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Experimental Investigations of a Springback in Hydromechanical Deep Drawing of Low Carbon Steel 1008 AISI

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Keywords:
Blank; Deep Drawing; Hydroforming; Springback; Sheet.

Highlights:

- *The article aims to study the effect of spring-back in hydro mechanical deep drawing process.*
- *The article focuses on the effect of low fluid pressures and holding time on spring-back.*
- *A P-300 projector is used to measure the spring-back value by highlighting and matching the axes.*

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Abstract: Hydro mechanical deep drawing (HMDD) is an emerging technology that reduces the number of sheet-forming stages and increases the production of advanced lightweight materials with intricate shapes. This study aims to verify the springback in HMDD and the effect of holding time and fluid pressure on this phenomenon (springback). The springback was measured using a new method by matching the projector p-300 axes with the cylindrical cup wall. The difference between the wall and the axis represents the springback value. Using a blank of low carbon steel (1008-AISI) with 80 mm of diameter and a thickness of 0.7 mm. The effect of holding time (1, 2, and 3 minutes) and the fluid pressure (0.6, 0.8, and 1 N/mm^2) was studied. The used hydraulic oil was (code number 3803). The springback value of a cylindrical cup was calculated using the profile projector P-300. The result showed that the springback phenomenon was presented in the hydromechanical deep-drawing process but at a lower rate than the traditional deep-drawing process. The holding time and fluid pressure significantly affected the springback value. The springback decreased with increasing the fluid pressure and holding time.

تحقيقات تجريبية للارتداد المرن في السحب الهيدروميكانيكي العميق للفولاذ منخفض الكربون AISI ١٠٠٨

هبة الله جاسم حسيب، علي عبار خليف
قسم هندسة الانتاج والمعادن / الجامعة التكنولوجية / بغداد – العراق.

الخلاصة

السحب العميق المائعي الميكانيكي (HMDD) هو تقنية ناشئة لتقليل عدد مراحل تشكيل الألواح وزيادة إنتاج المواد المتقدمة خفيفة الوزن ذات الأشكال المعقدة. الهدف من هذه الدراسة هو التحقق من الارتداد المرن في HMDD وتأثير وقت التثبيت وضغط المائع على هذه الظاهرة (الارتداد المرن) تـم قياس الارتداد المرن بطريقة جديدة من خلال مطابقة محاور جهاز العرض p-300 مع جدار الكأس الأسطواني وأن الفرق بين الجدار والمحور يمثل زاوية. هذه الزاوية هي قيمة الارتداد المرن. باستخدام صفيحة من الصلب منخفض الكربون (AISI-١٠٠٨) بقطر ٨٠ مم وسمك ٠,٧ مم. تمت دراسة تأثير وقت التثبيت (١، ٢، و٣ دقائق) والتغير في ضغط المائع (٠,٦، ٠,٨، و١ نيوتن / مم٢). الزيت الهيدروليكي المستخدم هو (رقم الكود ٣٨٠٣). تم حساب قيمة الارتداد المرن للكوب الأسطواني باستخدام جهاز الإسقاط P-300. النتيجة ظاهرة الارتداد المرن موجودة في عملية السحب العميق المائعي الميكانيكي ولكن بمعدلات قليلة بالمقارنة مع عملية السحب العميق التقليدية، وأن وقت التثبيت وضغط المائع يلعبا دورًا رئيسًا في التأثير على ظاهرة الارتداد المرن كلما زاد وقت التثبيت وزاد ضغط المائع انخفض عامل الارتداد المرن.

الكلمات الدالة: التشكيل المائعي، السحب العميق، الارتداد المرن، صفيحة، لوح.

1.INTRODUCTION

In the hydromechanical deep drawing process, the drawing tool's die is replaced by a pressurized fluid, which simply uses the punch shape to produce a component. The pressure medium considerably raises drawing ratios by lowering friction between the sheet and the tool. Hydromechanical deep drawing can, therefore, be utilized for challenging items or smaller numbers during prototyping with less tool effort. However, due to the high pressure on the sheet, compared to standard deep drawing, the forming process requires more time, more time to change the workpieces, and more energy consumed per stroke [1]. While each sheet hydroforming operation has limitations and applications, the sheet metal should benefit the hydromechanical deep drawing process to reduce weight and cost while simultaneously increasing structural integrity, strength, and rigidity. Additionally, this procedure achieves these objectives while efficiently using common and readily available materials [2]. The overall cost of a sheet hydroforming part can be decreased by savings in tooling, materials, design, production, and assembly [2]. Spring is one of the most important phenomena affecting the sheet metal parts accuracy. Various processing and material parameters influence springback. One of the successful analytical attempts is presented, including functions covering the majority of the material and processing parameters influencing the thickness distribution and the quality of the product. Sun and Lang [3] studied formulas for springback solutions, developed when stretch bending under hydraulic pressure. Force T grew, the moment M dropped, and the springback reduced as the liquid chamber pressure increased, according to the formula. After hydroforming, the sheet portions are generally in a tensile stress state with reduced springback as the neutral layer of stress shifts inside the plate under fluid pressure. Khandeparkar and Liewald [4] presented a study on low-carbon steel (DC04) and stainless steel (DIN 1.4301). For a punch diameter of 100mm, a die set with a deep drawing ratio of up to 3.0 was designed and built. A fluid counter pressure of up to 200 MPa can be applied to the die set without breaking it. A micro-metering pressure control valve controlled the pressure. The FEM solver LS-DYNA was initially used to model the process. Wall segments, i.e., cylindrical and conical, formed the punch geometries. Punch bottom facial characteristics produced intricate positive and negative aspects. Complexity transfer from the punch to the blank surface at very deep drawing ratios was studied. It was possible to attain extended limiting deep drawing ratios of $\beta_{o,max}$= 3.0 for DC04 and $\beta_{o,max}$= 2.875 for DIN 1.4301. Saravanan et al.[5] numerically studied three metal sheets (aluminum, copper, and high-strength steel) with thicknesses from 1.2 mm to 1.8 mm used during the bending process. The parameters analyzed were the tool angle radius, plate strength, and coefficient of friction. Boğoçlu and Baki [6] studied the application of draw beads, used in the sheet metal die industry during the deep drawing of a vehicle body component with a tensile strength of 270 MPa. The study aimed to reduce the amount of springback. They research how material thickness and elasticity module affect springback behavior. Tomáš et al. [7] showed the springback phenomena' impact on stamping. Along with the complexity of the process itself, the springback caused an inaccurate output. Because it is challenging to determine the amount of spring back without simulation, numerical simulations (Auto Form, PAM-STAMP) were performed. The springback compensation approach to lessen it was the main topic of this study. Salahshoor et al. [8] studied the governing factors, including die radius, pressure path, the gap between the mold and blank holder, and friction coefficient in the deep hydrodynamic drawing. The result was part thinning reduced and maximum punching force by reducing friction between the blank holder and the paper. However, increasing the friction coefficient between the plate and the punch by 0.2 increased the forming quality and reduced part thinning. Mulidrán et al. [9] studied the springback impact on the deep drawing process (V-shaped sheet metal part made of DC06 steel with a thickness of 0.85 mm). Molds for the hydromechanical deep drawing process were created and constructed by Mosa et al. [10]. A low carbon (AISI-1008) blank with an 80 (mm) diameter and three different thicknesses (0.5, 0.7, and 0.9 mm) was selected to study the procedure. It was completed in three stages: the first without pressure, the second with 8 N/mm² pressure, and the third with 1.5 N/mm² pressure. Cinar et al. [11] studied the springback impact on A6061 SM in addition to bend angle, die shoulder radius, and blank holder force. A6061 springback also considered the bend operations of V-bending and deep drawing. Zhang et al. [12] studied the three-layer blanks (multilayer metal) assembly of aluminum alloy (2024-0); each blank thickness was 0.5mm, and all the aluminum blanks were set at (0 angles) with the rolling direction during forming. Semi-spheroid-shaped parts using hydromechanical deep drawing were used to study the effects of different variables, such as cavity/pre-bulging pressure, die-binder gap, and pre-bulging height on thinning and spring back. Pre-bulging parameters included pre-bulging pressure (1, 3, and 5 MPa), pre-bulging height (3, 4, and 5 mm), and the distance between the binder and the die (1.58, 1.59, and 1.60 mm). The upper layer had the maximum thickness, the bottom layer had the thinnest, the middle layer had the best and the lower layer had the worst wall thickness distribution, according to the hydromechanical deep drawing simulation results using the finite element method. Ahmed and Khleif [13] studied the usage of a complex and hemispherical cup formed from an 80 mm in diameter and 0.7 mm thick galvanized steel blank using a hydromechanical deep drawing method. Hydraulic oil was used to apply different fluid pressures. These researchers conducted their studies in the following three states: Since the experimental work was conducted without fluid pressure, the result of the initial state displayed wrinkles. Wrinkles and other flaws were ironed out by applying an extra 1 N/mm² in the second state. The third state completion occurred at 1.7 N/mm². This study's primary objective is an experimental investigation of the HMDD process. Various parameters affecting the springback phenomenon of low-carbon steel have been studied and analyzed using fluid pressure and different holding times.

2.EXPERIMENTAL WORK

2.1.Apparatus and Procedures

The profile projector (Model- P-300 from Dr. Heinrich Schneider Messtechnik company in Germany) was used in the Ministry of Industry and Minerals, the General Company for Hydraulic Industries/ Al-Fidaa Company.

2.2. Experimental Setup

A cylindrical cup is often produced via hydromechanical deep drawing (HMDD) of sheet metal. The blank utilized was made of low carbon steel (1008-AISI), with a thickness of 0.7 mm and a diameter of 80 mm. The chemical composition of low-carbon steel (1008-AISI) is listed in Table 1. The chemical composition of the metal was carried out using a spectrometer device at the General Company for Engineering Inspection and Qualification/Ministry of Industry and Minerals. The hydromechanical deep drawing device used for producing cylindrical cups was designed and manufactured in Mosa et al. [14]. Fig.1 shows the device parts. Fig.2 shows the production of the cylindrical cups system.

Table 1 The Chemical Composition of Low Carbon Steel(1008-AISI).

C %	Si %	Mn %	P %	S %	Cr %	Mo %	Ni %	Cu %	Al %	Fe
0.0639	0.0082	0.193	0.0074	0.0066	0.0171	0.0027	0.0274	0.0059	0.0442	Bal

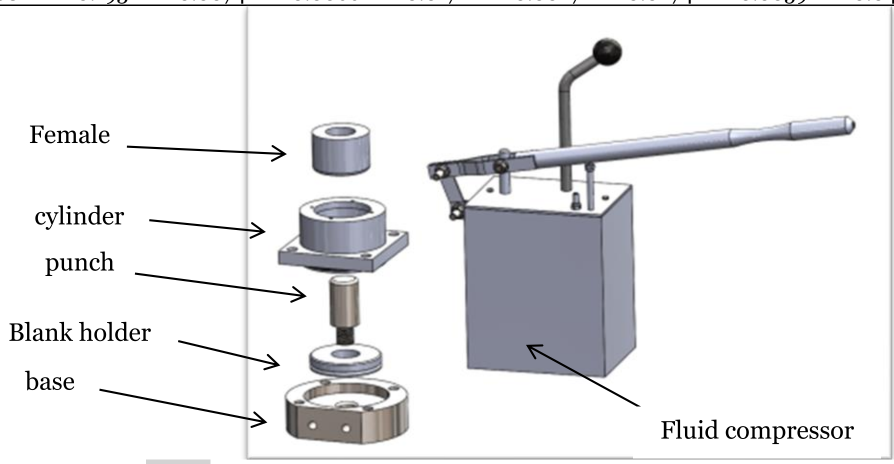

Fig.1 The Hydromechanical Deep Drawing Device.

Fig. 2 HDD Device and System.

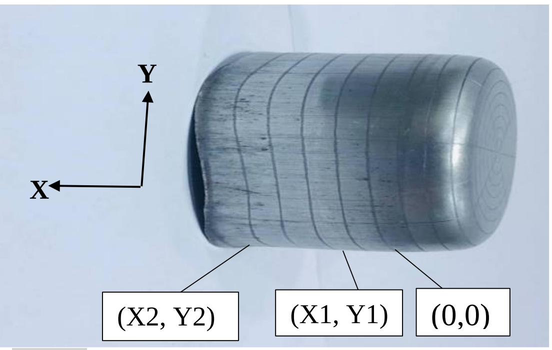

Fig. 3 The Path of Linear Points Established Along the Transverse Axis.

The complete process can be abstracted as follows:

1- The hydraulic oil in the compressor is full (Code No. 3803). Pumping hydraulic oil into the cylinder allows measuring the pressure using a pressure gauge. Between the female (viewed from the top) and the blank holder (viewed from the bottom), the cylindrical blank is inserted within the cylinder. Under the blank, there will be fluid.
2- From the top, the blank is inserted into the cylinder between the female die and the blank holder. Under the blank, there will be fluid.
3- Press the female die using the hydraulic press force. The force from above and the fluid downward pressure are applied to the blank. In this stage, the shaping process begins.
4- To facilitate simpler product egress, relieve the hydraulic press's force and discharge fluid from the fluid compressor.

The springback was measured based on the axes by projecting a set of points on the surface of the cylindrical cup and their alignment with the axis in the X-direction and a deviation in the Y-direction, creating an angle representing the springback value. The Springback measurement was done by measuring a set of straight points along the transverse direction of a cylindrical cup on the same sideline, as shown in Fig.3. The cup was installed horizontally, and the light was shone vertically to clarify the transverse direction. The angle line slope equation was used to calculate the springback value. The profile projector P-300, shown in Fig.4, was used to measure the springback.

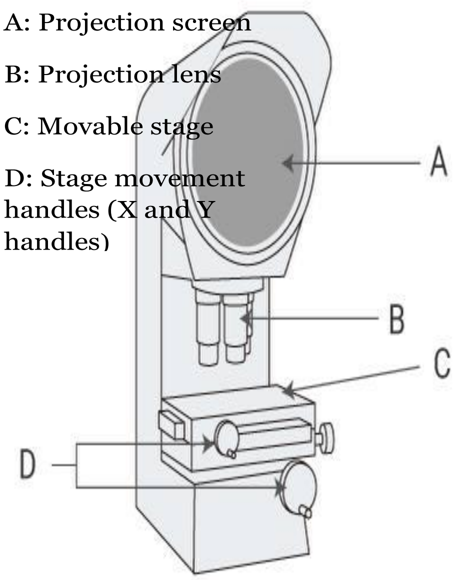

Fig. 4 The Profile Projector P-300.

3.RESULTS AND DISCUSSION

The cylindrical products are characterized by a straight wall; therefore, the springback measurement is unclear as in the inclined wall, so most of the research was directed to products with an inclined wall. This work investigated the springback in the straight wall after considering a set of points on the straight wall and calculating the angle that represents the springback through the following equation:

$$Ks = \tan^{-1}\frac{y}{x} \qquad (1)$$

where:

Ks= the Springback factor.

Y= the opposite (the distance of the last point from the straight wall in the Y-axis).

X= adjacent (the straight wall distance in the X-axis)

Fig.5 shows the relationship between the above equation variables and explains the method of calculating springback.

3.1.Effect of Holding Time on the Springback Behavior

The springback factor increased with decreasing holding time. An example of this case is the drawing of a cylindrical cup made from low-carbon steel with a thickness of 0.7 mm. The result showed that when the piston pressure was 1 N/mm², the fluid pressure was 0.6 N/mm², and the holding time was 1 minute, the value of the springback factor was 0.34355, while when the holding time was 2 minutes, the springback factor was 0.33928, i.e., the springback reduced by 1.249%, at 3 minutes, the springback was 7.885% less than 1 minute, and 6.726% less than 2 minutes, as shown in Fig.6. The experimental setup and results for the three holding times used in this work and the fluid pressure are summarized and listed in Table 2 and Fig.7, respectively.

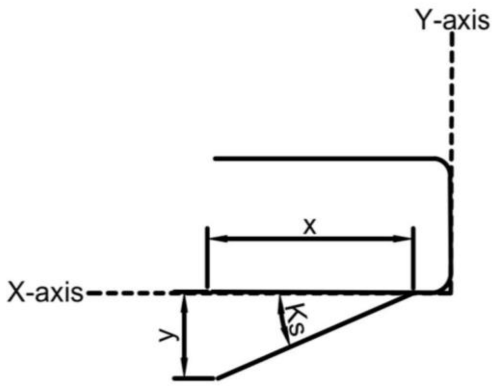

Fig. 5 The Method of Calculating the Springback.

Table 2 Springback Factor Values Obtained Experimentally.

Materials	Fluid pressure N/mm²	Press pressure N/mm²	Holding time(min)	Springback factor Ks
Low Carbon Steel	0.6	1	1	0.34355
			2	0.33928
			3	0.31646
	0.8	1.2	1	0.32479
			2	0.31134
			3	0.30896
	1	1.4	1	0.30014
			2	0.29541
			3	0.29235

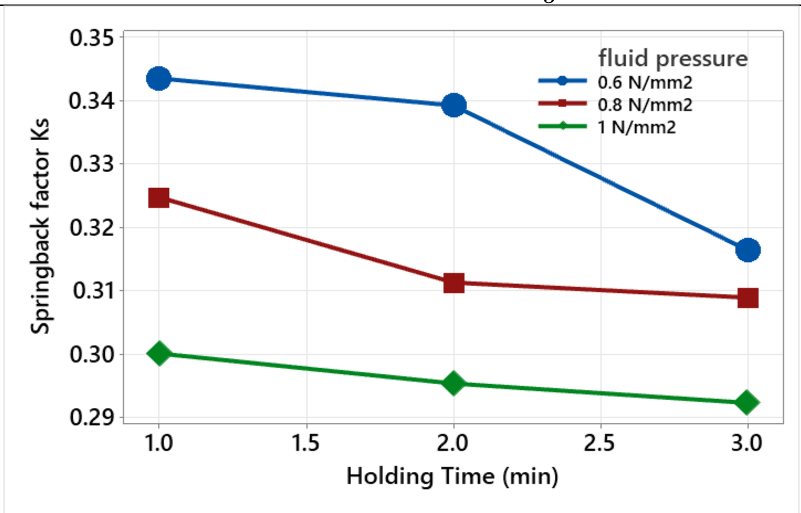

Fig. 6 Holding Time and the Springback Factor for Different Fluid Pressures.

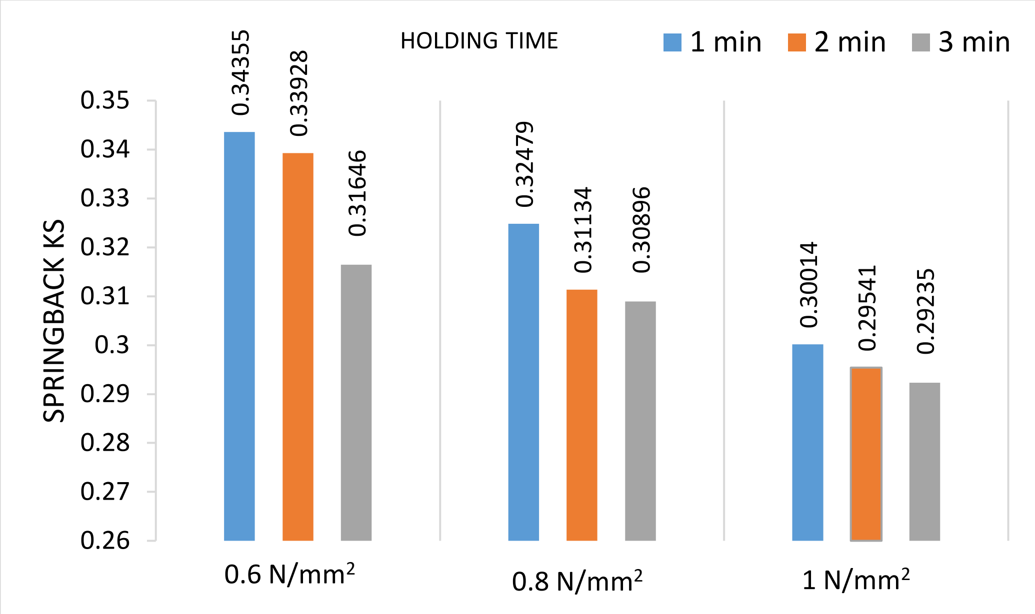

Fig. 7 The Relationship between Holding Time and the Springback Factor at Different Fluid Pressures.

3.2.Effect of Fluid Pressure on the Springback

Increasing the fluid pressure decreased the springback. For example, at 0.6 N/mm² in low-carbon steel, at a holding time of one minute, the springback factor was 0.34355; at 0.8 N/mm², when the holding time was 1 minute, the springback factor was 0.32479, and at a pressure of 1 N/mm², when the holding time was also 1 minute; the springback factor was 0.30014 for the same holding time. The springback decreased by 5.77% when the fluid pressure changed from 0.6 N/mm² to 0.8 N/mm², decreased by 8.21% when the fluid pressure changed from 0.8 N/mm² to 1 N/mm², and by 14.46% when the fluid pressure changed from 0.6 N/mm² to 1 N/mm². The higher the fluid pressure, the less springback for the same metal with a fixed thickness of 0.7 mm. It was also the same case when the holding time was (2,3) minutes, as shown in Fig.8.

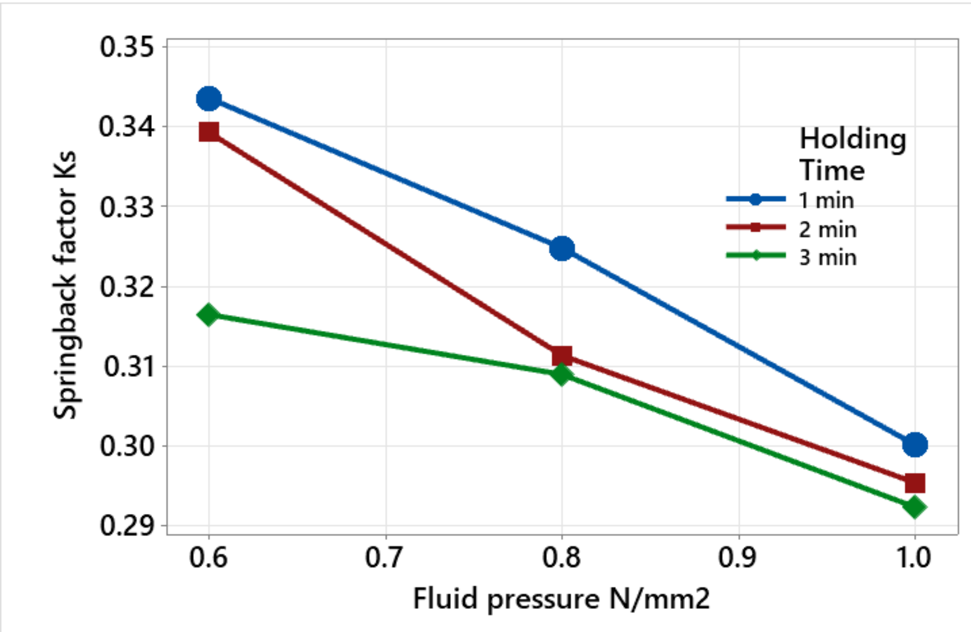

Fig. 8 Effect of Fluid Pressure on the Springback.

The difference between this work and the previously published works is that this work investigates the springback in a cylindrical cup in the hydromechanical deep drawing process under fluid pressure and holding time variables. Table 3 compares the results between this work and the literature survey.

Table 3 Various Relevant Literature Surveys on the Research and their Results.

Ref.	No	Year	The parameter	Operation type	Results
[3]	1	2017	Effect the blank thickness, yield strength, and elasticity modulus on springback	Hydroforming process	As a result of the hydroforming process's two-way pressure acting on the sheet's thickness direction, friction persists, and the stress differential is minimal. The springback is small after unloading.
[4]	2	2008	A die set with a maximum possible deep drawing ratio, $\beta_{o,max}$= 3.0, for a punch diameter (Ø) 100 mm was designed and constructed.	Hydromechanical deep drawing	It has been successfully studied to raise the deep drawing ratio, transfer complex curves from the punch to the blank surface, reduce drawing stages, and improve component quality.
[8]	3	2019	Die profile radius, pressure path, the gap between the die and the BH, and friction coefficient	Hydromechanical deep drawing	Increasing the die profile radius decreases the thinning of the part and maximum punch force. However, increasing the friction coefficient between the sheet and the punch decreases the part's thinning.
[10]	4	2021	BHF, thickness, fluid pressure, pressure press	Hydromechanical deep drawing	The cylindrical cup will acquire wrinkle faults if the BHF is too low, and the goods will burst if it is too high. The fluid pressure must be suitable for the BHF to provide a defect-free final product.
[12]	5	2016	Pre-bulging pressure, die-binder gap, and pre-bulging and spring back using three-layer blank (multilayer metal)	Hydromechanical deep drawing	The regions were divided into three-layer blanks (B1, B2, and B3). The springback of the three regions at the edge is higher than the regions within the cup; and B1 is greater than B2, and B2 is greater than B3.
[13]	6	2022	Hydraulic oil was used to apply different amounts of fluid pressure	Hydromechanical deep drawing	A product may be defect-free if the blank holder force (BHF) is in the proper range. Inconsistencies in the cylinder cup appear as wrinkles when BHF is low, while the cylinder cup breaks when BHF is too high. As a result, the BHF value should vary depending on the product type and its thickness and substance.

4.CONCLUSIONS

In this work, an experimental investigation was conducted in the hydromechanical deep drawing process. The research studied the effects of the holding time and the fluid pressure on the springback in the forming process of low-carbon steel. Some basic conclusions can be drawn as follows.

- The value of the springback increased as the holding time decreased. That is, the longer the holding time of the mold, the less springback was, and the springback can be discarded entirely when the holding time exceeds 3 minutes.
- Increasing the fluid pressure decreased the springback. The higher the fluid pressure and the press pressure, the lower the springback value for the same holding time.
- The sheet metal used in this research, low carbon steel (1008-AISI), was isotropic, causing a stable springback value in all directions.
- The hydromechanical deep drawing process does not need a high holding time of more than 4 minutes because it is a fast and accurate process, and the stresses were distributed evenly, decreasing the springback, especially in the cylindrical cup shape with a high holding time.
- The lowest springback value at fluid pressure was 1 N/mm², and the holding time was 3 minutes.

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