Effects of a Void on Copper Shaped-Wire Drawing by 2D Finite Element Analysis

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Abstract

In this paper, the influences of a void on copper shaped-wire drawing were investigated. The deformations, the mean normal stress and the plastic strain of a copper shaped-wire that contain a void were calculated by 2D finite element analysis. The necking, bending and miss alignment occurred. In case of non-central void wire, the extremely void deformation occurred. For the same void length, the drawing stress was strongly influenced by void size and slightly influenced by eccentric length. The drawing stresses of central void wire greater than non-central void wire.

1. Introduction

One of the reasons for the high manufacturing costs of superfine wires is the fracture of wires during processing. The causes of wire fracture have been actively studied for a long time. However, there are a few published reports [1]. Avitzur [2-4] proposed the conditions under which internal fracture occurred using an energy method. Rogers [5] and Yoshida [6] studied the occurrence of damage and voids during the drawing using a slip-line field method. Chen [7] and Yoshida [6, 8-10] studied the causes of internal cracking and how such cracks grow, using finite-element analysis (FEA) and proposed some processing conditions to prevent defects. The most important problem is wire fracture due to inclusions. Raskin [11] reported the causes of wire fracture during copper wire drawing based on his survey of 673 wire breaks, that 52%, 13%, 13%, 5%, 5%, and 12% are attributable to inclusion, central bursting or central void, tension break, weld break, silver break and others, respectively.

2. Theoretical Wire Drawing Model Analysis

The wire drawing processes are classified as indirect compression processes, in which the major forming stress results from the compressive stresses as a result of the direct tensile exerted in drawing. The converging die surface in the form of a truncated cone is used. The analytical or mathematical solutions are obtained by free body equilibrium method. By summing the forces in the wire drawing direction of a free body equilibrium diagram of an element of the wire in the process of being reduced, then combining the yield criterion with equation for the axial force, integrating the resulting differential equation, and simplifying, the equation for the average drawing stress is obtained.

In the derivation of the average drawing stress for drawing for a constant shear factor, neither a back pull stress nor the redundant works were included. These terms may be added, respectively, to give the equation for the front pull stress for drawing.

By use of the upper-bound theory, which gives the upper bound on energy consumption, Avitzur derived the equations for the drawing stresses of rounds wire for a constant frictional shear factor with no backward tension in drawing.

The above mention equations are only used for homogeneous wire drawing investigation. But non-homogeneous wire drawing such as wire drawing which contain a void is more complicated problem to investigate by those simply equation. In this case, the behaviors of wire drawing with a void are easily investigated by 2D FEA.

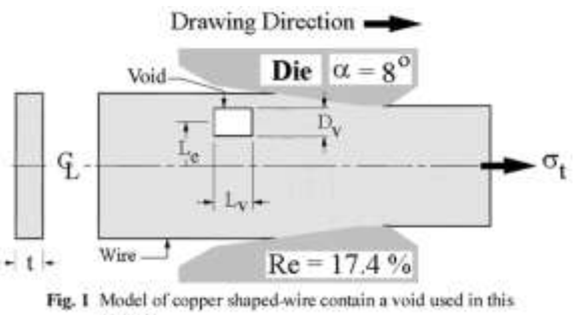

Fig. 1 Model of copper shaped-wire contain a void used in this analysis

3. Optimal Die Half-Angle Experiment

The author investigated the effects of die half-angle on drawing stress during wire drawing by experiment to find out the optimal die half-angle of copper wire. The copper wire were used as specimens have their properties as E = 120000 MPa, σ_Y = 150 MPa, and ν = 0.3. They have a diameter of 5.5 mm. The reduction/pass of copper wire drawing was 17.4 % so that drawn wires have a diameter of 5 mm.

In this Experiment, the various die half-angles such as 4, 6, 8, 10, and 12 degrees were used. The drawing stresses of copper wire during drawing at room temperature versus the die half-angle were obtained. For a die half-angle of 4 degrees, the drawing stress was large. For the die half-angle of 6, 8, 10, and 12 degrees, the drawing stress decreased as the die half-angle increased until 8 degrees approximately and then increased as the die half-angle increased. The minimum drawing stress and the largest elongation were at a die half-angle of 8 degrees. So that the optimal die half-angle for copper wires drawing was approximately 8 degrees.

4. FEA Results and Discussion

2D finite element method was used for analyze the effect of a void on copper shaped-wire drawing. Fig. 1 shows the analytical model was used. The white part was a void in a copper shaped-wire. The void was non-centrally located in the copper shaped-wire and the eccentric length was set as L_e/D_o, the ratio of void eccentric length to dimension of wire cross section. The authors assumed that the wire was a copper and has the material properties and drawing conditions used in this analysis were shown in Table 1. The void length was set to be constant at L_v/D_o = 0.26, and the void size D_v/D_0, the ratio of void dimension to dimension of wire cross section, was varied as 0.0, 0.2, 0.4, 0.6 and 0.8. The die half-angle (α), reduction of area (Re) and coefficient of friction (μ) were set at 8 degrees, 17.4 %, and 0.05, respectively. The authors assumed that the materials used were not work-hardened during the process. This analysis, a wire was considered as a copper shaped-wire contains a non-central void and also a copper shaped-wire contains a central void subjected to steady deformation.

Table 1 Material properties and drawing conditions used for FEA

	Copper (wire)
Young's modulus E (MPa)	120000
Yield stress σ_Y (MPa)	150
Poisson's ratio ν	0.3
Die half-angle α (deg)	8
Single reduction Re (%)	17.4
Coefficient of friction μ	0.05

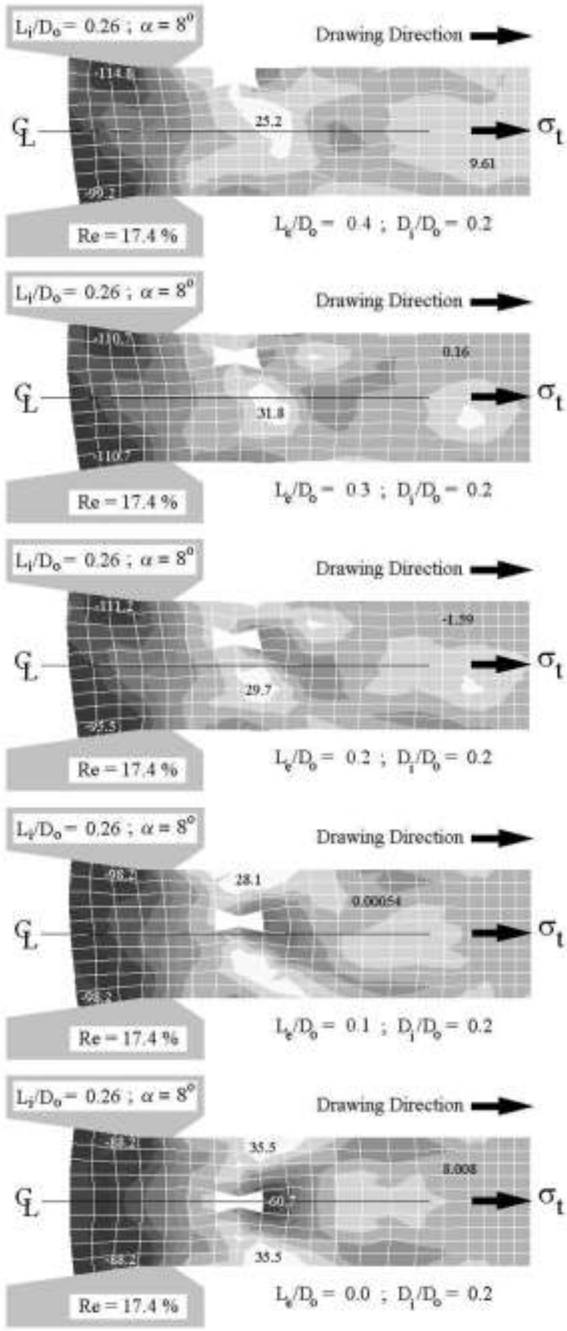

Fig. 2 The deformation and mean normal stress distributions of copper wires contain a non-central constant sizes void

The deformation and mean normal stress distributions of drawn wires contain a non-central constant sizes void, a constant eccentric length various size void and a central various size void were obtained as shown in Fig. 2, Fig. 3 and Fig. 4, respectively. We can clearly see that the necking due to central and non-central void wire drawing slightly occurred and can be neglected. The deformations of matrix around the void boundary were very large. The void shape was transformed.

4.1 Eccentric Length Effect. Bending and miss alignments increase as L_e/D_o increases and occurred at die inlet zone. During the drawing of wires contain a non-central void, a maximum tensile stress on side surface of void increase as L_e/D_o increase until L_e/D_o equal to 0.2 then decrease. A maximum tensile stress in wire cross section where contain void as the void exit the die decrease as L_e/D_o increase. The extremely compressive stress occurred on the die contact surface, the opposite side that far away from void location as shown in Fig. 2, and increase as L_e/D_o increase. At die inlet zone, bending and miss alignments increase when L_e/D_o increases.

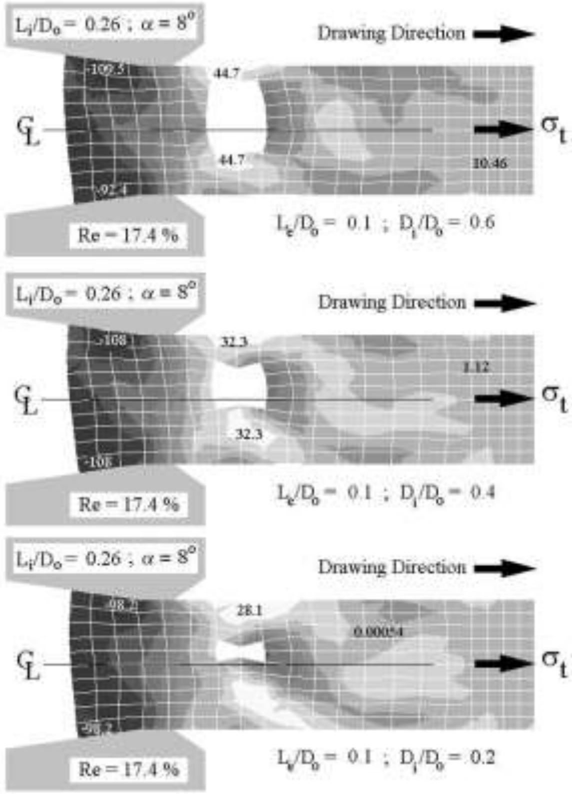

Fig. 3 The deformation and mean normal stress distributions of copper wires contain a constant eccentric length various size void

4.2 Void Size Effect. For D_v/D_o = 0.2, 0.4, 0.6, and 0.8, the deformation behaviour of drawn wires contain a non-central void with L_e/D_o = 0.1 and 0.0 were obtained as shown in Fig. 3 and 4, respectively. Meshes of both drawn wires that contain non-central and central voids were very large deformed around the void boundary as shown in Fig. 3 and Fig. 4. Bending and miss alignments also increase as D_v/D_o increase and occurred at die inlet zone. During the drawing of wires contain non-central void, a maximum tensile stress around the surface of void and in wire cross section where contain void as the void exit the die increase as D_v/D_o increase. In case of central void wire drawing, a maximum tensile stress increase as D_v/D_o increases until D_v/D_o equal to 0.4 then decrease. The extremely compressive stress occurred on the die contact surface, the opposite side that far away from void location as shown in Fig. 2, and increase as L_e/D_o increase.

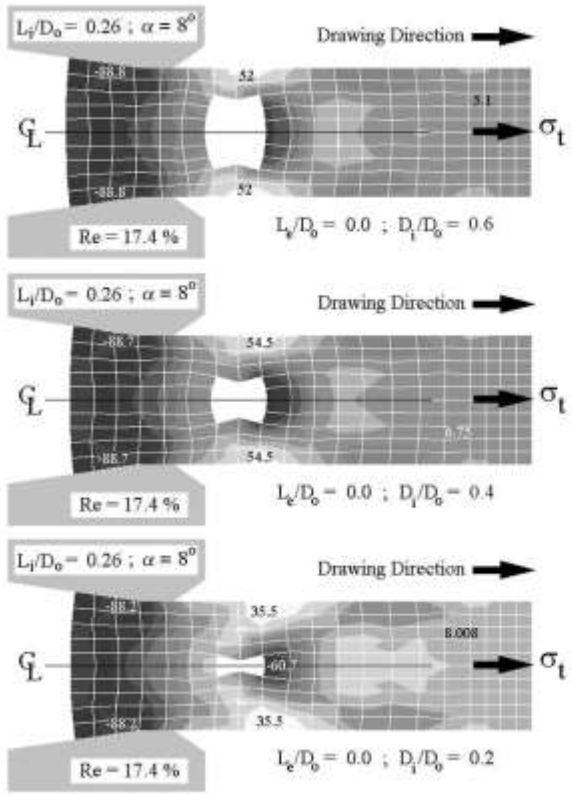

Fig. 4 The deformation and mean normal stress distributions of copper wires contain a central various size void

4.3 Drawing Stress Comparison. Fig. 5 shows drawing stress (σ_v/σ), the ratio of drawing stress of wire contains void (σ_v) to drawing stress of wire without void (σ), as a void passes through the die.

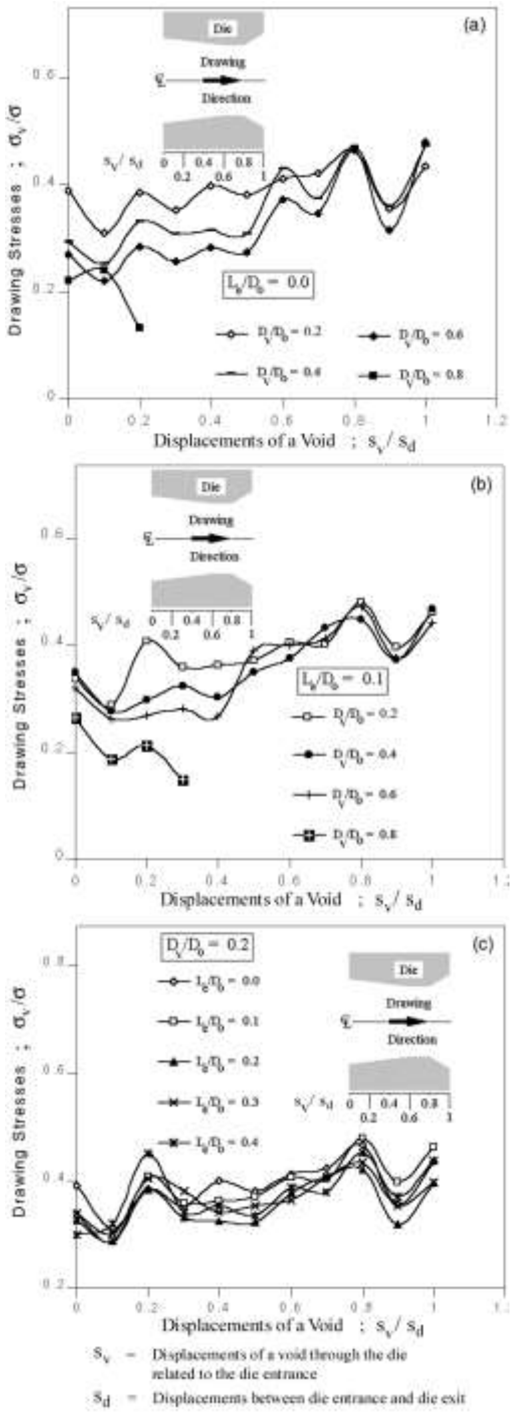

Fig. 5 The drawing stresses of copper wires contain a non-central constant sizes void, a constant eccentric length various size void and a central various size void versus the displacement of a void

The drawing conditions were D_v/D_o = 0.2, 0.4, 0.6 and 0.8 and L_e/D_o = 0.0, 0.1, 0.2, 0.3, and 0.4. L_e/D_o was slightly influence on drawing stress decrement. But D_v/D_o was strongly influence on drawing stress decrement. The drawing stress decreases as L_e/D_o decrease and D_v/D_o increase. As D_v/D_o constant, the lowest drawing stress was found in wire, which contains a void that located on wire centerline. Because of influence of void deformation that occurred during non-central void wire drawing, in case of the same D_v/D_o, the drawing stresses of wire contain non-central void higher than wire contain central void.

5. Conclusions

1. The necking due to central and non-central void wire drawing slightly occurred and can be neglected.
2. The deformations of matrix around the void boundary were very large.
3. The void shape was transformed.
4. Bending and miss alignment magnitudes directly varied with eccentric length.
5. For constant eccentric length, the increase of maximum tensile stress on side surface of void and in wire cross section where contain void as the void exits the die were directly influenced by void size.
6. For constant void size, the maximum tensile stress around the surface of void was slightly influenced by eccentric length while the maximum tensile stress in wire cross section where contain void as the void exits the die was inversely influenced by eccentric length.
7. The extremely compressive stress occurred on the die contact surface, the opposite side that far away from void location and increase of its magnitude was directly influenced by eccentric length.
8. The drawing stress decrement due to a void was found.
9. The eccentric length slightly influences on drawing stress decrement.
10. Decrease of drawing stress was directly influenced by eccentric length.
11. Because of influence of void deformation that occurred during non-central void wire drawing the drawing stress of wire contain non-central void higher than wire contain centric void.

Based on FEA results above, the wire drawing with void, high maximum tensile stress rapidly increases as non-central void size increase, wire fracture during wire drawing process was induced by a large non-central void in the wire material although the drawing stress decrease as non-central void size increase.

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