EXPERIMENTAL AND NUMERICAL SIMULATION ANALYSES ON STRAIN DISTRIBUTION OF SHEET METAL DRAW FORMING

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الملخص

أُجريت هذه الدراسة للتحقق من تأثير متغيرات التصميم الهندسي، وكذلك جودة رقائق الصلب المستخدمة في عمليات السحب (التشكيل) العميق لإنتاج بعض المكونات المعدنية للأجهزة الكهربائية. قدرت المتطلبات اللازمة لهذه العملية من قوة الضغط المؤثرة والسماحات البينية لأجزاء القالب وفق متطلبات النظريات التصميمية العامة. حيث طبقت نظرية الخطوط الشبكية وكذلك التحليل التشبيهي الإحصائي في تحليل الانفعالات المتوزعة على سطح المنتج. نفذت جميع التصاميم بوسطه برنامج حاسوب يحدد تحليل توزيع الانفعالات، بالإضافة إلى تحديد التباين في سمك المناطق الحرجة والمتغيرة مع زوايا التشكيل. حيث أنجز العمل على رقائق من الصلب "Mat-1" (EU(DC03 و "Mat- 2" (EU(DC04. كانت نتائج التحليل للتشبيه الافتراضي مقبولة والمقارنات مرضية بين هذه النتائج التحليلية للانفعالات المتوزعة مع النتائج المستنبطة من الانفعالات المقاسة. كما أظهر عدد من القطع المعدنية المنتجة بعض التشرخات في مواقع حرجة على السطح، ويرجع السبب إلى حدوث تقاطعات بين حزم الانزلاق في الشبكة البلورية، مما أدى إلى نُشوء التصدعات وتقدمها خلال التشكيل بالإضافة إلى التقاطعات بين هذه الحزم والحدود البلورية. يعزو هذا العيب لمثل هذا النوع من الصلب ذو المطيلية العالية إلى انخفاض كفاءته للتشكيل نتيجة لتراجع الجودة في عملية التنقية خلال المراحل الأخيرة لإنتاجه.

ABSTRACT

An investigation is made on the effect of material quality and design parameters on drawn sheet metal used for producing different speakers shell in electronic products. The required drawing force and clearance between punch and die were estimated according to the general design theories. A grid method and a numerical simulation analyses are both adopted. An advanced computer program was used for designing and evaluating the strain distribution, and thickness variation along the frame edges. Two different sheet materials are selected, one is locally produced coded "Mat-1" and the other is recommended and supplied by the contractor coded "Mat-2". A good simulation and considerable correlation were achieved between the analyzed and measured strain distribution. Some shells of material "Mat-1" developed cracks initiated at slip band-slip band, and slip-G.B intersections, such ductile failure is most likely related to the deficiency in material cleanliness, which reduced its quality for draw forming.

KEYWORDS: Sheet Metal; Draw Forming; Grid Method; Numerical Simulation; Strain Distribution.

INTRODUCTION

The appearance of ductile failure in the manufacturing process of drawing parts is an important ground for refusal. Therefore, it is necessary to detect and analyze the cause of failure even before processing by utilizing and applying what is available of analysis methods and techniques. The finite element method seems to be the most promising aid for crack prediction in sheet metal forming. In fact the experimental investigation only describe global effects correctly but not local effect as for instance the distribution of mechanical stresses at a certain location in the drawing sheet. Using numerical analysis and computer programs help to provide product designers, process engineers and draw development engineers to conduct early feasibility studies, with fast and accurate formability analyses for evaluation and validation of drawing components [1]. During steel making process, many oxide inclusions can be formed, which is controlled by killing of the steel and give good control of flotation [2]. Tension and compression state of stress is found during drawing process, tensile stress due to the punch pulling the blank into die cavity, and a compressive stress acts in the tangential or hoop direction [3]. Many factors affecting material drawability, anisotropy has a pronounced effect on rolling texture of rolled sheet metal, strain hardening, It can also affect the distribution of strain by the action of drawing, and enhance the material's resistance to wrinkles [3, 4]. In commercial draw forming, clearance between punch and die of 10 - 40 % greater than the metal thickness is recommended [5]. In this paper, two different types of cold rolled steel sheets are used and the results will concentrate on the key findings associated with both, the experimental and numerical simulation as investigation tools to predict the crack causes in cold rolled steel sheets under the action of draw forming.

EXPERIMENTAL WORK

Materials Specification

The used cold rolled steel sheets are coded as "Mat-1" &"Mat-2" supplied by [6], and [7] respectively, the both steel sheets with nominal thickness of 0.7 mm, and within the chemical compositions and specifications as presented in Table (1).

Table 1: The materials specifications, and chemical composition

Metal	Standard	Quality	Chemical composition					
			C%	Mn%	Si%	S%	P%	Fe
"Mat-1"	EU (DC03)	Deep drawing	0.10	0.45	0.03	0.035	0.035	Balance
"Mat-2"	EU (DC04)	Extra deep drawing	0.08	0.40	0.03	0.030	0.030	Balance

The chemical composition in Table (1) indicates that, the two steels are low carbon steel (1010), and (1008) according to AISI designation. These steels possess a minimum content of Silicon, in order to reduce the solid solution strengthening, and also reducing the elastic recovery in the wake of draw forming process.

Tensile Properties

Tensile test was carried out on standard tension specimens according to specification [DEN 1623/SM3]. The specimens have machined off the same material strips of "Mat-1". The loaded specimens were observed throughout the test until final fracture occurred. A laboratory tensile test report is received from National Libyan Iron and Steel Company (NLISC). For metal "Mat-2" all tensile data obtained from the data sheet of the product by the supplier [7]. All tensile data are used for further study and analyses.

Shell Shape and Dimensions

Speaker shells are one of electronic devices product where the flat sheets are pressed and formed into shells shape. The shape and dimensions of the produced shell considered in the present work is shown in Figure (1). Other necessary parameters for die design are checked and investigated to make sure they are within the design requirement limit.

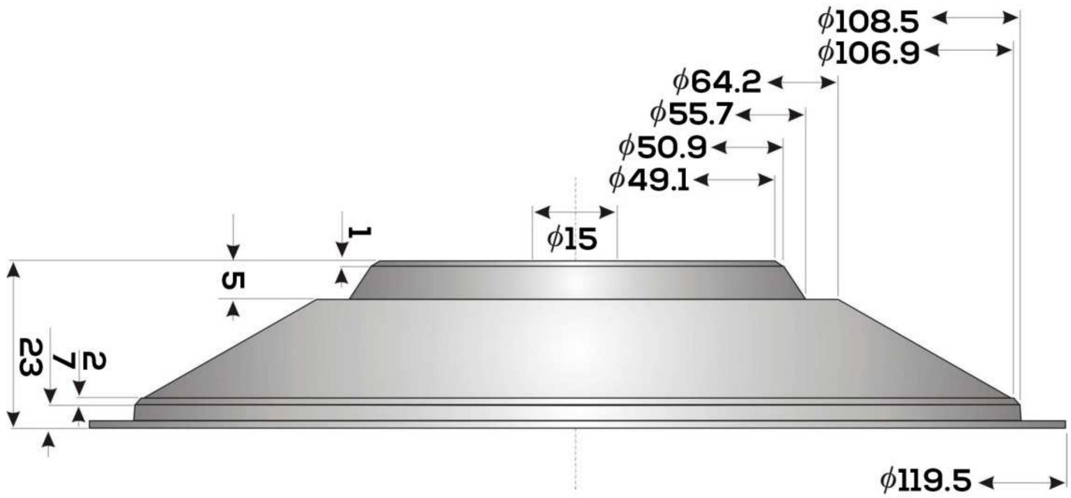

Figure 1: The dimensions of the speaker shell in (mm)

Required Blank Size; by applying solid work facilities and the constant volume rule, the blank diameter ' D_0 ' is determined according to the formula [5].

$$D_0 = \sqrt{\frac{4A_s}{\pi}} + \Delta_{Allowance} \cdots \tag{1}$$

Where: $\Delta_{Allowance}$ = The Trimming Allowance ≈ 8mm, As = the Surface Area

Limiting Drawing Ratio (LDR); the severity of drawing process 'M' as the inverse of LDR, in such work is expressed by the relationship of the blank diameter to the cup diameter [5].

$$LDR = \frac{D_0}{D_p} \tag{2}$$

Where: D_0 = Blank Diameter, D_p = Effective Punch Diameter

Shell Height To Blank Diameter Ratio; the need for redrawing is expressed by the shell height to the blank diameter ratio h / d. **Blank thickness to blank diameter ratio (R_t)** [5]; is a measure to the severity of wrinkling as the percentage of thickness to blank diameter ratio, or

$$R_t = \frac{t}{D_0} \times 100 \tag{3}$$

Where: t = Blank Thickness

The Maximum Shell Height Limit; this limit is calculated according to the following formula

$$h = \frac{D_0^2 - d_m^2}{4d_m} \tag{4}$$

Where: h = Shell Height, D_0 = Blank Diameter, d_m = Mean Diameter of the Shell [5].

Clearance (c), between Punch and Die; when the gap between punch and die is too generous, the process will rather resemble stretching. An insufficient clearance between the tooling will produce thinner wall, which is an effect called ironing [4], too small clearance promotes compacting and compression. The proper clearance was found as [5]:

$$c = 1.1t \sim 1.4t \tag{5}$$

The Required Drawing Force; tensile strength of the material is commonly used as the basis for estimating force or pressure requirement in draw forming. For present condition, the required drawing force (F_d) is approximated with the following equation [5]:

$$F_d = \pi D_p t\left(S_u\right)\left(\frac{D_0}{D_p} - 0.7\right) \tag{6}$$

Where: S_u = Ultimate Tensile Strength

The Required Blank – Holding Force; the numerical value of the blank holding force (F_h) is important mostly for calculating the total drawing force. The force exerted by the blank holder on the flange is estimated as [5]:

$$F_h = 0.015 S_y \pi\left[D_b^2 - \left(\mathrm{D_p} + 2.2t + 2r_d\right)^2\right] \quad . (7)$$

Where: D_b = Blank Diameter, S_y = Yield Strength =, r_d = Die Radius

Practical Shell Drawing:

Grid method is effectively used to analyze the resulted strains as the sheet metal subjected to different stresses. In present study a gridded network was made on the upper side surface of the blank by scratching with a sharp tip scrabble tool to make small squares with dimensions of (4 x 4) mm. as in Figure (2). After the metal is deformed into desired shape in speaker's factory of Electronic General Company (Tajura-Tripoli), the strain distribution is visualized, and critical strained areas are clearly spotted. The deformed small squares are investigated, some of them are found to be elongated and the others are contracted as in Figure (3). The strain values were measured across diameter of produced shell surface using an optical macroscope, with more attention made at the regions close to the appeared cracks.

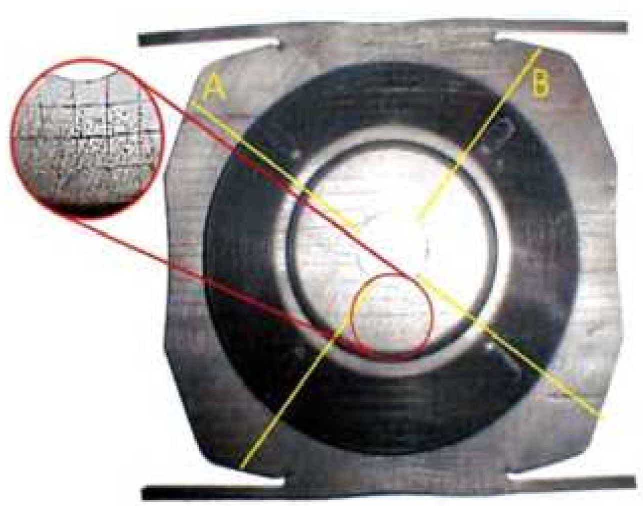

Figure 2: The drawing grid on the blank surface

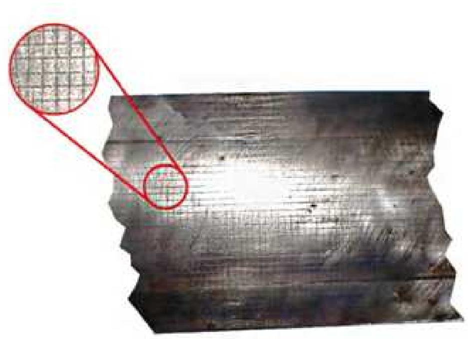

Figure 3: The drawing grid on the drawn part

Material Modeling:

The first material used is "Mat-1", all mechanical properties and parameters obtained from tensile test results are fed to the computer program, then the properties and parameters of "Mat-2" as supplied by the contractor [7], are also fed. *For part geometry editing*; solid model requires a skin representing the surface top, bottom and edges of the part, Figure (4), shows the shell after editing. *For meshing the part surface*; as meshing considered the heart of formability analysis, the program suggests a minimum and maximum mesh size based on part geometry. After the meshing is made and inspected, the analysis is applied as shown in Figure (5).

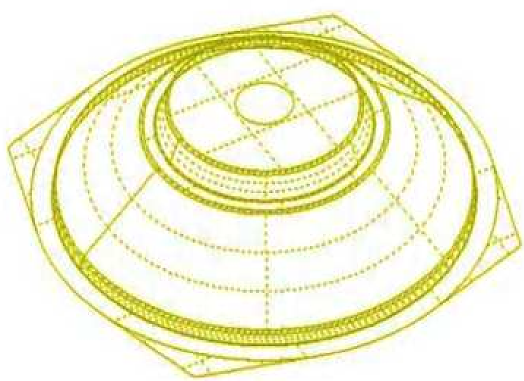

Figure 4: Wire shell after editing

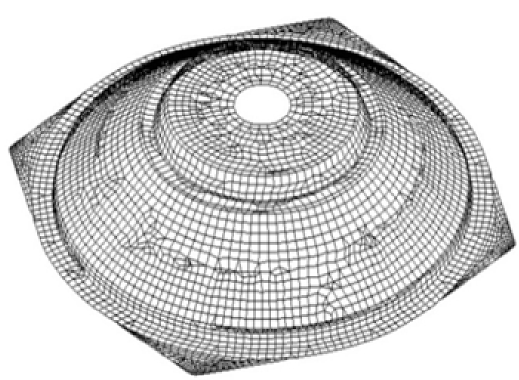

Figure 5: Mesh shell surface

RESULTS

Die Geometry Investigation

According to the design procedures, all parameters for die design are checked and investigated. This finalized the design work, and calculating the critical parameters that affect speaker shell manufacturing. The data obtained from all calculations are tabulated in Table (2).

Table 2: Die design parameters

D_0	LDR	$M = \frac{1}{LDR}$	$\frac{h}{d}$	Rt	h_{max}	F_d	F_h
141mm	1.8	0.56	0.29	0.49	44.2mm	20KN	86KN

Figures (6&7) show locations and values of clearance between punch and die C1, C2, & C3, and the radius of drawing punch R1 & R2.

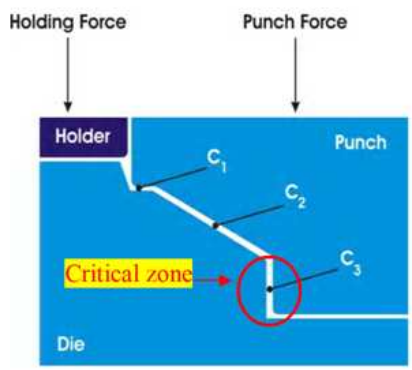

Figure 6: The clearance between punch and die

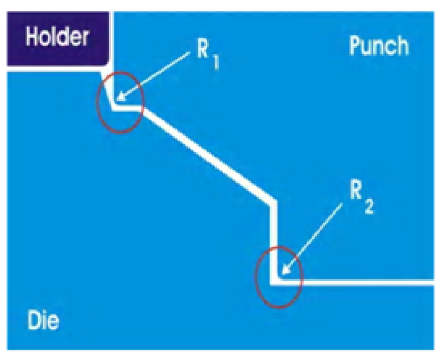

Figure 7: The radius of drawing punch at two critical points

Tensile Test Results and Related Calculations:

All tensile test results obtained for "Mat1" is shown in Table (3). These results are used as a basis for determining the material workability and formability.

Table 3: The tensile test results

E-Mod GPa	Proof Stress MPa	Upper yield MPa	Lower yield MPa	σm MPa	Strain at σm %	Fb kN	Strain at Fb %
194.9	280.20	274.35	270.96	371.01	19.35	11.9	37.06

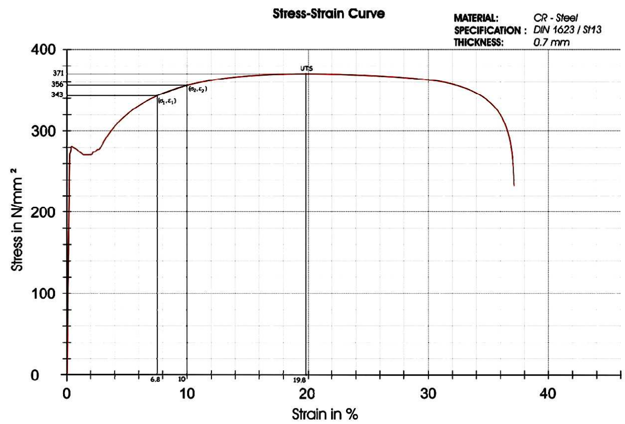

Figure 8: The Stress Strain curve for "Mat1".

Where: σm= Max Stress, F_b = Brake Force

Strain hardening exponent and strength coefficient were calculated from the plastic deformation region of the received stress–strain curve Figure (8), at stress equals to 343 and 356 MPa. These values are substituted in equation (8) as follow.

$$\sigma = k\, \varepsilon^{n} \qquad (8)$$

Where: k = Strength Coefficient, n = Strain Hardening Exponent

$343 = k\,(0.068)^{n}$, and $356 = k\,(0.1)^{n}$

The, strain hardening exponent (n) is found to equal (0.0965), and strength coefficient (k) is equal to (444.5 MPa). The plastic strain ratio 'R' as a measure of the resistance to through thickness thinning, is also found to equal (2.8994).

The Actual Measured Strain Results:

Strain values along the shell diameter are estimated, and all data are graphically presented versus diameter (section) length as (Grid Experimental Line) in Figure (8). It can be seen that, a large gradient of straining along the diameter, reaches the maximum values at locations represent two transitions of surface plane, from vertical to 35°, and from 35° to almost vertical then horizontal.

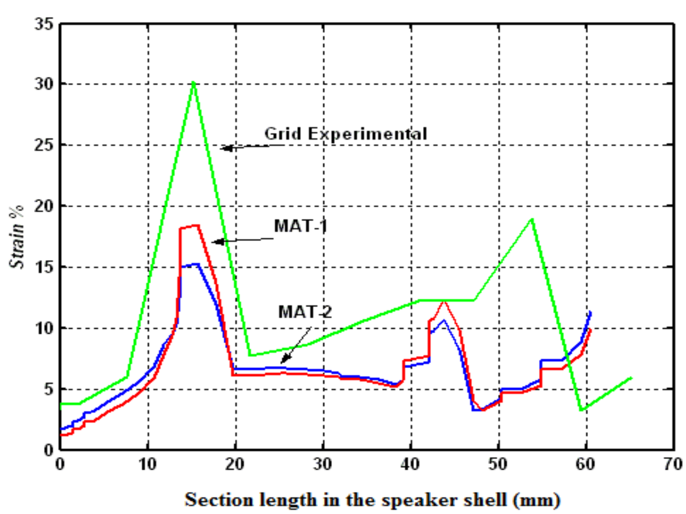

Figure 9: Long diameter strain distribution for "Mat-1", "Mat-2'' and the measured ones.

Simulation Forming Contours:

Safety Zone Contour; Figure (9) shows strain % distribution of both materials, at sections where the shell suffered from high tensions, the most critical strain values in these sections reached 18 % for metal "Mat-1" at the bottom region, and 14 % for proposed metal "Mat-2" at the same region too. Figures (10), and (11) also illustrate two visual plots of six colored zones occurred on the drawing part after simulation forming of "Mat-1" & "Mat-2". From the strain gradient, it can be distinguished the failed regions where splitting is likely to take place.

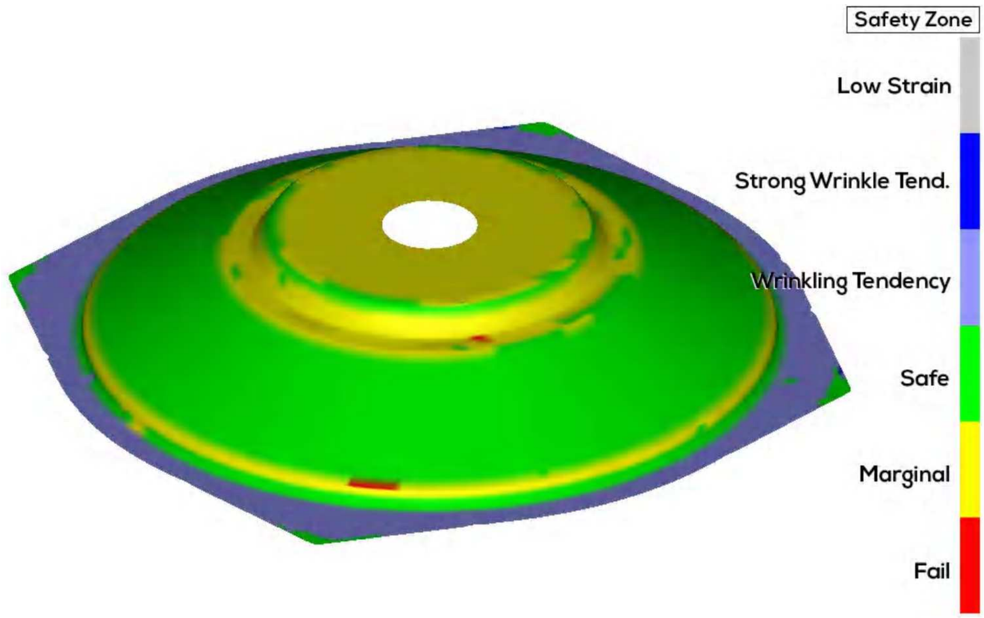

Figure 10: A safety zone contour for "Mat-1" after forming.

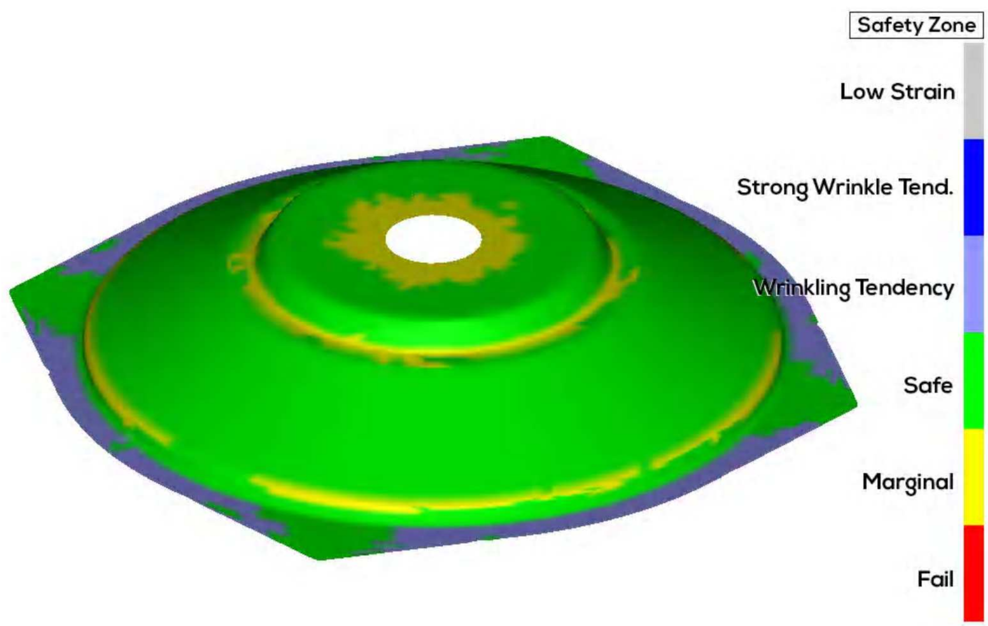

Figure 11: Safety zone contour for "Mat-2" after forming.

DISCUSSIONS

The shell production sequence was found to be well designed, terms of six processes in one press stroke cycle of the machine namely, the strip is fed, held, punched, drawn, formed and then trimmed. During the drawing step of the process about 10% of the produced shell developed single or double circumferential cracks with different sizes as shown in Figure (12).

This particular defect is believed to be attributed to the lack of final stages of steel making cleanliness [8], a small amount of oxygen atoms or sulfide inclusions will have sever effect on ductility. Also material anisotropy related to cold rolling inhomogeneous microstructure, and improper annealing treatment serves no useful effect [9].

For Design Requirement; all required parameters for die design were reviewed and recalculated, then compared with the actual die measurement. The results showed the used punch and die parameters such as clearance, and hold down force are within the limitation of standard range [5]. The hold down force was calculated and applied as input data; no sign of defect could be related to such force which agrees with Keeler [10] approach.

For Stretchand Bent Zone: Figure 6, shows the three locations of failed zones, as bending and stretching took place. The surrounded area with close circle represents the location where most cracks are initiated and grown, which is considered as critical zones. In theory [11], for inner stretched, and outer shrunk zones, there is a narrow ring of metal which has not been subjected to simple tensile loading throughout the drawing process. In different planes of critical zone the value of tensile loading produces resolved shear stresses exceeded the shear strength of the material, and tearing occurs. Since the size of the die radius depends on the metal thickness, it can be suggested that the tearing could be related to the die radius to thickness ratio.

Grid Method Strain Analysis:

From the actually measured strain results, the maximum values of linear strain of 0.3 was found at the location where the stretching followed by bending near the bottom flange of the shell, another high strain of 0.18 also found at the bending zone. During the numerical simulation analysis, the holding force condition was made only at the outer surrounded edge, while the center of the shell is kept free (not available for soft ware to hold the center). Under loading the material at the center of blank sheet flown to outer side and the value of strain recorded was less than the obtained ones. Such simulation conditions produced a clear shift of "Mat-1" & "Mat-2" plotted lines to the left hand side as shown in Figure (8).

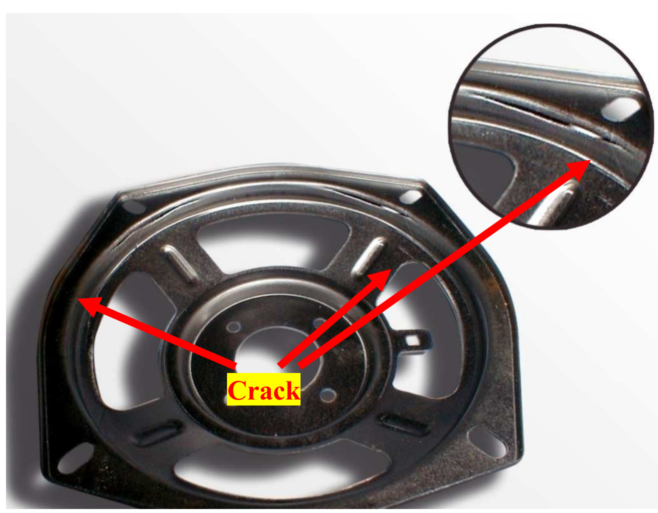

Figure 12: The cracks resulted at critical zones.

All data were fed as required to program, and applied to the shaped shell, then presented as relations of strain versus length. At critical locations with higher values of strains in "Mat-1" comparing to "Mat-2", is recorded, which is expected to refer to the amount of thickness reduction at that critical zones. For such microstructure mainly (bcc) ferrite, the slip system is low and the micro-crack formation mechanism is more likely controlled by slip induced grain boundary opening (triple point), and slip band-slip band intersection [9].

CONCLUSIONS

Based on the results obtained in this paper the following conclusions can be drawn:

- As a deep drawing quality "Mat-1" developed cracks at critical zones in both the actual tested and in simulation forming contours while "Mat-2" with extra deep quality didn't show any defects.
- The used punch and die have adequate design parameters, the fillet and corners on the punch and die are found to be within the design limit.
- The simulation analysis has proven to be in close agreement with the grid method strain distribution, and showed the critical zones under high stresses that suffered cracks.
- Good agreement was achieved between the strain and thickness variation analysis of "Mat-1"&"Mat-2".

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