Study of the Influence of the Elastic Rubber Cushion on Product Quality Formed by a Multi - Point Forming (MPF) Process

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ABSTRACT

The Multi-Point Forming (MPF) is an advanced flexible manufacturing technology for three – dimensional sheet metal forming. This is replacing the conventional solid dies by a set of discrete punches called (punch group).

This work presents the design and manufacturing of (MPF) dies. It covers also, the effect of using an elastic cushion on the quality of products. This technique eliminates the formation of dimples which, otherwise reduces the quality of product. The work falls into two parts. Part one includes the use of ANSYS, which employs a finite element method (FEM) for the simulation of MPF components, namely: upper jaw, lower die and cushion. In the other part (experimental), a complete MPF die was designed and manufactured in the local market.

The copper sheet metal was selected to study the influence of the elastic cushion on the quality of product which formed by MPF process. This rubber was used to avoid the dimples occurring on the metal surface. Experimental and numerical results showed that this technique produces a better quality free from dimples. The cushion proved to be effective in elimination of the thickness change. The thickness change was found to be in the range (0-0.05) for a blank of 2 mm.

Hence, it is recommended that the (MPF) method is effective in product quality. However, two layers of cushion are necessary to separate between the work piece and pins to reduce the work piece deformation. Also, the numerical simulation was used by (ANSYS) software which was compared with the experimental result. A good agreement for numerical and experimental results was found.

Keywords: Forming processes, Multi pin forming (MPF), Dimples, Finite Element Method (FEM)

دراسة تأثير استخدام مطاط الطبقة المرنة على جودة المنتج المشكل بأستخدام اصابع التشكيل

الخلاصة :

تعتبر عمليات تشكيل الصفائح المعدنية بأستخدام اصابع التشكيل من عمليات التشكيل الحديثة والمتطورة جدا و التي عن طريقها يتم استبدال رأس التشكيل(punch) المستخدمة في القوالب الصلبة التقليدية بمجموعة من اصابع التشكيل الصغيرة المنفصلة ذات النهايات المستديرة او المسطحة.

في هذا العمل تم تصميم وصناعة منظومة متكاملة لعملية التشكيل بالاصابع لغرض دراسة تأثير استخدام الوسادة المرنة (المطاط) على جودة المنتج المشكل بهذه الطريقة. حيث ان استخدام المطاط خلال عملية التشكيل يعمل على منع تكون النقر وبالتالي نحصل على منتج غير مشوة.

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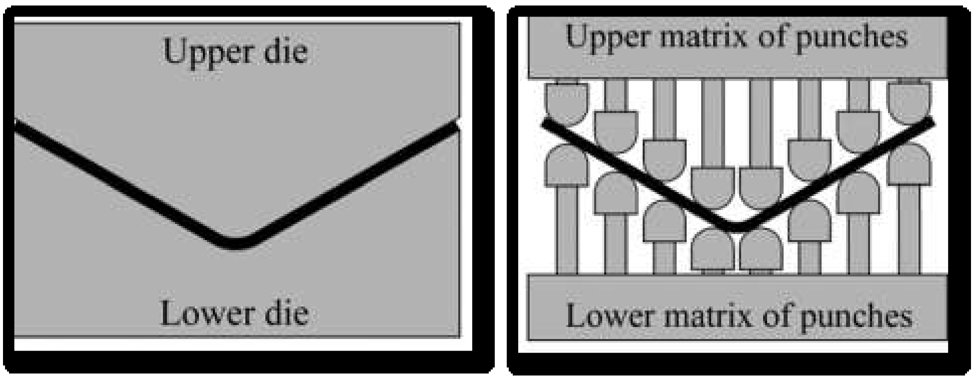
يتضمن العمل جزئيين رئيسيينالجزء الاول الجانب التحليلي حيث تم اجراء محاكات حاسوبية بأستخدام طريقة العناصر المحددة (FEM) ببرنامج (ANSYS) لغرض محاكاة منظومة التشكيل بالاصابع (MPF). اما الجزء الثاني(العملي) تضمن تصميم وتصنيع جميع اجزاء المنظومة الميكانيكية المستخدمة في عملية التشكيل. النتائج العملية والتحليلية بينت أن استخدام المطاط في عملية التشكيل بالاصابع تعمل على تحسين المنتج وحمايته من النقر التي تحدث في سطح المعدن نتيجة التشكيل بهذه الطريقة. اضافة لذلك فأن وجود الطبقة المرنة على وجهي الصفيحة المراد تشكيلها يعمل على تقليل التغيير الحاصل في سمك المعدن خلال عملية التشكيل حيث وجد بأن معدل التغيير كان بمعدل (0-٠,٠٥ ملم) بالنسبة لسمك المعدن المستخدم والذي هو (٢ ملم) .
وقد تم الاستنتاج بأن استخدام الطبقة المرنة (المطاط) على وجهي الصفية المعدنية المراد تشكيلها بطريقة الاصابع ضروري جدا لغرض الحصول على منتج خالي من العيوب ذو سمك منتظموتقليل التشوة الحاصل بقطعة العمل خلال عملية التشكيل. حيث تم مقارنة نتائج الجانب التحليلي مع النتائج العملية وقد بينت توافق جيد.

INTRODUCTION

Multipoint forming (MPF) or multipoint press forming (MPPF) technology is a flexible 3D manufacturing process for varied large sheet similar to the forming process of solid dies. In solid dies, two opposite solid dies (upper and lower) are used to press onto a blank and form into particular shapes. MPF used matrix pins with specific shape with adjustable height by means of line actuator see figure (1) [1].



(a) (b)

Figure (1): (a) Conventional process , and (b) MPF process [1].

In this process, different shaped parts require different dies. Sometimes, to form a sheet metal part several sets may be needed. The design and manufacturing of dies is a costly work and must rely on the experience of designers and workers. The idea of die forming of variable shape has always been attractive as a means of reducing die design costs. Several researchers have studied re-configurable tooling systems in metal forming to develop discrete reconfigurable dies for forming sheet metal. The system consists of small, individually positioned pins, mounted in two rectangular matrices. The die in this system is an opposed die, which is formed by the pins on each of the matrices. The obtained results could lead to the development of these new types of equipment which assure the decreasing of the cost testing and production [2].

Dimpling and spring back are the main forming defects on the process of multi-point stretch-forming, which directly affect the multi-point stretch-forming in aerospace and other practical applications in the field [3]. As the part is formed on the die, the sheet formability can be increased by placing a rubber pad. Variation in the thickness of rubber pad leads to the reduction of stress in the rubber material which affected the blank deformation negatively. Placing two rubber pads of small thickness on both sides of the blank does not eliminate dimpling and it affects the parts with no major improvement in formability. It is, hence, required to select a pad thickness equals to the sheet blank thickness which is more appropriate application as compared to other applications with rubber pads [4].

There are many factors affecting on the dimples formation in sheet metal, sheet thickness greatly influences the sheet forming, because deformation resistance and forming limit of metal vary with sheet thicknesses. Dimples are decreased when the thickness sheet metal increase as under the same conditions because, deformation resistance increases [5].

The material type also influences the sheet forming. Mechanical properties of sheet metal with different materials are different, and forming properties are also different. Its yield limit is small; therefor plastic deformation occurs at smaller tensile stress that is the ability to resist local deformation is weak. Hence it is prone to dimples. In contrast, the higher the yield limits of sheet metal, the greater is the hardening exponent. In other words, the resistant ability to local plastic deformation is more intense. Hence, dimples are less obvious [5].

The rubber deformation is characterized by the wave appearance. Their form depends on the gap between the pins, the pins stroke and the rubber thickness, as shown in figure (2).

When the interpolator thickness is small and when the pins stroke is large, geometrical form errors appear in the part sections and, when the rubber interpolator thickness is large, the process of deformation could be affected because of the uncontrolled flow of the elastic medium. This is more accentuated when the pins stroke is large [6].

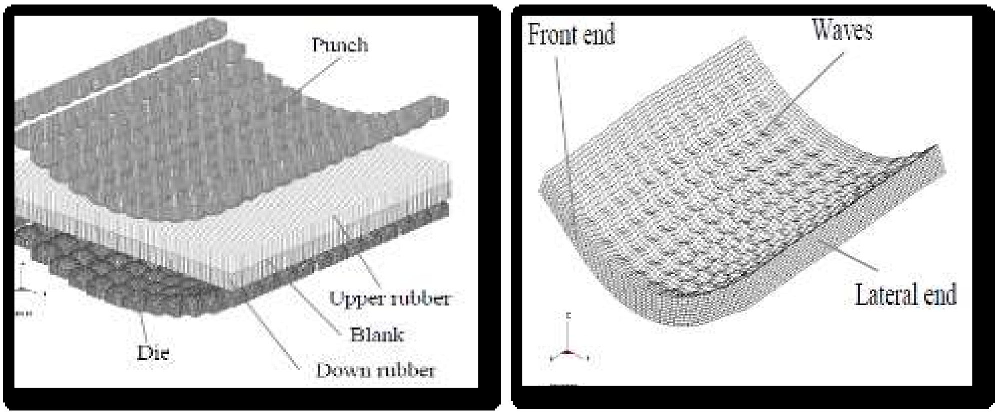


Figure (2): Rubber before and after forming [6]

Numerical Simulation of MPF Process:

In order to reduce time, overall cost and efforts, the numerical simulation was used with the same conditions applied in the experimental work. Simulation of MPF process gives a good imagination about this process to reduce and prevent the failure of overall process caused by the defect in tools design and product defects because it explained the process of formation before the practical application, which requires a lot of tools and costly preparations. Therefore, the ANSYS FEM software was used to simulate and control the MPF parameters in this work as shown in figures (14) and (15).

MPF was modeled within the numerical simulation and then to compare its results with the experimental. In this study, two types of elements were used, one for the sheet copper and another one for the elastic layer (rubber).

SOLID element 183 was selected for rubber to build the model MPF process. This type of elements was used for 2-D model and it has two degrees of freedom at each node along the X and Y directions, as shown in figure (3). So it can be used as plane element (plain strain, plain stress, and generalized plan strain) or as an axisymmetric element. This element has plasticity, hyper elasticity, creep, large deflection and large strain capabilities for simulating deformations of nearly incompressible plastic materials and fully incompressible hyper elastic materials.

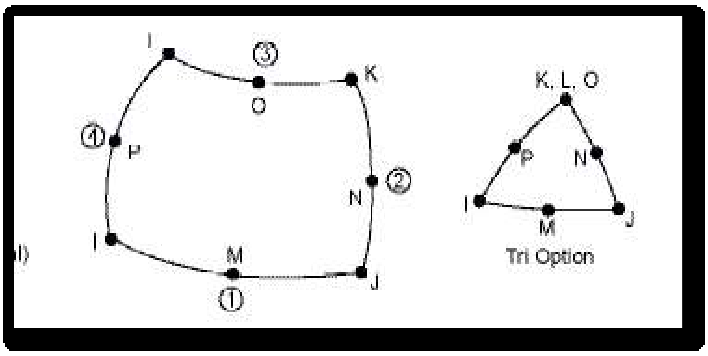


Figure (3): Element 183 geometry

While, the SOLID elements 182 was used for copper sheet. It has 4- nodes as shown in figure (4) which have two degrees of freedom along the X and Y directions. So it is used for building 2-D model and can be used as plane element (plain strain, plain stress, and generalized plan strain) or as an axisymmetric element. This element has plasticity, hyper elasticity, large deflection and large strain capabilities for simulating deformations of nearly incompressible plastic materials, and fully incompressible hyper elastic materials.

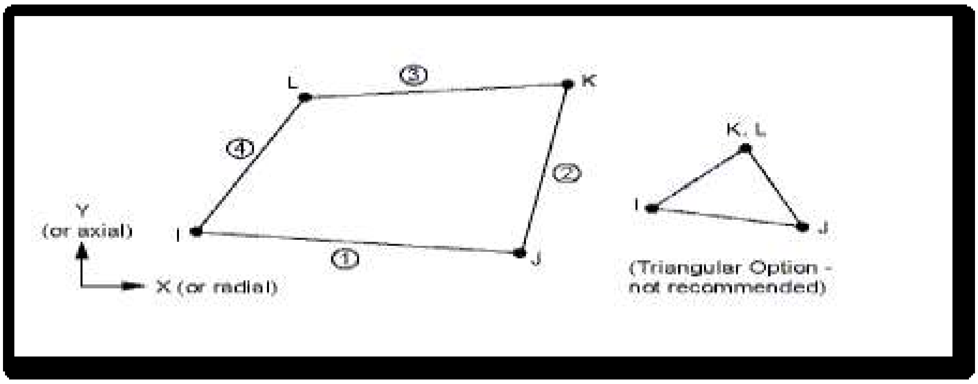


Figure (4): Element 182 geometry

The finite element model is dividing the geometry into nodes and elements bymesh the model geometry as shown in figure (5).

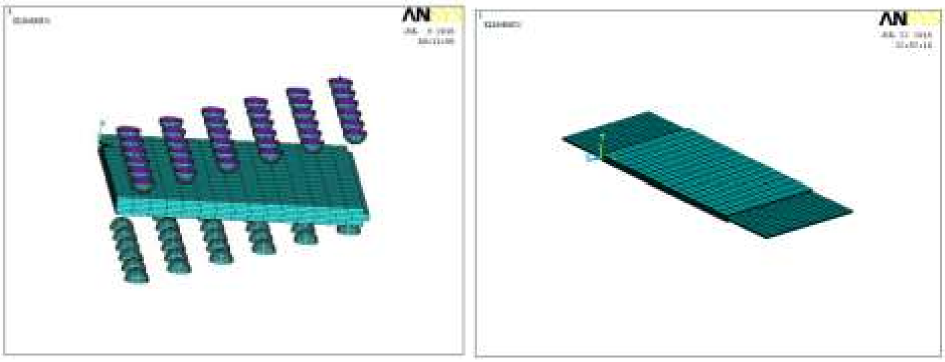


Figure (5): Mesh model by ANSYS

The next step of the finite element analysis involves applying appropriate boundary conditions and external loads. The analysis options are (large deflection, large strain, and large displacement), and loads can be applied to the solid model (key points, lines, and area). One of the boundary conditions was applied on the line which is common of symmetry axis. The other boundary conditions were a holding force of 9 KN on the blank holder, and 20 mm as a displacement on all upper pins.

Experimental Work:

The experimental work included three stages, stage one is the design and manufacture of MPF die. The second stage is the specimen preparation which includes the material properties tests. The third part includes the process of MPF technique.

Two cases were studied in this work, one without using elastic cushion and other with elastic cushion of 2 mm thickness in order to study the effect of using cushion on surface quality of product pieces. The thickness distribution of work piece is also evaluated in both cases.

Design and manufacturing MPF die:

MPF has been used to replace solid dies with three-dimensional surfaces. The main key of the MPF is the two matrices of punches allowing us to create a three-dimensional surface which is formed according to the shape of the design. The MPF was designed using (Auto CAD) program software. Figure (6) shows the die component as drawn by (Auto CAD).

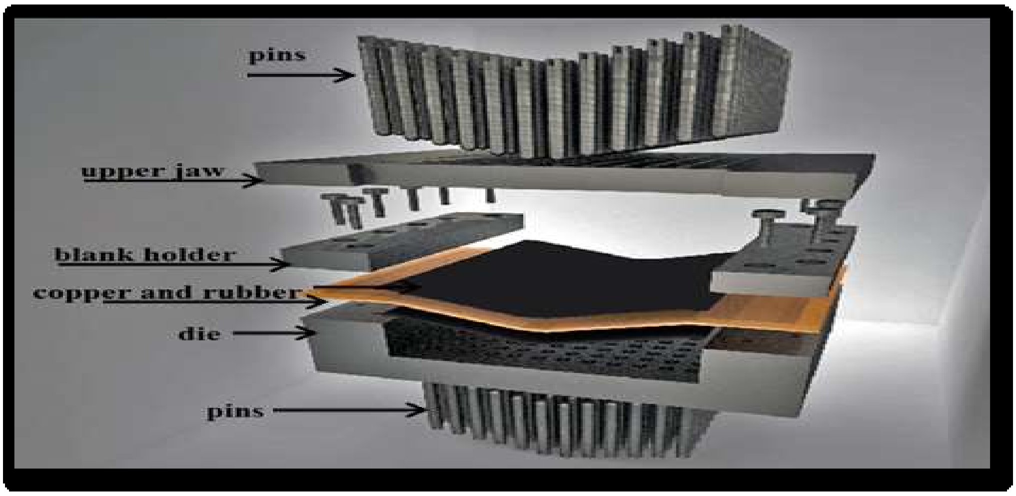


Figure (6): MPF die and pins design

Samples Preparation:

Chemical Composition:

In this work, copper sheet metal was chosen as work piece to study the effect of elastic cushion (rubber) use on MPF process. The chemical composition of the selected metal is achieved by spectrometer testing device. Table (1) shows the chemical composition of copper sheet metal.

Table (1) Chemical compositions of copper

Element	Cu	Ag	Al	As	Bi	Cr	Fe	Mn	Ni	P	Pb	Sb	Sn	Si	Zn
actual	99.43	0.012	0.13	0.026	0.0	0.0	0.42	0.15	0.0	0.0	0.0	0.0	0.0	0.13	0.1
standard	99.4	0	0	0.15	0	0	0	0	0	0.01	0	0	0	0	0

Also Steel material was chosen to manufacture all MPF press component. Table (2) shows the chemical compositions for steel. The steel used was of 1026 alloyed steel.

Table (2) Chemical compositions for steel

Element	Fe	C	Si	Mn	Cr	Ni	Mo	Cu	Al	U	W	P	Nb	B	S
Used %	98.2	0.26	0.09	0.66	0.03	0.12	0.02	0.02	0.01	0.02	0.013	0.02	0	0.01	0.044

Hardness Test:

The tester (HLN – 11 A) as shown in the figure (7) was used to measure hardness of copper and of steel. Hardness may make the die parts have a brittle behavior which means a crack possibility and these may lead to failure. The results for steel 1026 show that the hardness is 189 HB, and for copper is 102 HB.

Figure (7): Hardness Tester HLN – 11 A

Tensile Tests:

The tensile tests were done in the University of Technology/Mechanical Engineering Department laboratories. The (H50KT) tester is used to test the specimens. This test was performed in three direction where, the specimens were to (θ =0, θ =90°, and θ = 45° with respect to the rolling direction).

The tensile tests were performed on the specimens to draw the stress-strain curves, and predict the yield point and plastic deformation limit (mechanical properties for copper metal) as shown in the table (3).

Table (3): Mechanical properties for copper metal

Material	Young's Modulus E (GPa)	Yield stress σ_y (MPa)	Poisson's ratio ν
Copper	120	70	0.35

The specification of the tensile test is according to the American Society for Testing and Materials specifications (ASTM). The tensile specimen's geometry and dimensions for standard (ASEM E8-M) are shown in figure (8) [7].

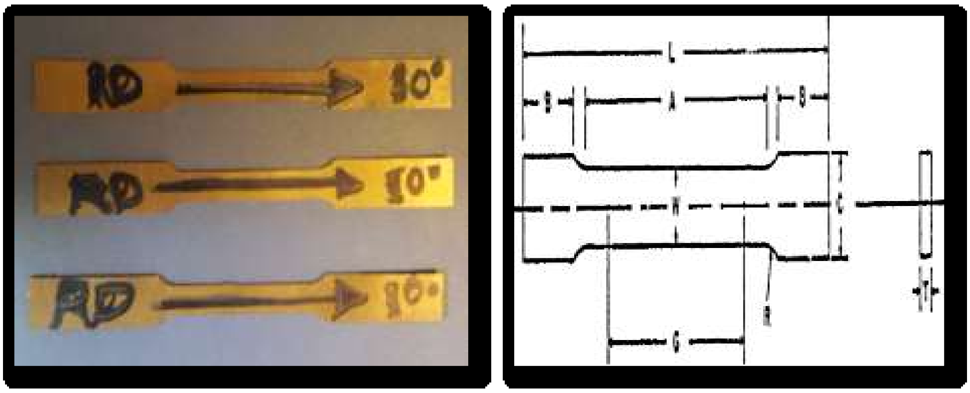


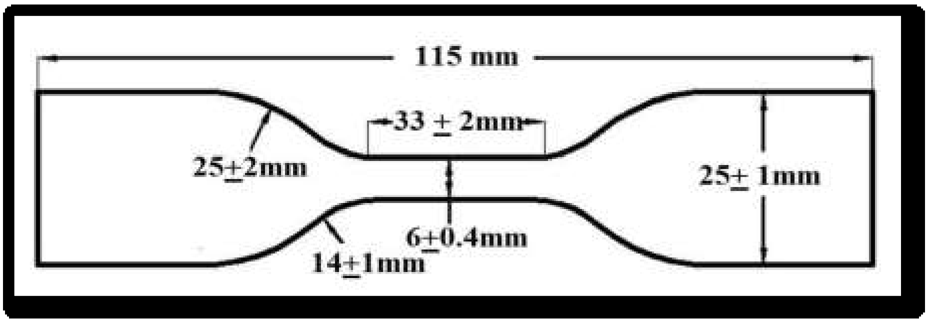
Figure (8): Rectangular cross section tensile test specimen, ASTM E8-M.[7]

Where:
L=100 mm
A=32 mm
B=30 mm
W=6 mm
C=10 mm
G=25 mm and R=6 mm
The same testis used for the rubber specimen to know the mechanical properties for rubber as shown in the table (4).

Table (4): Mechanical properties for elastic layer (rubber)

Material	Young's Modulus E (MPa)	Yield stress (MPa)	Poisons ratio
rubber	**25**	**10**	**0.48**

The rubber tensile specimen was prepared by special laser tool to get accurate profile with exact required dimensions as shown in figure (9).



(a) Schematic

(b)Photograph
Figure (9): Tensile Specimen for rubber [8]

product quality formed by MPF with and without rubber:

The copper sheet metal selected was with thickness (2) mm formed in to (V-shaped) with depth of (20) mm by the MPF die. The designed and manufacture die is used. Two cases were studied. One work piece with no rubber and other was with rubber. This was to study the effect of elastic layer on product quality and thickness distribution along sheet metal.

MPF are consists of six parts as shown in figure (6) (Die, pins, copper, rubber, upper jaw, and blank holder) all these parts manufacture in local market using CNC machine with other tools.

The procedure steps for a typical MPF operation are as follows: Step 1: fixing the rubber cushion on the pins of die (if using rubber). Step 2: Fixation of the sheet metal on the die by two holders. Step 3: Placing the second rubber cushion on the upper surface of metal (if using rubber). Step 4: fixation of the upper jaw by using four guides. Step 5: Application of the press force. Step 6: and finally, raising the upper jaw. Figures (10, 11, 12, and 13) show the different steps.

Figure (10): Final product formed by MPF process with rubber.

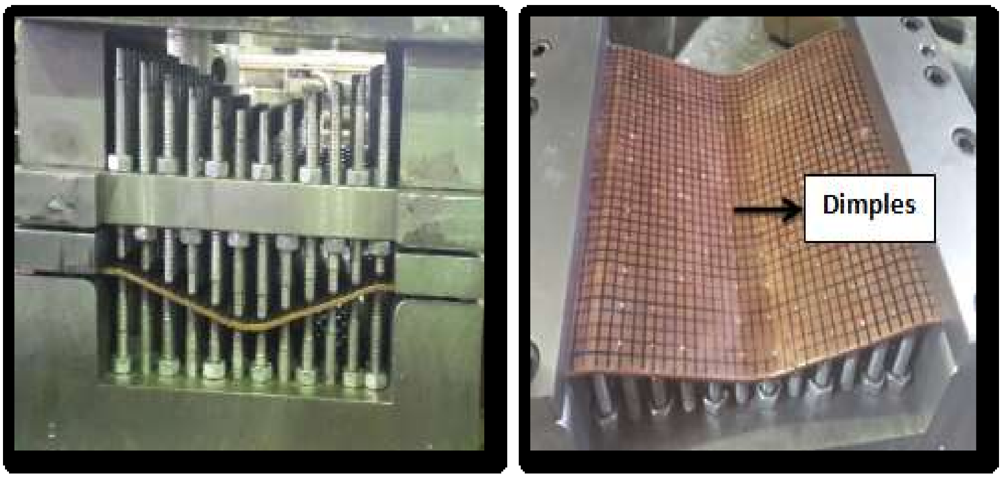


Figure (11): Final product formed by MPF process without rubber.

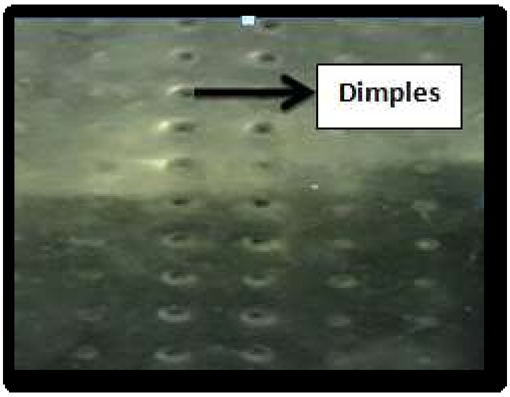


Figure (12): Rubber deformation after MPF process

Figure (13): Thickness distribution along sheet metal formed by (a)MPF without rubber (b) MPF with rubber

Results and Discussion:

Product quality:

The use of elastic cushion is necessary to avoid dimpling phenomenon occurring. The elastic cushion will take over the local effect of the pins press and ensure a uniform load distribution on the sheet metal which gave a good quality of the product surface as shown in figure (10). On the other hand the use of elastic cushion leads to increase pins stroke hence, increases the elastic stresses on the sheet metal and changes its behavior which affects the final product quality.

When the MPF process is done without elastic cushion the pins concentrate loads on the sheet; then dimples form in the sheet. Therefore, it can be said that the elastic cushion takes all direct contact load, figures (11, and 12).

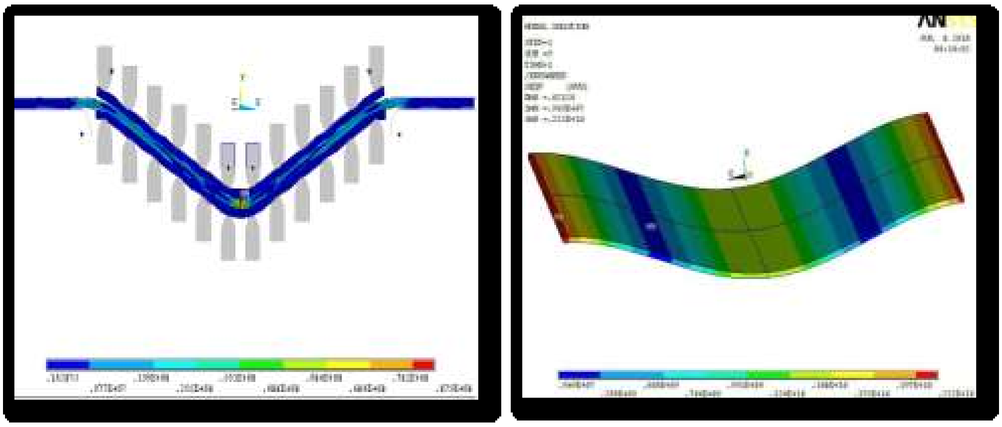
Based on previous studies [4], the thickness of rubber taken was equal to the thickness of sheet metal as recommended; this choice ensures a better product quality, figure (10). When using two layers of rubber thickness of elastic cushion adds to the work piece thickness, this leads to increase local stresses. However, it reduces dimples formation and reduces deformations in final product. Hence, the press force on work piece as compared to MPF without rubber increased, see table (5). Figure (14, and 15) show the product surface quality numerically results by ANSYS.

Table (5): press force in experimental work for MPF with and without rubber

Copper thickness (mm)	Rubber thickness (mm)	Press force(KN)
2	4	100
2	0	80

Thickness distribution a long sheet metal:

In general, the variation of product thickness is very small and homogenous because of the concentrated load at the regions of contact between the pins tips and the product surface. When using elastic cushion, the cushion helps distribute the press force, hence, unify stress distribution therefore, a regular thickness along the final product results. While, MPF process without rubber, the variation of metal thickness is more than with rubber. This is because; dimples occur in the sheet metal and the touch between pines and metal surface is direct as shown in figure (13) (a) and (b) which shows the thickness variation when using MPF with and without rubber experimentally, as measured in every element by using a micrometer as shown in figure (13). Figures (14 and 15) show the variation of thickness as predicted by ANSYS, with and without cushion, respectively.



(a) (b)

Figure (14): MPF with rubber (a) 2-D modeling, (b) 3-D modeling

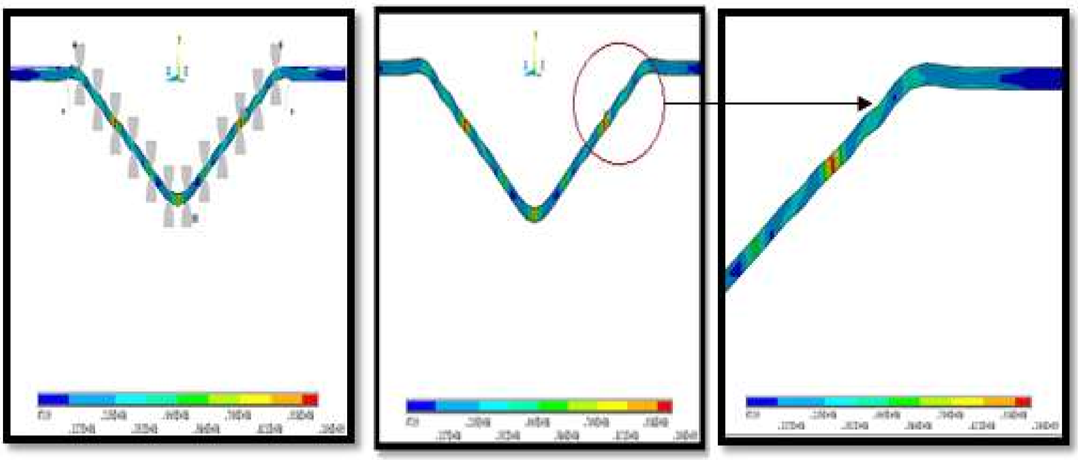
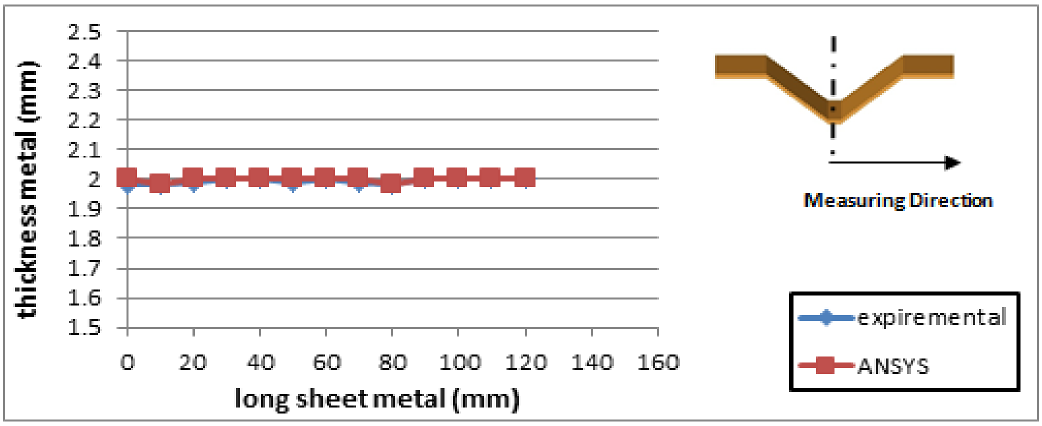
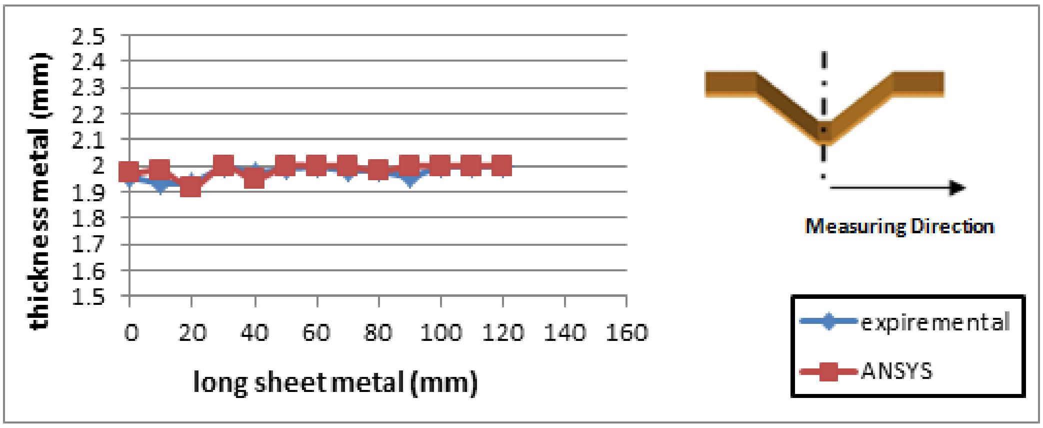


Figure (15): Final product formed by MPF without rubber

Figure (16) shows the thickness variation when using MPF with and without rubber experimentally and numerically. It shows a good agreement between the experimental and numerical results.



(a)



(b)

Figure (16): Product variation thickness with distance (a) with rubber, (b) without rubber

CONCLUSIONS:

From the experimental and numerical work, the following conclusions are presented:

1. A MPF die was designed, manufactured and used. The products were better than that of conventional method. However, it can be used for any shape.
2. Rubber cushion proved to increase product surface quality.
3. Rubber cushion of thickness equal to the work piece thickness produces good product surface quality.
4. Rubber cushion prevented the occurrence of surface dimple.
5. A very small thickness variation was seen when using the MPF process.
6. A good agreement is seen between the experimental and the numerical studies. However, this study can reduce cost, time and effort.

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