



EXPERIMENTAL AND FINITE ELEMENT ANALYSIS OF SQUARE DEEP DRAWING PROCESS FOR LAMINATED STEEL-BRASS SHEET METALS

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ABSTRACT

In this paper, the drawability of two-layer (steel-brass) sheets to produce square cup, is investigated through numerical simulations, and experimental tests. Each material has its own benefits and drawbacks in terms of its physical, chemical and mechanical properties, so that the point of this investigation is taking the benefits of different materials, like (low density, high strength and resistibility of corrosion), at the same time and in a one part. ANSYS18 software is used to simulate the deep drawing process of laminated sheet. The deep drawing processes for square cup were carried out under various blank holder loads with different lubrication conditions (dry and lubricant) and with variable layer arrangement. The materials were low carbon steel st1008 and brass CuZn30 sheets with thickness of 0.5mm and 0.58mm respectively. The thickness of laminated sheet blank was 1.1 mm and its diameter was 83 mm. The drawn cups with less imperfections and satisfactory thickness distribution were formed in this study. It is concluded the greatest thinning appear in the corner of the cup near the punch radius due to extreme stretching take place in this area. Experimental forming load, blank holder load, and thickness distribution are compared with simulation results. Good agreement between experimental and numerical is evident.

KEYWORDS: Deep Drawing, Finite element, ANSYS, Formability, Laminated sheet, Composite materials.

تحليل عملية السحب العميق المربع للصفائح المعدنية المركبة فولاذ-براص بواسطة العناصر المحدودة والتجارب العملية

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الخلاصة

في هذه البحث، تم دراسة قابلية السحب لصفحة مركبة (فولاذ - براص) لإنتاج كوب مربع، عملياً ونظرياً. كل مادة لها فوائدها وعيوبها الخاصة من حيث خصائصها الفيزيائية والكيميائية والميكانيكية، وبناءً على ذلك الهدف الرئيسي من هذا البحث هو الاستفادة من خصائص المواد المختلفة، مثل (الكثافة المنخفضة، القوة العالية ومقاومة التآكل)، في نفس الوقت وفي جزء واحد. استخدم برنامج ANSYS 18 لمحاكاة عملية السحب العميق للصفائح المركبة. تم تنفيذ عمليات السحب العميق للكوب المربع تحت قوى مسك مختلفة مع ظروف تزييت مختلفة (جافة ومزيتة) وترتيب طبقات مختلفة. كانت المواد من الفولاذ الكربوني المنخفض st1008 والصفائح النحاسية CuZn30 بسمك 0.5 ملم و 0.58 ملم على التوالي. كان سمك العينة المركبة 1.1 ملم وقطرها 83 ملم. تم تشكيل الكؤوس مع عيوب أقل وتوزيع سمك مرضي في هذه الدراسة. وبخلاف ذلك إلى أن أقل سمك يظهر في زاوية الكأس بالقرب من نصف قطر البنج بسبب التمدد الشديد الذي يحدث في هذه المنطقة. تم مقارنة قوة التشكيل، قوة المسك، وتوزيع السمك الناتجة من التجارب العملية مع نتائج المحاكاة. وقد وجد ان التجارب العملية تتوافق بشكل جيد مع عملية المحاكاة.

INTRODUCTION

Deep drawing process is one of the most popular and widely investigated sheet metal forming process and is widely used in various industries". In the deep drawing process, a flat sheet metal blank is formed into a cylindrical, box-shaped or other complex hollow-shaped product by means of a punch, which presses the blank into a die [Gupta H.N., 2009] [Lange K.,1985]. A laminated sheet comprises of at least two metals with different material arrangements and various thicknesses. Generally, layered sheets can be made by many processes, such as cold and hot roll bonding, adhesive bonding or explosive bonding. The deep drawing operations of composite sheet metal can be utilized in producing of components with different internal and external conditions like resistance of corrosion and wear, electrical and thermal conductivities. With this regard, such products are progressively utilized in numerous fields like the vessels, aerospace, automotive, medical instruments, and electrical industries [Huang-Chi T, 2010]. Composite bimetal sheet metals have completely different disfigurement behaviors, compared with a single-layer sheet. These behaviors depend mainly on the combination of materials and their assembly conditions. Recently, many research efforts have been focused on composite sheets due to the extensive variety of uses. Huang-Chi Tseng et al., 2010 studied the formability of Aluminum/ copper (Al/Cu) clad metals through Punch stretching test and square deep drawing. [Morovvati et al., 2010] proposed a new analytic approach to investigate the plastic wrinkling of two - layer sheet metal in deep drawing process. They utilized composite and equilibrium equations in energy method. Also, FEM and experimental data were utilized in order to validate the method. Results demonstrate that the optimum blank holder force is reliant on the geometry of blank, material properties and layer arrangement. [O.A.Sokolovan et al., 2012] studied the formability of (stainless steel/ polypropylene-polyethylene polymers PP-PE/ stainless steel) sandwich composites. Deep drawing process carried out by using two punches square and circular. The result shown that the geometry of punch and the core thickness have a high effect on the forming behaviour of the three-layered sandwiches. [M. Nourjani Pourmoghadam et al., 2013] investigated the plastic wrinkling formation for (Al2024/ Polyamide6 /Al2024) sandwich sheets. [Amir Atrian and Faramarz Fereshteh Saniee, 2013] studied the effects of some parameters on the deep drawing process of steel / brass laminated sheets, experimentally and with finite element analysis.[Haibo Li et al., 2013] investigated the delamination of laminated sheet in U channel bending and deep drawing of step5bottom square cup experimentally and with finite element analysis. The results of the forming of U channel show that increasing forming velocity somewhat reduces the propensity of delamination, and increasing blank holding force reduces the incidence of delamination. At the same time, the results of the cup drawing expose that the wrinkling of outer sheets often induced delamination. The hydro mechanical deep drawing process of two-layer aluminum A1050-steel St13 sheet was investigated experimentally and numerically by [S. Bagherzadeh et al., 2015]. The results presented that the maximum punch load in experimental was greater than the results of finite element simulation and theoretical results. The results indicated that the HMDD process with appropriate fluid pressure increases formability and limiting drawing ratio of aluminum / steel sheets than conventional deep drawing. [Farshid Dehghani and Mahmoud Salimi, 2015] studied the behavior of clad sheet compared with single layer sheet through experimental and finite element method. The thickness variations and limiting draw ratio of copper/stainless steel bimetal sheet were investigated. The results demonstrated that the thickness distribution of stronger metal (stainless steel) was slightly more uniform than the weaker one (copper). [Roya Darabi et al., 2017] investigated the effect of different metal properties of layers on the formability of laminated Aluminum AL3105-Carbon steel St14 sheets analytically and experimentally. The

Results Demonstrated that the formability of two-layer sheet is improved by rising the strain hardening and strain rate sensitivity exponents of sheets. The most imperfections happened in this process were wrinkling, earring and rupture that can be reduced by correctly adjusting of the related parameters like blank holder force, clearance and surface conditions [M. Nourjani, 2013]. The blank holder force is one of the most important factors which affects the drawability of sheet metal. The selection of appropriate blank holder force is critical When it is insufficient the wrinkling can take place. On other hand, fracture or tearing can occur when the blank holder load is too high. In the present work, the deep drawing process of laminated sheets to produce square cups is investigated. The effects of some process parameters like blank holder force, layers arrangement and lubrication conditions (dry and lubricant) on thinning and required drawing force were studied using finite element method via ANSYS software and experimental test.

EXPERIMENTAL

Material and Specimen Preparation

The raw materials of the laminated sheet are low carbon steel 1008 and brass CuZn30 with thickness of 0.5 mm and 0.58 mm respectively, which their chemical composition are tested using atomic absorption spectrometer and the results are furnished in Table 1. Tensile tests were conducted to find out the mechanical properties of the metals. The test is carried out using universal tensile testing machine. Tensile test specimens were prepared “according to (ASTM - E8) standard” as shown in Fig. 1, and were cut using wire-cut Electron Discharge Machine (EDM). The mechanical properties of steel and brass were listed in Table 2. The sheets of steel and brass were joined together by small layer of polyurethane adhesive and then punched to make composite sheets. Before joining the two layers together, the surfaces of the sheets are degreased in order to improve the attachment performance at specimen. Thickness of two-layer sheet was 1.1 mm.

Deep Drawing Process for Square Cup

The deep drawing for square cup tests were performed to investigate the drawability of steel-brass multilayer laminated sheets under different blank holder force, layer arrangement and lubrication conditions (dry and grease lubricant). The experimental set-up is shown in Fig. 2. The geometry and dimension of tools for square deep drawing tests is illustrated in Fig. 3. All tests were carried out by Universal Testing Machine (UTM) of 300 kN capacity with ram speed of 20 mm/min. Drawing tests were carried out using circular blanks with diameter of 83 mm. The blank holder force has been gradually increasing up to 4 kN and provided by spring. When the steel sheet is the outside layer of the cup and the brass sheet is the inside layer, the composite sheet named S-B and the other one that in which brass sheet is outside layer of cup, the sheet called B-S. The tests were performed with grease lubricant and without lubricant. The specimens after forming are shown in Fig. 4. The thickness strain distributions along diagonal and transvers directions of the produced cup were measured by using a micrometer.

FINITE ELEMENT ANALYSIS

An implicit finite element code was utilized for simulation of the square deep drawing of the laminated sheets to observe the forming process virtually. Due to symmetric conditions, one quarter of a 3D model was simulated in ANSYS18. The two-layers of the laminated sheet were meshed with 3D element solid185. The friction coefficients that used for steel and brass

were 0.23 and 0.22 respectively [Amir Atrian 2013]. The punch, the die and the blank holder were modelled as a rigid in order to reduce computation time. The material behaviors were considered as bilinear anisotropic, rate-independent Hill plasticity. The anisotropic behavior of the material was considered using Hill's quadratic yield criterion. Contacts between blank and the tool (punch, die and blank holder) and between two layers of blank were performed with contact pair manager. All contact surfaces were modelled with 3D element TARGE 170 for target surfaces and 3D element CONTA 174 for contact elements. A finite element model was constructed as shown in Fig. 5. The deformed model showed in Fig. 6.

RESULTS AND DISCUSSIONS

In this part, the influences of all the parameters on the punch load–displacement diagram have been concluded and discussed. Figure 7 (a and b) generally shown the punch load–displacement diagrams obtained from experimental and finite element analysis. These curves show similar trends, the punch force increases almost linearly, and reached the maximum force when the punch stroke is about (37-43) %. Then the punch force decreases progressively at the stroke of about 70%. Later, it is increased due to drawing the remainder flange (cup corner) and ironing of thickened edge. The process conditions for these outcomes are blanks diameter of 83 mm, grease lubricant condition and blank holder force of 4 kN. This figure demonstrates that finite element results commonly predict a bigger forming force to perform the process. These overestimations of the FE result are about 8.7 % for B-S and 12.7 % for S-B. The maximum experimental drawing load was 47.9 kN for S-B and for B-S was 46.76 kN. In experimental results for S-B case, the grease lubricant was reduced the maximum required drawing force about 2.5%, compared with dry condition, while for B-S case the lubricant was reduced the force about 2 %. The two-layer cups formed with grease lubricant have excellent surface quality, compared with the dry condition. Figure 8 (a and b) represent the drawing force under dry and lubricant conditions for the two cases. Some tests with various layer arrangements were accomplished to study the influence of layer arrangement. The behavior of laminated sheets in the deep drawing process varies from single-layer sheets and depends on the arrangement of layer and thickness. The result showed that the required drawing force of case B-S lesser than case S-B about 2.4 % as shown in figure 9. This is due to a lower friction coefficient, the frictional stresses on the brass sheet is lesser than that on the steel sheet [M. Nourjani, 2013]. For S-B and B-S blanks experimental tests and FE simulations were executed under different BHF's. Figure 4 represents the produced cups without defects, while figure 10 demonstrates the failed cups with wrinkling and tearing. Also, figure 11 illustrates the drawn cups under different BHF's from low to high BHF through FEA. For each case, the thickness distribution of both layers were measured along diagonal and transvers directions after cutting the cup by using wire cut EDM machine. Figures (12 to 15) show the thickness strain distributions for the two cases obtained by finite element simulation and experimental. The minimum thickness distribution is taken place almost in the area of punch radius at the cup corner. It can be expressed that the layers in this area are exposed to lower work hardening. The results showed that the outside layer of cup are subjected to more extension due to higher tensile stresses at the outside layer, this make the layer thinner. For this reason, the outside layer is subjected to higher risk of rupture. Good agreement is evident between experimental and FEA.

CONCLUSIONS

The main goal of this paper was to study the drawability of steel-brass laminated sheets through experiment test and finite element simulation. 3D finite element model of the square deep drawing for laminated sheets was developed to expect the significant factors of process

ensuring an effective forming. Experimental tests were performed to validate the finite element simulation. Conclusions are brief as follows:

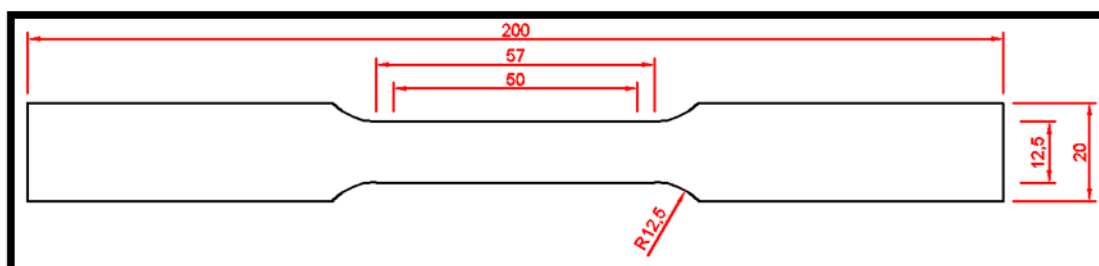
1. The deformation states vary along the die cavity, and the flow of metal at the cup side walls is more uniform and easier than that in the cup corner. Therefore, almost earring defect is concentrated at cup corners.
2. The results of this study shown that the layer arrangement has a significant effect on forming behavior during the deep drawing processes.
3. The thickness distribution measured along various directions showed that the laminated cup thickness along diagonal direction was less than that of transverse direction about 16.5 % for S-B and 13.7% for B-S experimentally, and about 37.6 % for S-B and 38.6 % for B-S in FEA.
4. The results present remarkable variances in the deformation of the outer and inner sheets i.e. (The thickness distribution of the same layer in different layer arrangement (inside and outside) shown that the outer layer thinned more than inner layer).
5. The lubricant results cause a reduction in the maximum drawing force, and the usage of lubricants produce a good surface finish.
6. The finite element analysis and experiment results present that the tearing occurred at the punch radius area in the cup corner and the outer layer fails first due to the higher tensile stresses.
7. Good agreement was found between finite element and experimental results. The maximum drawing force that obtained from simulation was greater than experimental force about 13 %.

Table (1): Chemical composition of steel and brass.

Element (wt%)	Material	
	Low Carbon Steel	Brass CuZn30
C	0.0377	-
Si	0.0235	-
Mn	0.217	-
P	0.0205	0.0048
S	0.0067	-
Cr	0.0453	-
Mo	<0.002	-
Ni	0.0272	0.0017
Al	0.046	-
Cu	0.0624	69.1
Fe	bal.	0.057
Zn	-	30.78
Pb	-	0.0068
Sn	-	0.0026

Table (2): Mechanical properties of materials.

Property	Material	
	Low carbon steel	Brass CuZn30
Yield stress (MPa)	166.1	163.04
Tensile strength (MPa)	326.5	303.2
Young module (GPa)	200	114
Poisson ratio, ν	0.3	0.34
Elongation (%)	24.21	33.34
r0	1.964	0.939
r45	1.491	1.057
r90	2.661	1.024

**Fig. (1): Schematic of the tensile test specimen and its dimensions.**

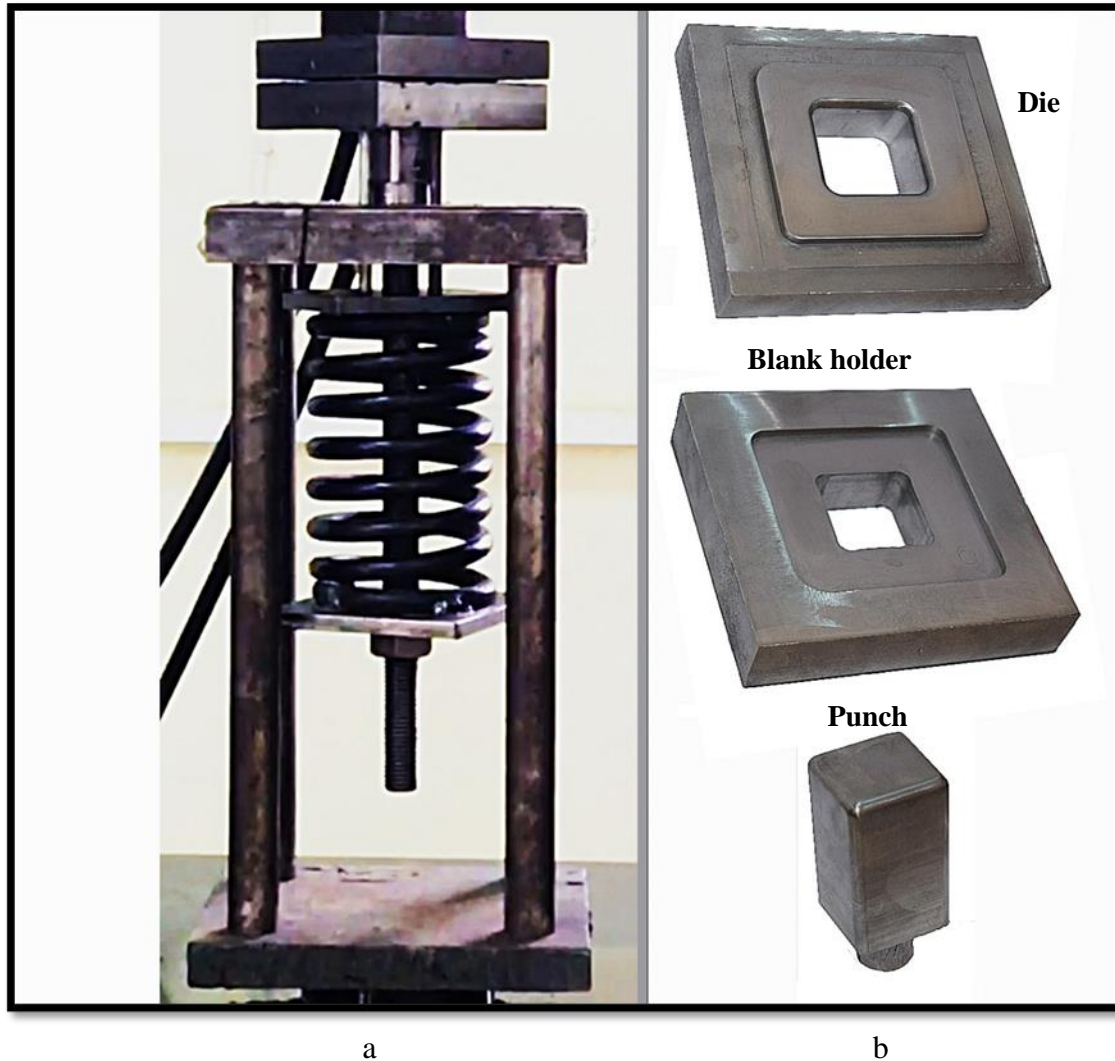


Fig.(2): Die for deep drawing process (a) assembly die, (b) punch, die, and blank holder.

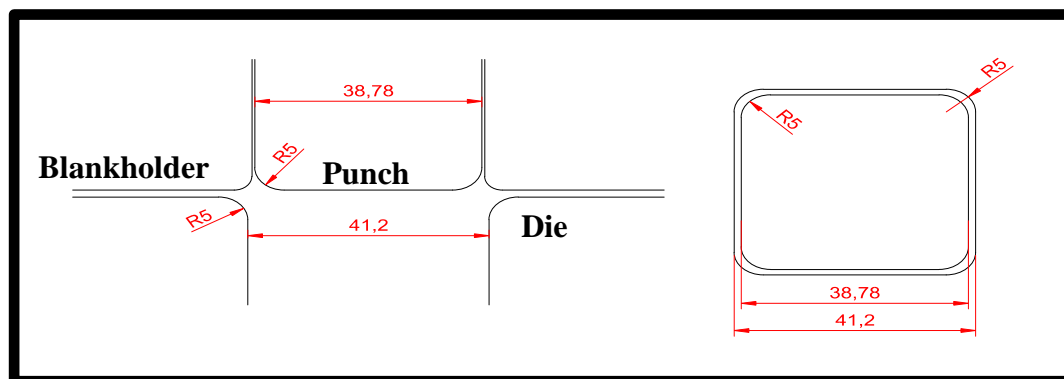


Fig.(3): The geometry and dimension of square deep drawing tool (all dimension in mm).

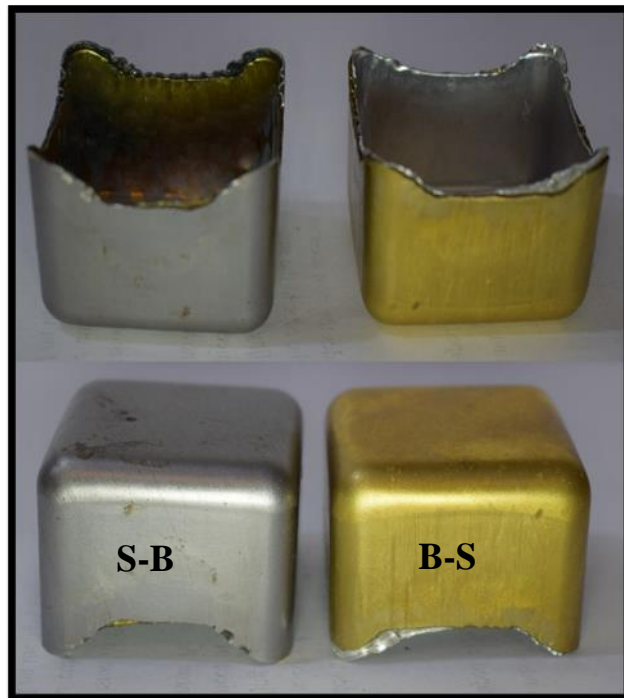


Fig.(4): The final shape of square cup for B-S and S-B.

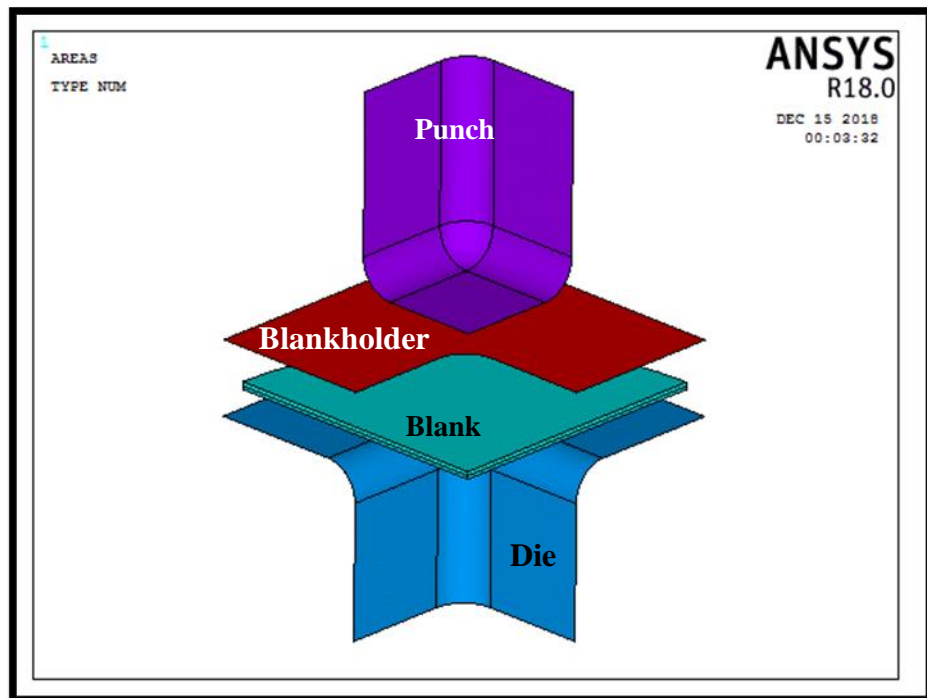


Fig.(5): 3D model for the square deep drawing process of laminated sheets.

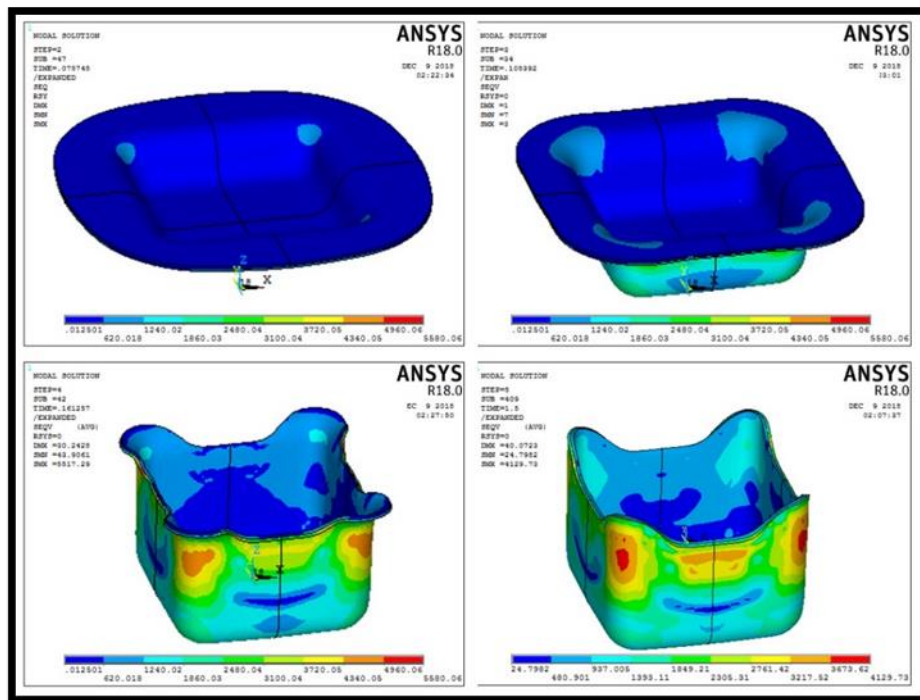


Fig.(6): Square cup forming of laminated sheet through the simulation process.

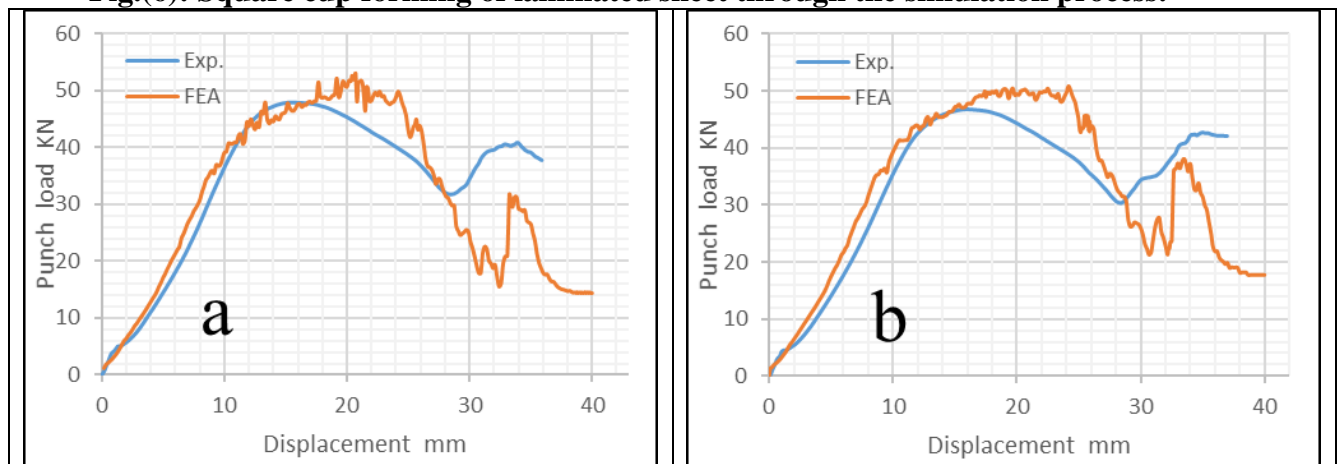


Fig.(7): Experimental and FE simulation drawing force for (a) S-B and (b) B-S sheets.

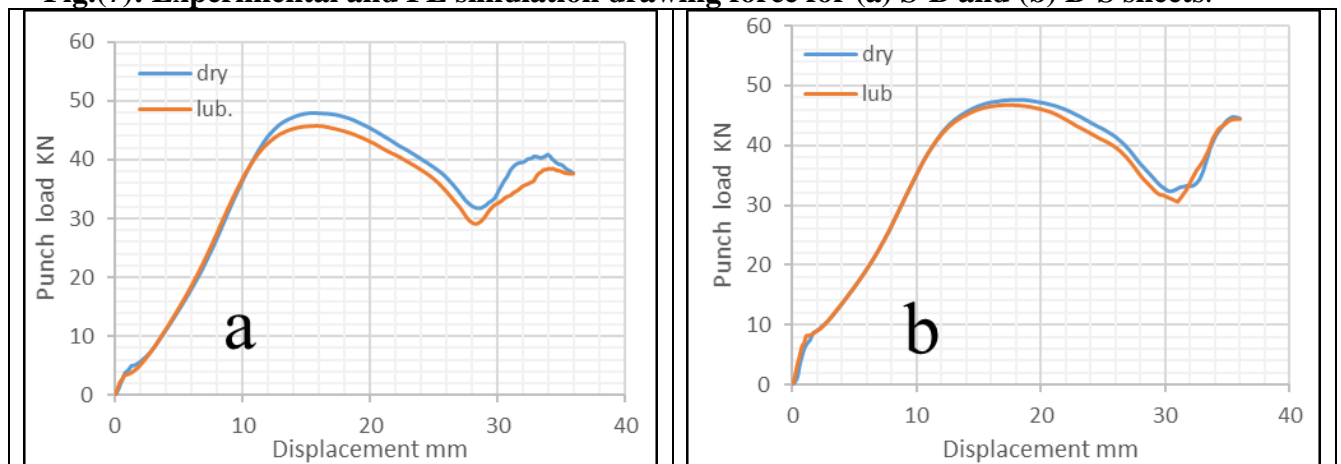


Fig.(8): Effect of lubrication conditions on the Forming load for (a) S-B and (b) B-S composite sheets.

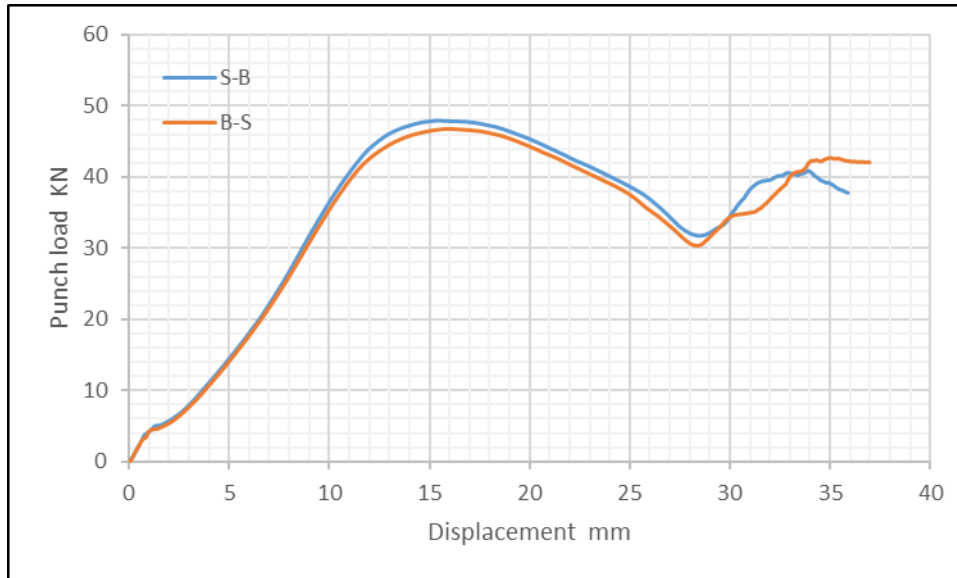


Fig.(9): Comparison of S-B and B-S forming load.



Fig. (10): The defective cups with tearing and wrinkling.

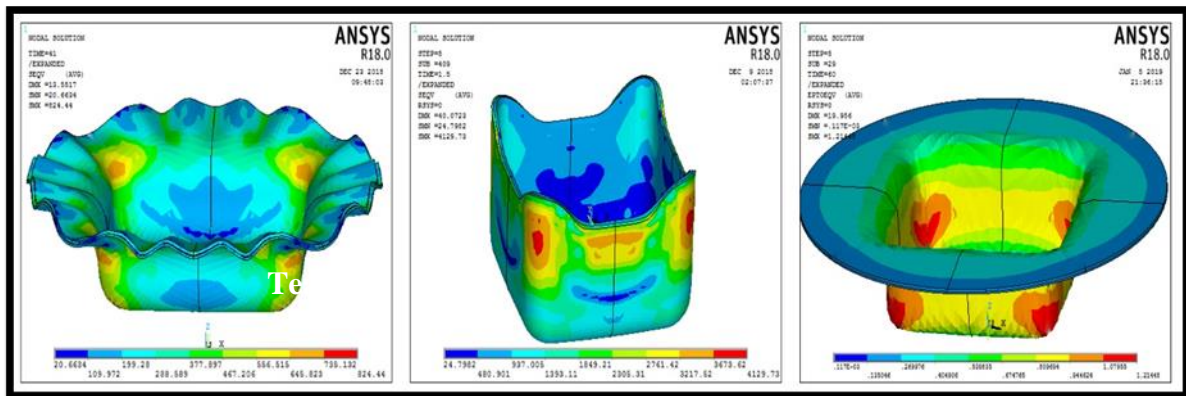


Fig.(11): Drawn cups under different blank holder force through the FEA

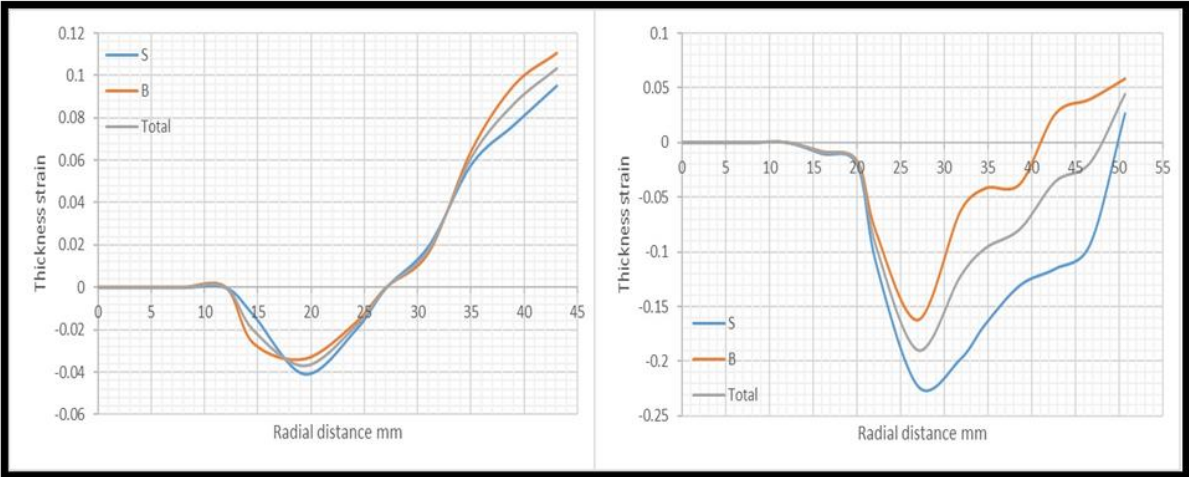


Fig. (12): Experimental thickness strain distributions of S-B along (a) transverse and (b) diagonal directions.

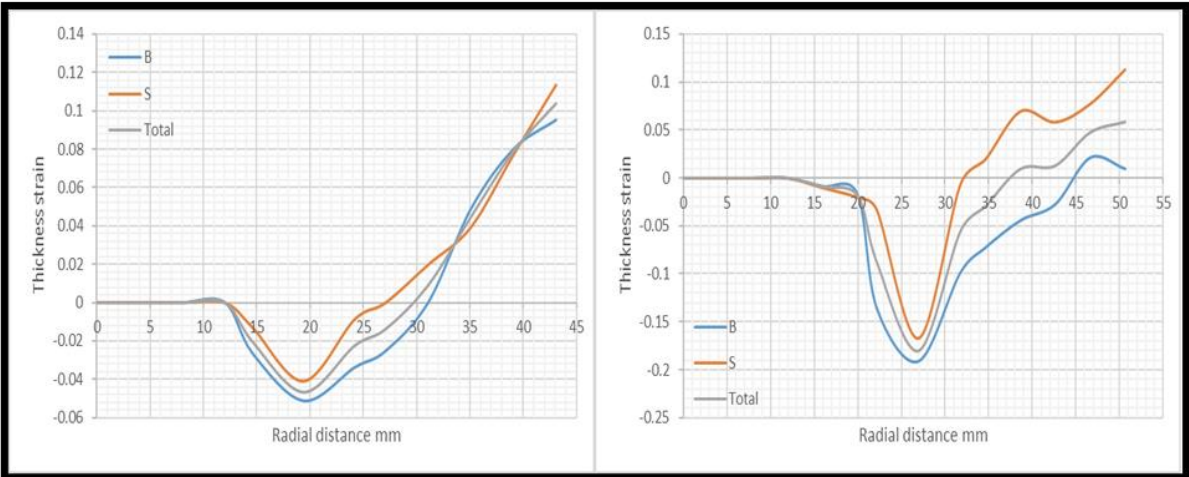


Fig. (13): Experimental thickness strain distributions of B-S along (a) transverse and (b) diagonal directions.

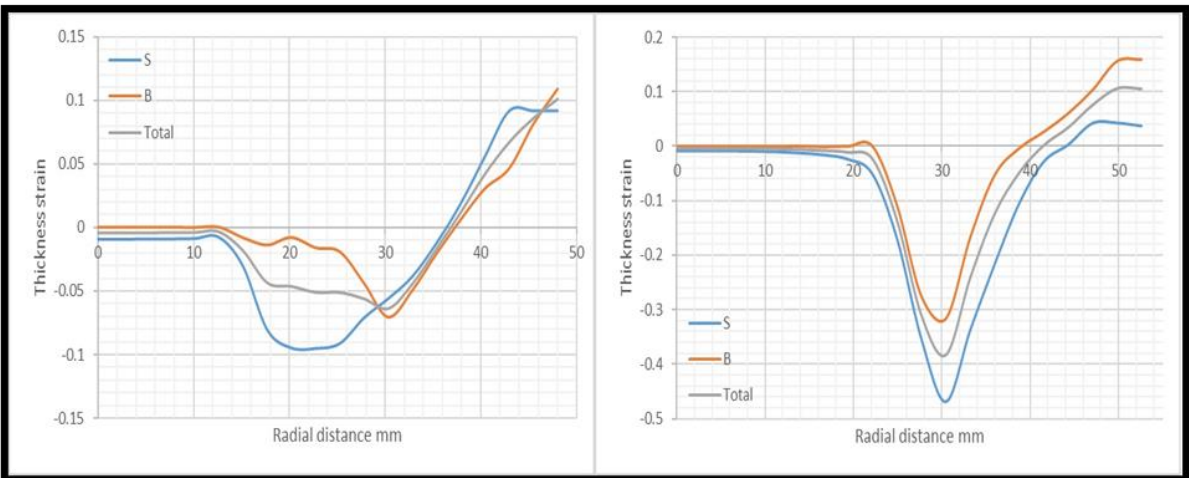


Fig. (14): Thickness strain distributions obtained by FEA of S-B along (a) transverse and (b) diagonal directions.

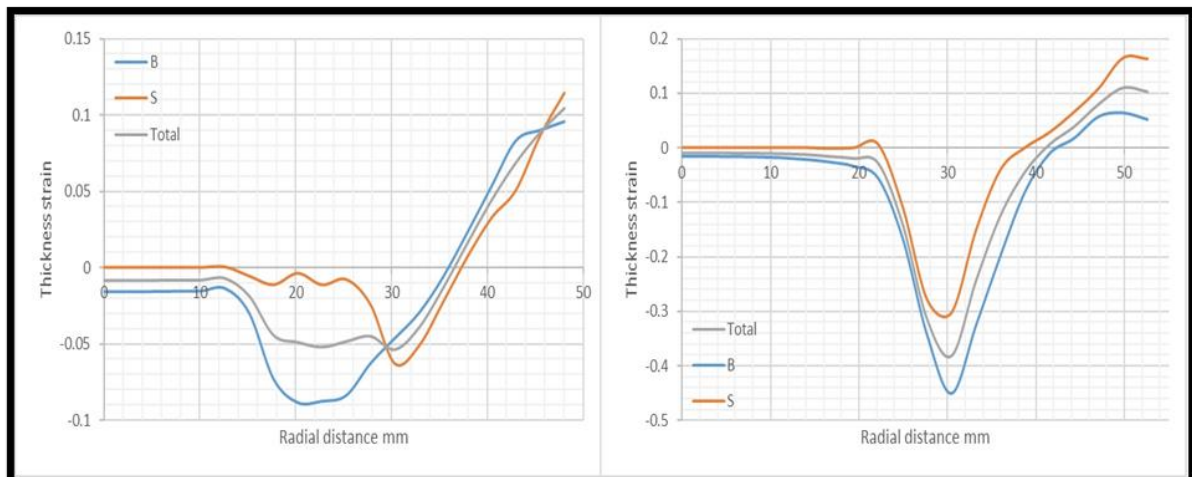


Fig. (15): Thickness strain distributions obtained by FEA of B-S along (a) transvers and (b) diagonal directions.

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