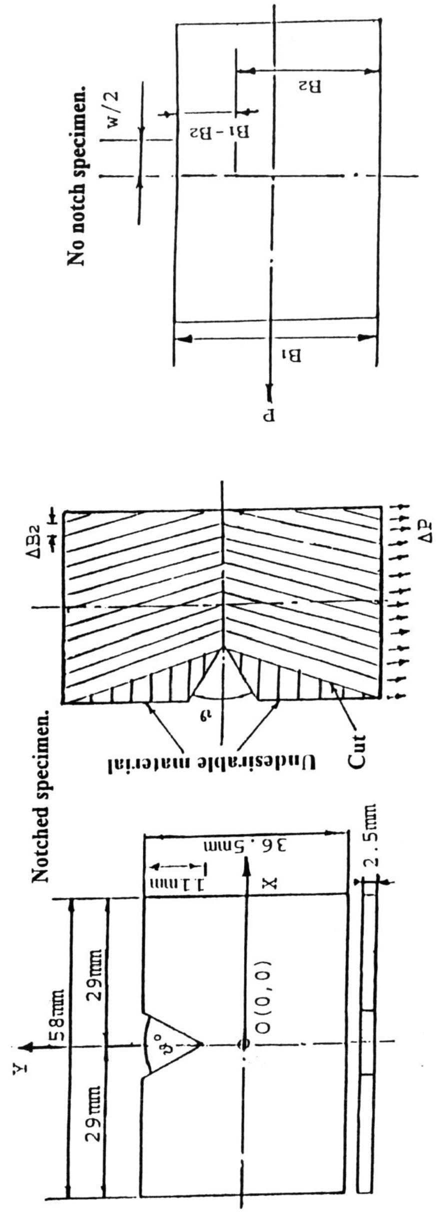


Fig. 1. Notched and no notch test specimens.

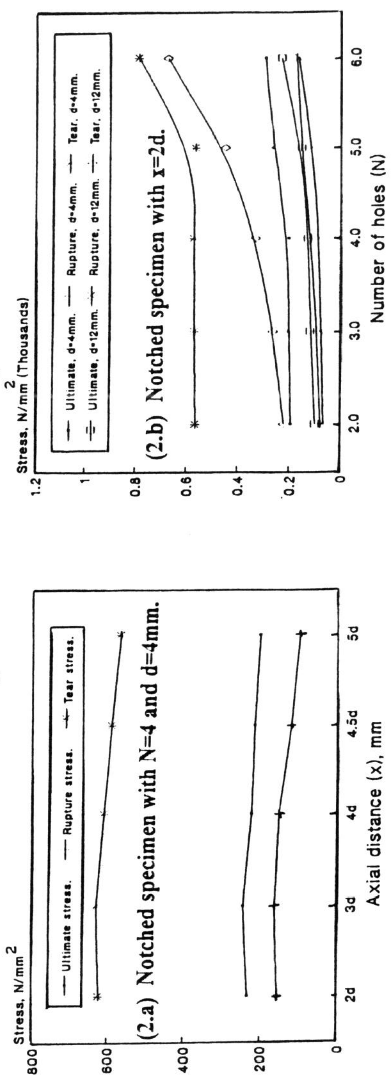
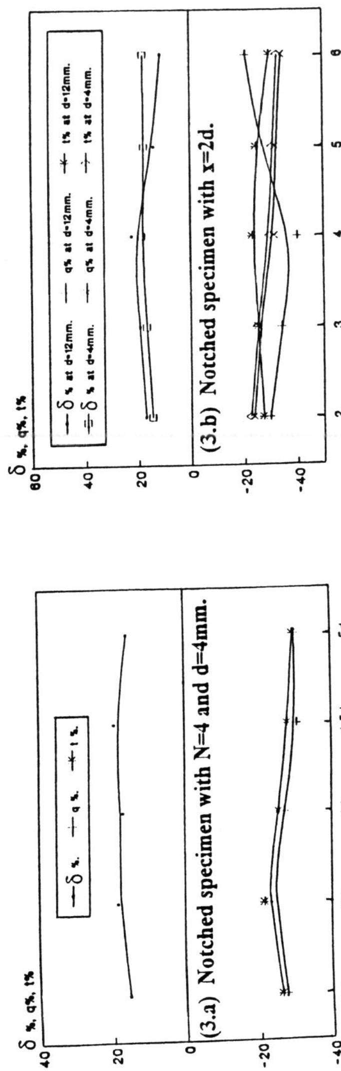


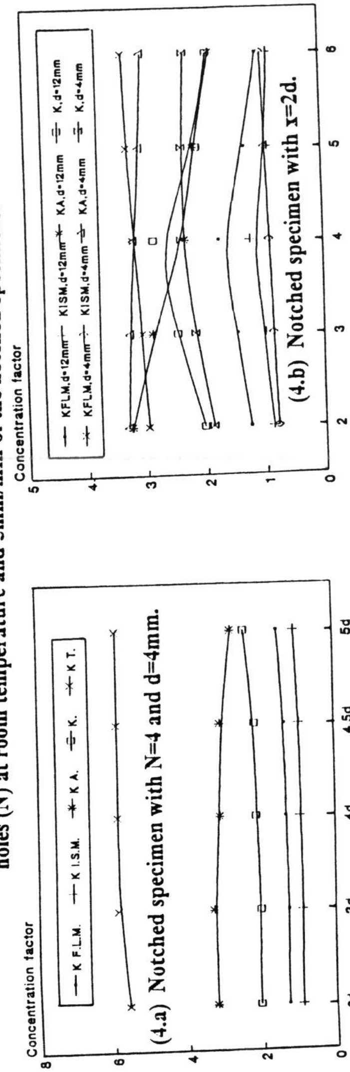
Fig. 2. Variation of material strength with the axial distance (x) and number of holes (N) at room temperature and 5mm/min of the notched specimens.



(3.b) Notched specimen with x=2d.

(3.a) Notched specimen with N=4 and d=4mm.

Fig. 3. Variation of deformation values with the axial distance (x) and number of holes (N) at room temperature and 5mm/min of the notched specimens.



(4.b) Notched specimen with x=2d.

(4.a) Notched specimen with N=4 and d=4mm.

Fig. 4. Variation of stress factors with the axial distance (x) and number of holes (N) at room temperature and 5mm/min of the notched specimens.

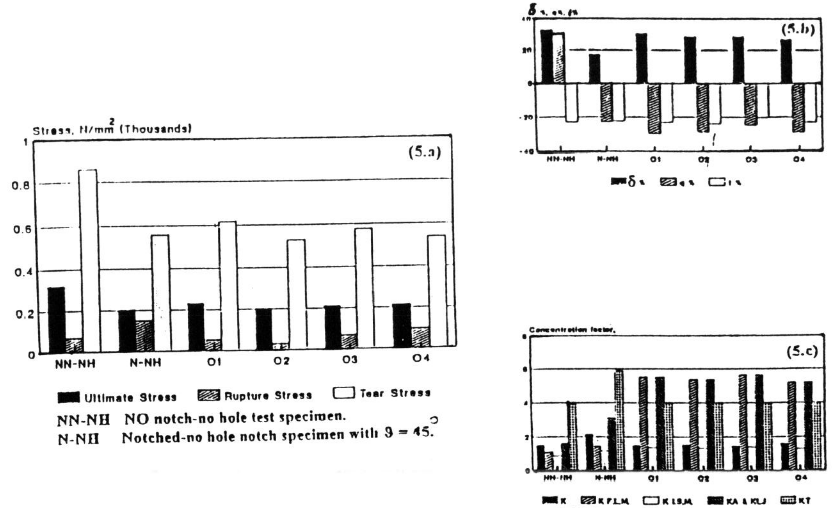


Fig. 5. Effect of the hole position on the no notch specimen strength, ductility, and stress factors at d=8mm, N=1, 5mm/min and room temperature.

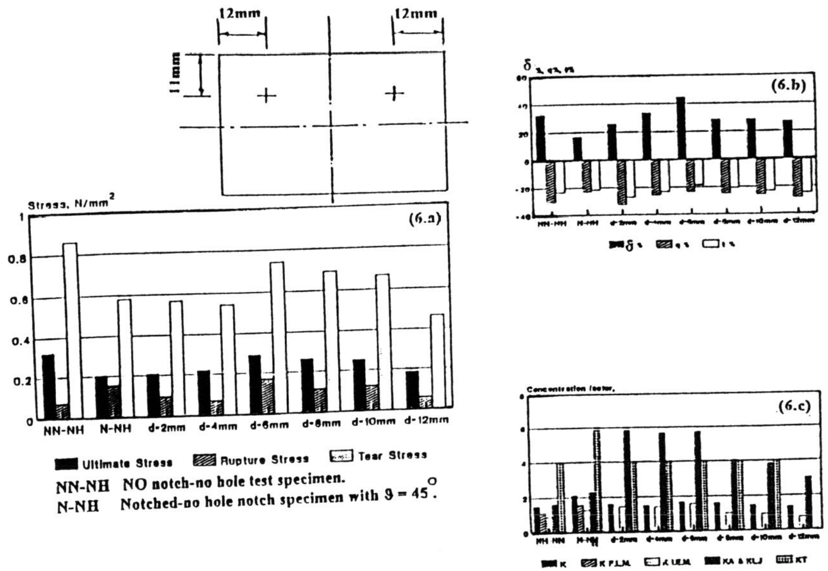


Fig. 6. Effect of the hole diameter on the no notch specimen strength, ductility, and stress factors at x=2d, N=2, 5mm/min and room temperature.

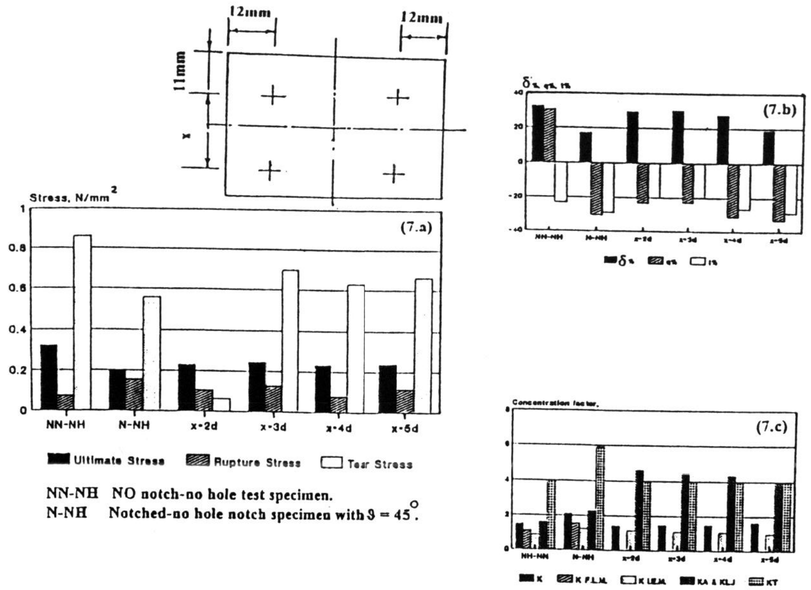


Fig. 7. Effect of the axial distance x on the no notch specimen strength, ductility, and stress factors at d=4mm, N=4, 5mm/min and room temperature.

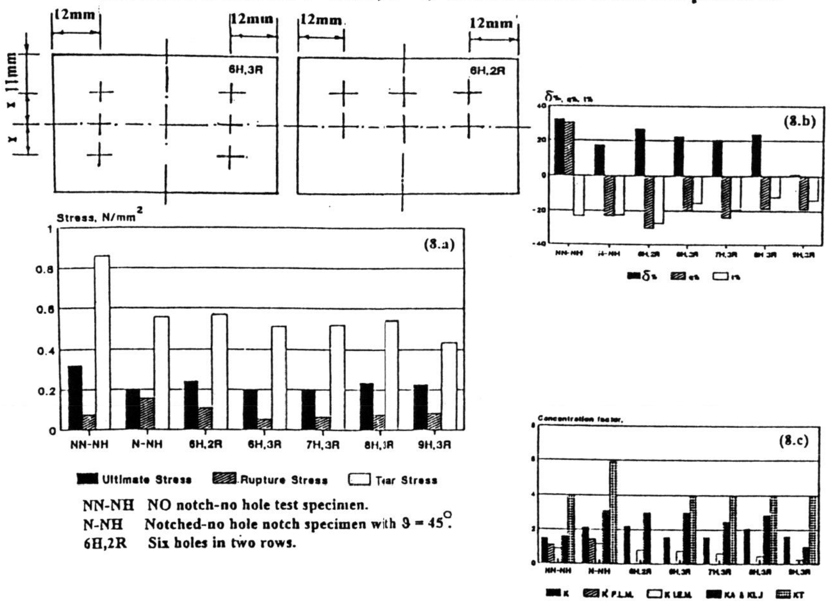


Fig. 8. Effect of the hole number N on the no notch specimen strength, ductility, and stress factors at x=2d, N=4, 5mm/min and room temperature.