A Review on Different Approaches for Deep Drawing of Square Cup

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Abstract - *Mostly three different approaches like experimental, numerical and combination of both experimental-numerical are practiced in deep drawing of square shape cup. The present study focuses on the current status and potential of future developments in the deep drawing of the square shape cup. The different approaches like experimental, numerical, and experimental-numerical are explored in detail to predict and reduce the defects while performing a deep drawing process. The review is to suggest an appropriate technique as per the different drawing conditions, type, and behavior of the material to achieve uniform thickness in the cup. In case of the experimental approach, the various process parameters like punch travel, blank holding, die/blank holder force, angle, and diameter, drawing ratio were studied to improve the product parameters like long run lubrication, uniform thickness distribution, a flow of material and efficiency. The experimental-numerical approach investigates the impact of variable blank holding forces, varying temperature, irregular cup shape, damage prediction at different blank parameters. The obtained evidence indicates that deep drawing process parameters such as drawing speed and tooling temperature need to be focused in case of the deep drawing of the square cup. These could offer an excellent opportunity in the field of automotive and aerospace industries.*

Key Words: **Sheet metal, Deep drawing process, Rectangular cup, Experimental, Numerical**

1. INTRODUCTION

The sheet metal forming is a widely used manufacturing process due to low cost and high speed. Among the sheet metal forming process the deep drawing process achieved the most important where the high drawing depth is obtained by using hydraulic or mechanical power. The deep drawing process is utilized for the drawing a cup of different shapes like circular [1-4] and square [5] which has a wide variety of application. The application includes the manufacturing of panels, gas tanks, truck oil filters. Similarly, it is also utilized in the manufacturing of household appliances like utensils, pots, pans for cooking, kitchen sinks, and bathtub.

2. Literature

The deep drawing of the square cup is practiced by most of the authors by using different approaches such as experimental, numerical, and combination of experimental and numerical.

2.1 Experimental approach

The experimental approach is practiced in the deep drawing of the square cup from last few decades. Bayratkar et al. [5] carried out 2D-draw bending analysis and deep drawing of the square cup of Hadfield steel for different punch travel using an experimental approach. Along with 2D-draw bending operation, the sidewall curls and spring back values were also investigated. Whereas, Danckert et al. [6] investigated the deep drawing of Aluminum and mild steel square cup using an experimental approach the thickness strain. The drawn-in of the flange were determined for punch travel of 40 mm which can be observed from the Fig. 1.

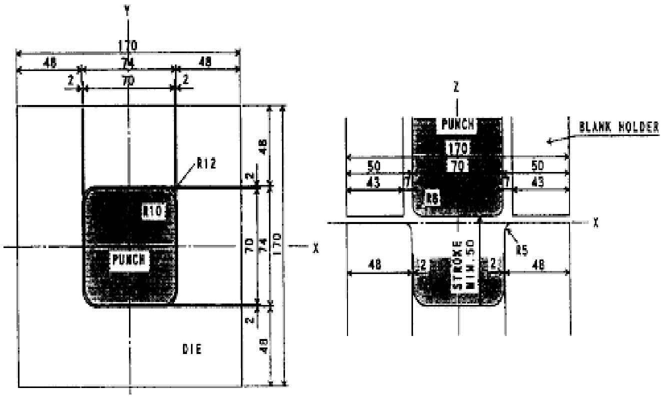

Fig -1: Schematic illustration of the deep-drawing tool for the square-cup deep drawing [6]

Similarly, Gavas et al. [7] performed an experimental analysis to reduce the friction between blank and blank holder by innovative the concept of the blank holder for square cup deep drawing by preparing and installing of the blank new practical approaches. The experimentation results like long run lubrication, uniform thickness distribution in the walls of cups and better flow of material along with more efficiency were found as shown in Fig. 2.

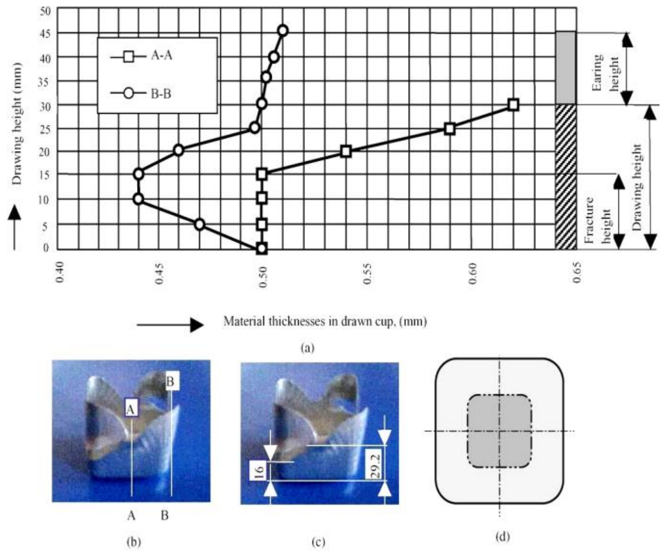

Fig -2: (a) Material thickness varies according to the drawing height of the drawn cup, (b) and (c) drawn parts, (d) blank [7]

Gavas et al. [8] performed experiments on different blank holder gaps of aluminum sheets for the deep drawn square cup and explained the reasons for the failure modes. Whereas, Hezam et al. [9] performed experiments for the developing a new process for increasing draw ability of square cups in which effects of punch load, blank thickness, and orientation on LDR are discussed. Similarly, Deng et al. [10] performed experiments to determine the through residual stresses distribution in a 2024 aluminum alloy deep drawn square cup by using layer removal technique and X-ray diffraction. At the bottom circular arc, the distribution of tangential residual stresses in the inner layer compressive residual stress was observed whereas in the outer layer the tensile residual stress.

Further, Marumo et al. [11] performed experimental analysis of square cup deep drawing in this the investigation of characteristics of the strain-hardening (n-values) on the deep draw ability of square aluminum and the combined effects of the corner radii of square tools were found. Whereas Morishita et al. [12] performed experimental analysis of square cup deep drawing using a counterpunch which is a new forming technology to improve the deep drawing ability of TBs, after the experimentation, it was observed that with increasing counterpunch pressure the limiting cup height also increases.

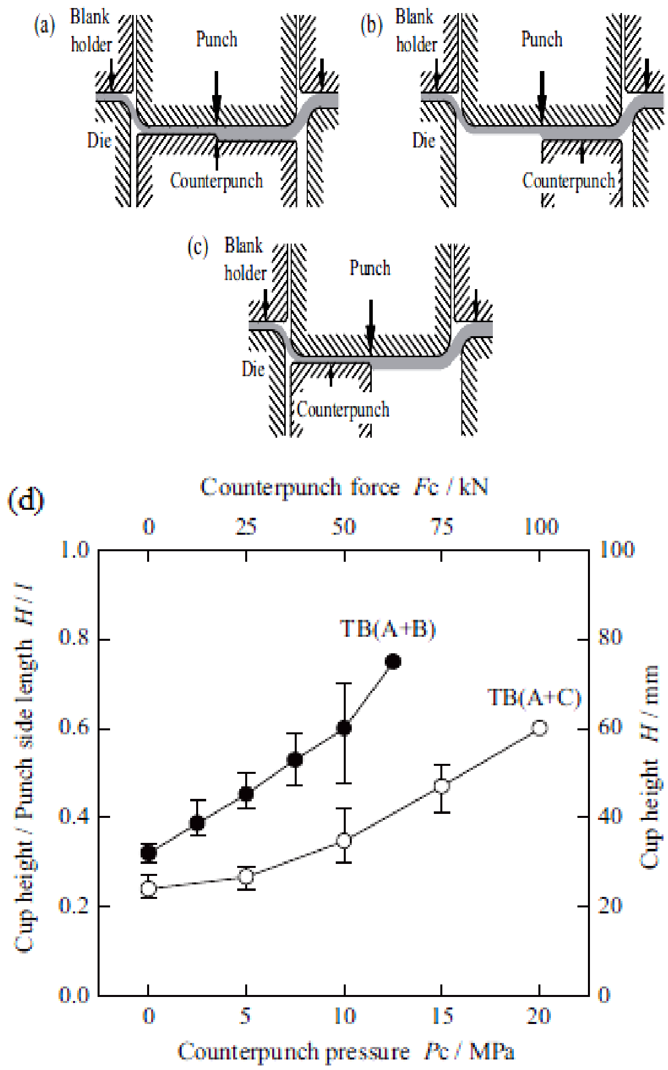

Fig- 3: Three different methods of clamping area by using counterpunch, (a) both thick and thin sheets, (b) only thick sheet side, (c) only thin sheet side, (d) effect of counterpunch pressure on the increase of limiting cup height by clamping method [12]

Also, it resulted that the action of counterpunch pressure is not necessary on the entire cup bottom, but it is only required on the thick portion of the sheet metal which is one of the good features of this forming technology as shown in Fig. 3 and 4.

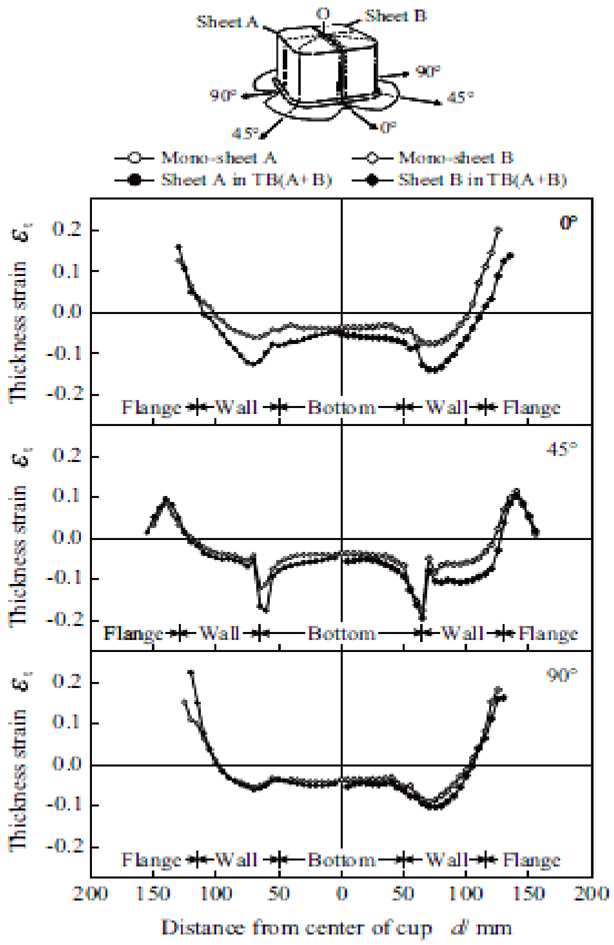

Fig -4: Distribution of thickness strain in cups of mono-sheets A, B and TB (A+B) for a cup height of 75 mm [12]

Sato et al. [13] performed an experimental analysis of deep drawing of the square cup where punch load along with LDR were measured. The increased in LDR was observed for the proposed method as compared to the conventional method. Similarly, Ozeket al. [14] performed an experimental analysis of the deep drawing of the square cup. An attempt was made to investigate the effects of die/blank holder angles, blank holder force, and die/punch diameter on the drawing ratio, punch force, and minimum wall thickness of angular squared deep drawing of DIN EN 10130–1999 steel sheets. The high limit drawing ratio and lower drawing failure were observed for the angular die as compared to the standard dies.

2.2 Numerical approach

Recently, the development was also observed in the utilization of the numerical approach for the deep drawing of the square cup. Han et al. [15] derived a modified membrane finite element to account the bending effect for sheet metal forming analysis. The developed algorithms were applied to drawing problems of the square cup for the investigation of thickness effect on the drawing load, strain distribution and size effect on an initial wrinkling which can be observed from the Fig. 5 a and b.

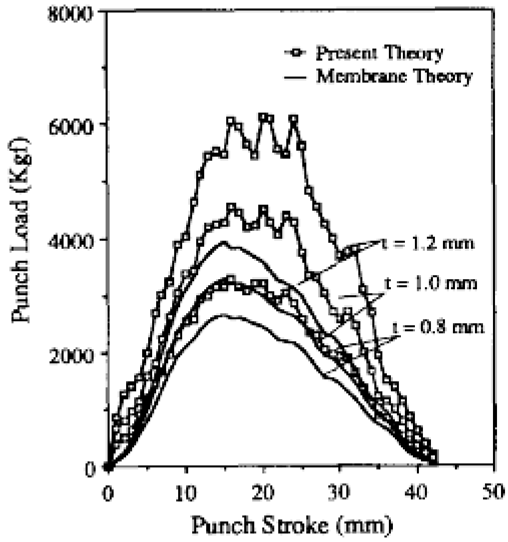

Fig -5: (a) Comparison of drawing load between the membrane theory and present theory with respect to various sheet thicknesses

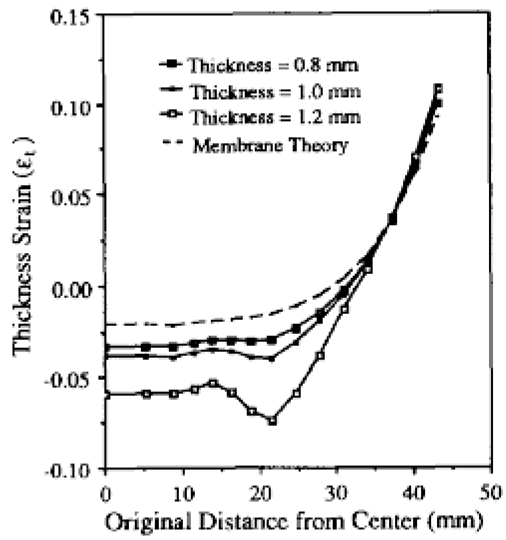

Fig -5: (b) Comparison of the thickness strain distribution in the diagonal direction [15]

Whereas, Huang et al. [16] developed a large deformation theory to study the stretching of the square cup. The predicted damage state in the product was simulated by using the criterion of strain energy density. The mechanics' deformation which includes distribution of stress, strain, and strain energy density, deformed geometry, and the variation of the punch load with displacement were studied as shown in Fig 6. The deformed surfaces of the blank were recorded for punch strokes of 4, 8 and12 mm. The cup center was observed to be distorted more on the punch side because of distortion was transmitted from the surface of the punch or die to the interior of the blank.

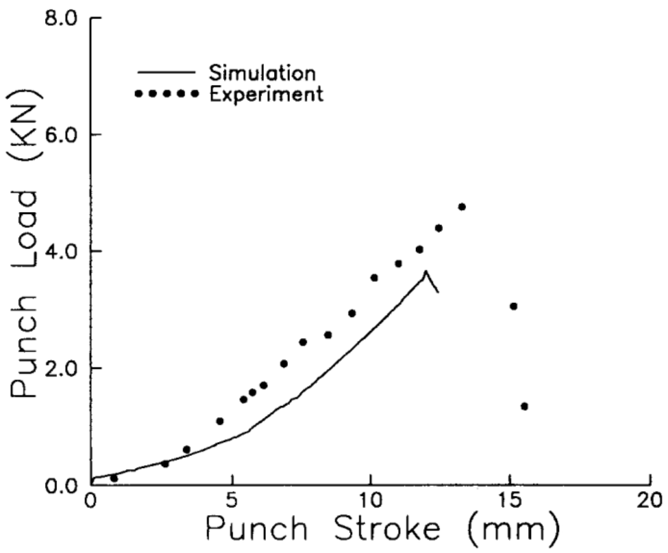

Fig -6: Relationships between the punch load and the punch stroke [16]

Similarly, Kaiping et al. [17] simulated the deep drawing of the square cup using an 8-node brick 3-D solid element with one integration point and 4-node quadrangular 3-D shallow shell element. The numerical results were obtained and compared which shows that the JET3D element is more economical and accurate. The Raphson scheme was used to solve the system equations. Whereas, Liu et al. [18] investigated the effect of crystallographic texture on the deformation behavior of the square-shaped commercially pure titanium (c.p.Ti) sheet in the dual-temperature deep drawing process. Mamalis et al. [19] simulated the deep-drawing of axis-symmetric cylindrical cups of coated galvanized steels by defining the upper and lower limits of the parameters. Whereas, Ronda et al. [20] used two constitutive models of the blank proposed by Estrin and Robinson and two friction models (non-linear pressure-dependent model and quasi-steady-state sliding model) for the finite element simulation of a deep drawing of the prismatic cup. The results were compared with the results obtained for the J2 elastic-plastic material model and the classical Coulomb friction model.

2.3 Combined experimental and numerical

Along with the experimental and numerical approach, the combination of experimental-numerical approach was also practiced by different authors. The deep drawing process was simulated by using a numerical approach and further validated by performing experiments. Kitayama et al. [21] performed an experimental analysis of square cup deep drawing by variable blank holder force (VBHF). In VBHF trajectory, a simple closed-loop type algorithm was elaborated. A low blank holder force (BHF) is used as an initial BHF which is further increased to prevent the wrinkling and tearing. The proposed algorithm was applied to the segmented VBHF trajectory. Similarly, Chen et al. [22] performed an experimental and finite element analysis of square cup deep drawing of magnesium alloy AZ31 (Aluminum 3%, Zinc 1%) sheets. The deep drawn cups obtained at different temperatures are shown in Fig 7.

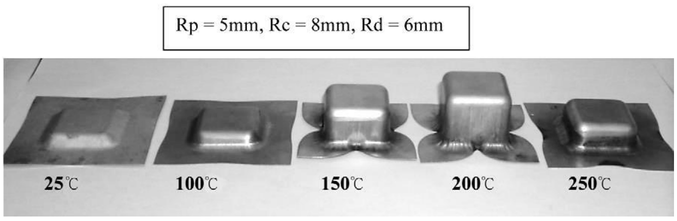

Fig -7: Drawn cups formed at various temperatures [22]

It was found that AZ31 sheets show poor formability at room temperature, but the formability goes on increasing significantly elevated temperatures up to 2000 ºC. The finite element simulations and experimental tests were carried out to investigate the effects of process parameters like forming temperature, punch radii, and die corner radii on the formability of with AZ31 sheets square cup drawing. The deep drawing of square cups of AZ31 sheets for the increasing temperatures was also performed in order to validate the finite element analysis results for different strain path. The experimental data and simulation results resemble agreement with the optimal forming temperature, punch radius and die corner radius.

Similarly, Demirci et al. [23] performed an experimental analysis of deep drawing of the square cup of AA5754-O aluminum alloy for the variable BHF. The numerical results of cup depth and wall thickness are shown in Fig. 8.

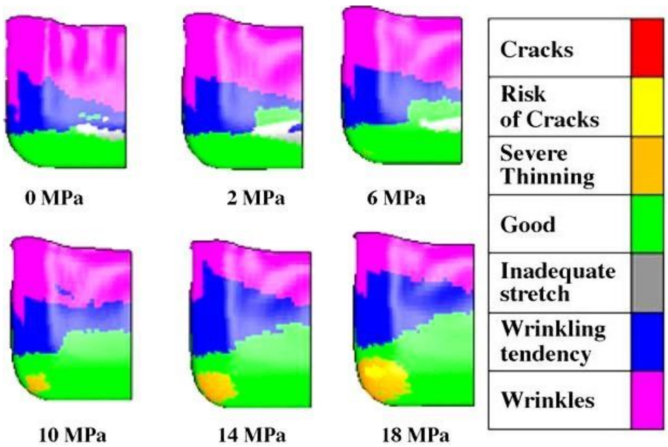

Fig -8: The numerical results of the deep drawing of a square cup of AA5754-O aluminum alloy [23]

No wrinkling and tearing occurred in BHF between 1.3 MPa and 8 MPa but the tearing was observed when the forces exceed to 18 MPa. At the 5 MPa, the best forming was observed. The developed numerical and experimental model is in harmony with each other at a rate of 85%. Whereas, Feng et al. [24] performed experimental and numerical analysis of deep drawing of the square cup to predicted the damage of irregular square cup, different blank hold process, and blank shape. The crack and thickness distribution was investigated with a numerical and experimental approach to optimize the BHF, and blank are shown in Fig.9.

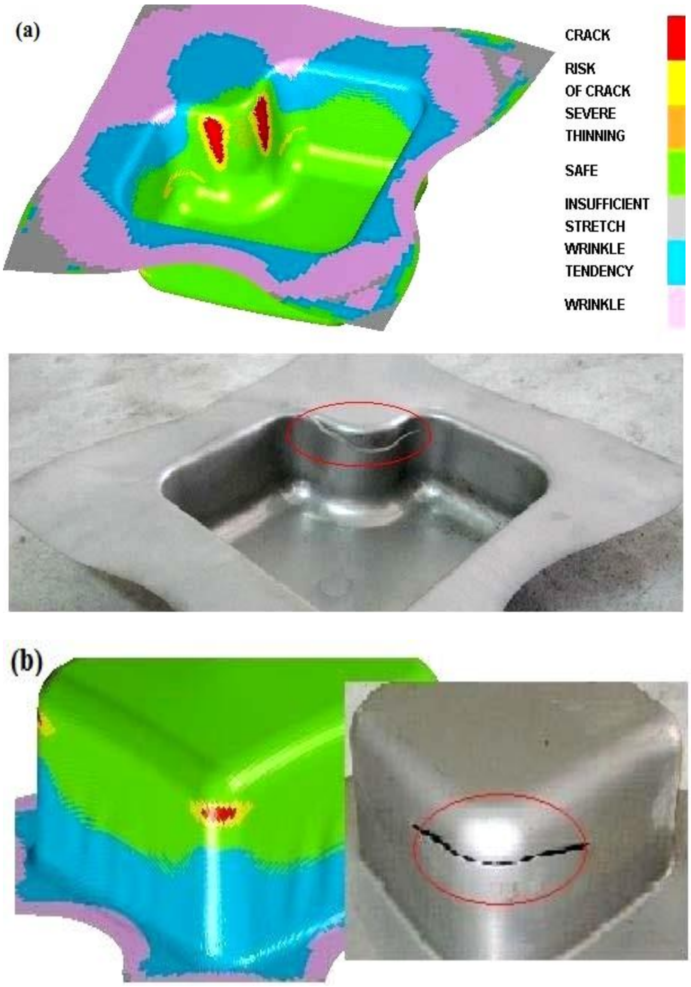

Fig -9: (a) Comparison of none optimized blank result, (b) Comparison of large BHF result [24]

Mamalis et al. [25] performed experimental and numerical analysis of deep drawing of square cup focusing on physical modeling and punch forces of the process from the microscopic point of view. The explicit non-linear finite element Code DYNA 3D analysis was carried out. The further comparison made over both experimental and simulation result for four coated steel. The theoretical results obtained are compared with the experimental and numerical results carried out on four coated steel sheets for this material found a good agreement. The punch load-punch travel experimental curve concerning Galvo 1 is plotted along with that obtained from numerical FE simulation as shown in the Fig.10. It was found that the small cup heights frictional forces are less and for considerable cup height it can be seen that the frictional forces are more significant. Fig. 11 shows macroscopic observation of different cup height and flange shape.

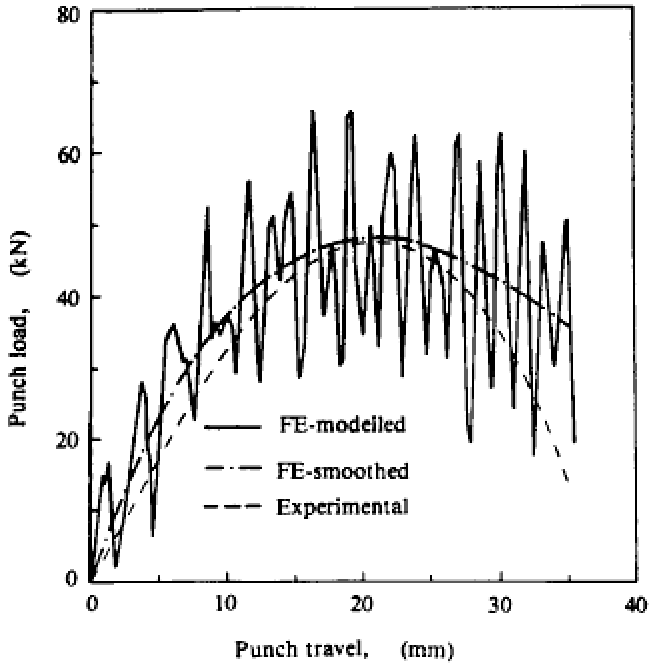

Fig -10: Punch load-punch travel experimental curve [25]

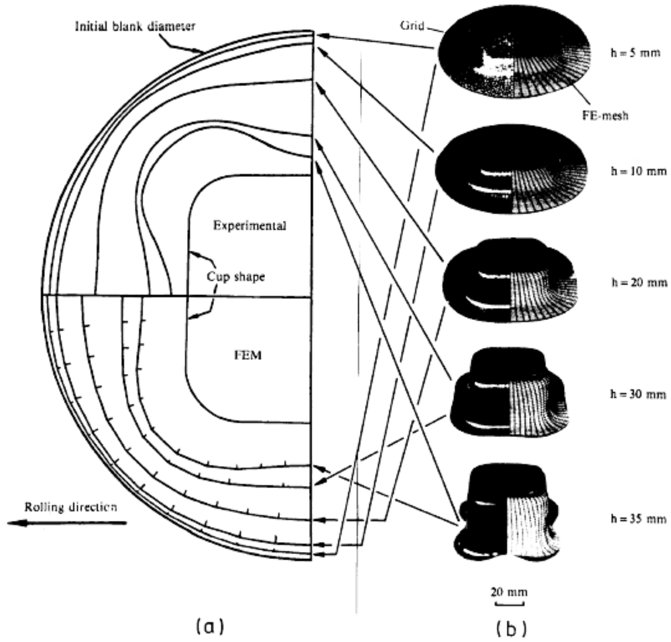

Fig -11: (a) Experimental and numerical predicted flange shapes, (b) macroscopic observations of the experimentally distorted grid and numerically predicted mesh for different cup heights [25]

The proposed explicit FE model predicts both the load curve and the material satisfactorily from the macroscopic point of view, for the examined model parameters. Also, Hassan et al. [26] performed experimental and numerical analysis of deep drawing of the square cup where the authors focus on the problems involved with the production of complex shapes using the sheet hydro-forming (SHF) process. The in-home equipments were used to perform tests on single sheet metal blanks.

Qiquan et al. [27] performed experimental and numerical analysis of deep drawing of a square cup of high tensile strength steel SPFC590 to investigate the drawing galling behavior in macro scale in semi-dry condition. The macro-scale galling was observed on the die and drawn cup surface after a few drawing cycles while using the Austempered ductile irons (ADI)) non-coated dies (cold alloy tool steel (SKD11, SLD) in a semi-dry condition. Simultaneously, the finite element method (FEM) with DEFORM-3D has used as a tool to simulate the square cup drawing process with respect to the drawing force distribution and volume change analysis. Whereas, Wijayathunga et al. [28] performed experimental and numerical analysis of deep drawing of the square cup by assuming that the sheet metal obeys Hill's anisotropic yield criterion to improve the material stability and reduce uneven material thickness. The Coulomb friction between the sheet metal and forming tools and work hardening characteristics of the material was also involved in the simulations to achieve a optimize solution for various blank shapes with identical surface areas.

3. CONCLUSIONS

The study focused on the current status and potential of future developments in the deep drawing of the square shape cup. The different approaches like experimental, numerical, and experimental-numerical are explored in detail to predict and reduce the defects while performing a deep drawing process. The defects in deep drawing process observed to affect the quality and manufacturing cost of the product directly. The analytical, numerical and experimental approach need to be utilized together to carry out deep drawing process to minimize the cost, time and maximize quality.

In the case of the experimental approach, results like long run lubrication, uniform thickness distribution in the walls, the sidewall curls, and spring back were found. It was found that by increasing the counterpunch pressure the limiting cup height also increases. The performed experimental analysis gives a review to investigate the effects of die/blank holder angles, blank holder force, and die/punch diameter on the drawing ratio, punch force, and minimum wall thickness.

In case of numerical approach, the deep drawing of a square cup which confirms the validity and versatility of the present algorithm which enhances the convergence of a solution procedure and guarantees the precision of numerical solutions for tool design, fracture prediction and process improvement in a complicated sheet-metal forming process. While some immediate concerns for the further enhancement of metal forming technology are the availability workpiece anisotropy, friction at the interface and optimizing of tool dimensions.

In case of combined numerical and experimental approach, VBHF trajectory a simple closed-loop type algorithm was elaborated a low BHF used as the initial BHF, which leads to prevention of wrinkling and tearing action. Whereas it was found that for the materials like AZ31 sheet shows poor formability at room temperature, but the formability goes on increasing significantly elevated temperatures up to 2000. The best formability was observed at 5MPa pressure while drawing for small cup heights.

The review suggests an appropriate technique for different drawing conditions, type, and material to achieve defect-free component. The obtained evidence indicates that the deep drawing process parameters such as drawing speed and tooling temperature need to be focused in case of the deep drawing of the square cup which could offer an excellent opportunity in the field of automotive and aerospace industries.

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