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DESIGN AND DEVELOPMENT OF AUTO-STEEL DRAW FORMING TEST DEVICE

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ABSTRACT

This work is concerned with the design and development of draw forming test device with double action draw forming mechanism. This device is designed to operate on universal testing machine (UTM). The dual phase auto-steel about 1.2 mm thick is used as deformable blank. The double action mechanism is generated by an external hydraulic system to equally apply the blank holder force (BHF). Hence, the punch force is driven by UTM's hydraulic system. The design load and die displacement is initially predicted by FE simulation at maximum load of 123kN and 14 mm displacement respectively. Draw forming result shows the fracture is recorded at 108 kN of punch force and 9.5 mm of displacement depth.

Keywords: formability, blank holder force, double action drawing, dual phase steel.

INTRODUCTION

Draw forming is a process of bending, stretching and drawing of a steel blank into a desired shape. It is influenced by the flow stress behavior which is governed by the forming process parameters such as die clearance, tool velocity, friction, blank thickness and BHF. The behavior of material flow is evaluated thru its formability with respect to the magnitude of material straining can be deformed before the crack is appeared [1]. It describes the material response during plastic deformation and localized failure until reaching the forming limit.

During pulling action of punch into die cavity the blank is subjected to different type of stresses. The cup side wall undergoes the longitudinal tensile stresses. While, the reduction of the blank diameter undergoes radial stresses which lead to hoop stresses in flange circumferential direction. Sufficient flow stresses enable to eliminate material defect such as wrinkle and delay fracture. The existence of wrinkles in the flange region is due to the behavior of buckling in hoop stresses. While excessive BHF is able to deteriorate the steel blank into ductile fracture much faster [2]. In this respect, proper method and device are required to qualitatively and quantitatively measure the material formability. Currently there are several methods to be applied. Limit drawing ratio (LDR) is a measure of maximum radius of the blank that can be drawn to the die opening under the drawing limit without failure [3]. Limit dome height (LDH) is a measure of penetration height of indenter prior to fracture. And forming limit diagram (FLD) is a measure to indicate the deformation with a linear strain ratio under the forming limit [4][5].

Unlike typical UTM which is designed for uni-axial material testing, formability test device in draw forming process is substantial to evaluate the material behavior in three dimensional stretching. As a result, various types of forming test device have emerged, such as Erichsen machine to carry out the formability test. In the beginning, it was used to measure the limit drawing ratio.

Here, the sheet metal is stretched over the hemispherical punch tool. Later, it is used for the limit dome height test which the attached indenter penetration depth is used to measure the material formability.

Hence, the objective of this work is to design and develop a circular cup draw forming test device which based on Erichsen machine design concept that can be operated on UTM. It is used to examine the formability of auto-steel blanks that corresponds to the loading in cup drawing process.

PHYSICAL MODEL

Circular cup shape

The desired circular cup shape of draw forming part to be produced is illustrated in Figure-1. The shape is based on the Erichsen cupping test geometrical features in order to demonstrate the automotive draw forming part in a reduced size. It features consist of flanging, bending, sidewall and punch nose shape region. The feature is formed by the process of plastic hardening of the blank. During the draw forming process, the material is constrained thru the stretching of sidewall feature by the induced multi-axial stresses of the surrounded die-wall. Formability of the material is evaluated to determine the success of draw forming process into the circular cup shape part.

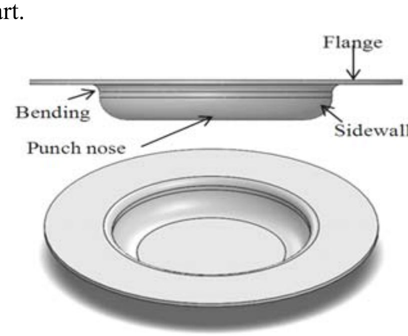

Figure-1. Physical model of circular cup shape part.

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Material

As to ensure that the test device has the maximum ability of material strength response to forces, the 1.2 mm-thick advance high strength steel (AHSS) is used as the deformable blank. The AHSS, dual phase steel (DP600) is prepared for the cup draw forming process. In order to draw forming the blank into circular cup shape, the received material is a ready cut of 85 diameter circular shape. The chemical composition of the steel is (in wt %) as in Table-1. As depicted in Figure-2, the elastic modulus is 201 GPa while yield and tensile strength of the steel sheet is 417 MPa and 818 MPa, respectively. The coupon test is conducted based on ASTM-E8-11 tensile test procedure at 0.00167/s strain rate of 50 mm gage length.

Table-1. Chemical composition of DP600.

wt%	C	Mn	P	S	Si	Cu	Ni	Cr	Ti	Al	Fe
	0.1	1.78	0.021	0.005	0.505	0.014	0.013	0.222	0.006	0.902	Balance

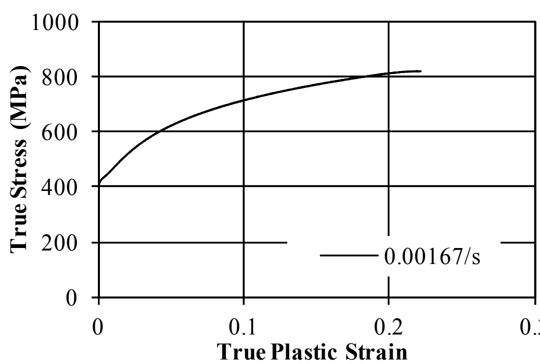

Figure-2. True stress strain curve at 0.00167/s.

FE SIMULATION

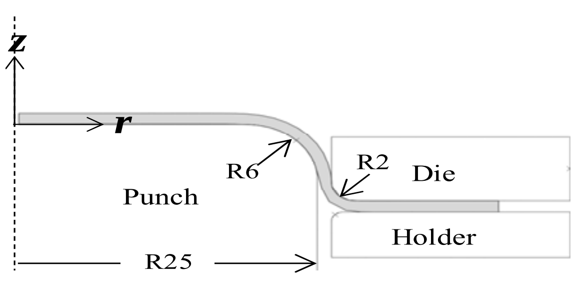

Figure-3. An axisymmetric FE cup draw forming model.

An axisymmetric FE cup draw forming model is used to simulate the draw forming process as shown in Figure-3. The FE results are to identify the parameter of punch force and draw forming depth respectively. The punch force specifies the type of universal testing machine (UTM) to be used while the draw forming depth determine the dimension of die cavity depth. The geometrical features of FE draw forming model is designed based on the typical draw forming part which consist of 3 forming rigid parts and a sheet metal as deformable steel blank with zero die clearance. The 1.2 mm deformable steel blank is meshed with 0.5 X 0.5 mm element size using 4-node quadrilateral element type. The tensile properties of DP600 grade dual phase steel are obtained from [6] with the extracted tensile test data at 5 mm/min loading rate as demonstrated in Figure-2. The one dimensional tensile test data is used to describe the piece-wise isotropic hardening behavior. Due to the behavior of contact interaction between blank and forming tool is unknown, the coefficient of friction to represent the process parameter setting is set as μ=0.16. The FE result shows that a maximum of 123 kN punch force and 14 mm of drawing depth is required to shape the circular cup part

RESULTS AND DISCUSSION

The loading mechanism

The fabricated draw forming test device is used to evaluate the formability of steel blank. In this respect, the load variation and displacement reading of material response are recorded using UTM's load cell and actuator system respectively. The loading mechanism of draw forming tool is illustrated as in Figure-4. From the FE results, an UTM equipped with load cell that can measure the punch ram force up to 200 kN is used. The circular cup shape is draw formed using two types of loading mechanism. First is to clamp the cup flange using BHF loading. This is to control the free-flow of material into the die cavity. While the action of punch to ram force the material into the die cavity is to draw into the circular cup shape. This pair loading characterize the double action draw forming mechanism which is usually used for larger drawn part. In normal practice, small and medium size parts are generally formed using single action draw forming. Conversely in this work, double action draw forming mechanism is used to draw forming small cup parts as illustrated in Figure 4. It is because the double action draw forming mechanism has the ability to provide uniform BHF on the flange region [7]. Thus it has better clamping control than the single action draw forming mechanism. In the conventional double action draw forming process, the punch and clamping device are loaded vertically from the similar path onto blank.

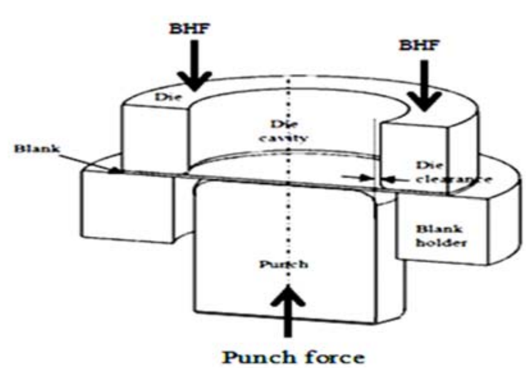

Figure-4. View of double action draw forming mechanism.

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In this design, an external hydraulic cylinder system as depicted in Figure-5 is attached to UTM to produce BHF. Thru the die to clamp the blank flat against the die face onto blank, the die is transferring the BHF which pushed by the oil flow of hydraulic cylinder. This is facilitated by the pressurized mechanism from the action of hydraulic hand pump to apply the desired blank holder force. Followed by the action of ram force of the punch tool to shape the blank, which is driven by the servo hydraulic of UTM. The punch is incrementally ascending to the steel blank and into the die cavity during draw forming process.

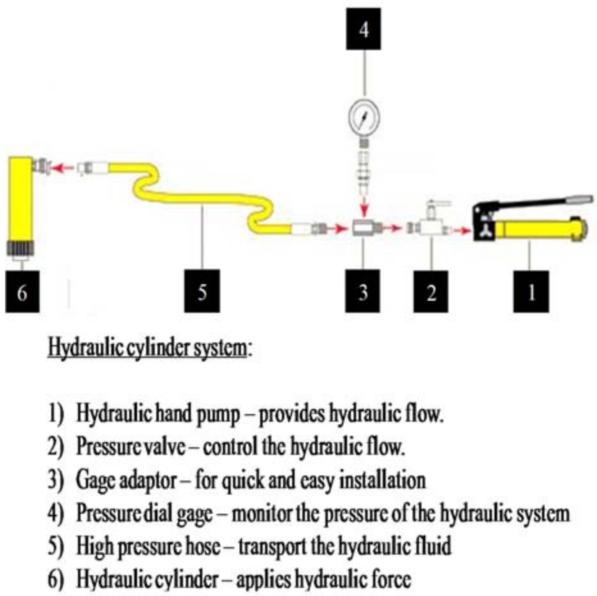

Figure-5. Hydraulic cylinder system.

The assembly setup

The test device consists of forming tool fixture and the loading mechanism. The structural design of draw forming tool fixture is reinforced with eight column frame. The steel blank is placed between the die and blank holder and then it is ram force with hardened hemispherical punch. As to tailor the structure of UTM, the fixture frame is fitted to the upper gripper with the hydraulic cylinder which attached to the frame. The forming tool fixture is assembled to the UTM's gripper. The die block is properly fitted to the hydraulic cylinder shaft. At the other end of the frame, the blank holder is fitted to position the steel blank. While at the lower gripper of UTM, a 50 mm diameter of the punch is properly fitted as depicted in Figure-6.

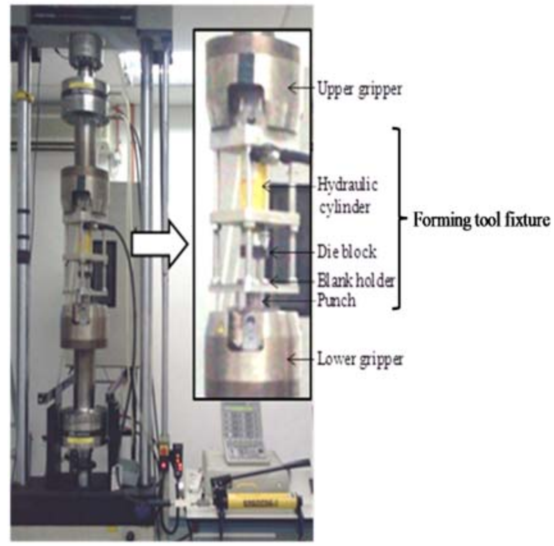

Figure-6. Draw forming tool setup.

The draw forming fixture is designed to ease the assembly and disassembly when transforming UTM into draw forming test device. The applied load mechanism of punch force and BHF are driven by the machine's hydraulic system and external hydraulic system respectively.

Cylinder force calibration setup

The role of blank holder is to clamp the blank with BHF. But in this design, the task is carried out by the die block in transmitting BHF during clamping. The issue is how to comprehend the amount of regulated force based only on the number of hand pumping action to generate force that push the die block. Thus, a procedure to measure the amount of regulated force to push die block is established. During the calibration procedure, UTM is used to measure the regulated force of the hydraulic hand pump. The fixture of the hydraulic cylinder is fitted to the lower gripper by facing the cylinder shaft upwards as demonstrated in Figure-7. In this calibration setting, the extracted hydraulic cylinder shaft which ascends the die block towards the compression platen is measured. Incrementally the pressurized oil flow in the hydraulic cylinder is regulated thru the number of hand pumping action to the amount of pushing force. The pushing force by the hydraulic cylinder is measured thru the UTM's display monitor. The process is conducted at different loading forces as to mark a scale of indicator on the dial pressure gage. Later during the test, the hydraulic hand pump is regulated to the marker of the desired reading of push force to be applied. For safety measures, BHF is limited up to 100 kN to uniformly apply onto a flange region of blank.

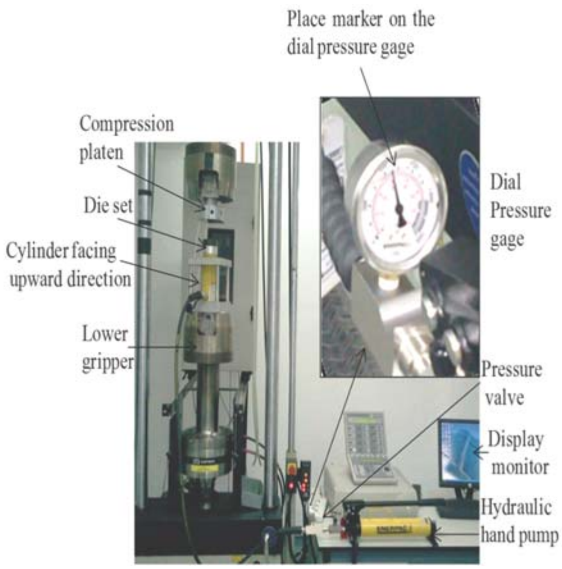

Figure-7. BHF calibration setup.

Draw forming test

The draw forming test is conducted at 5 mm/min loading rate. The recorded load-displacement data in the draw forming test is demonstrated as in Figure-8. In order to obtain the deformation and failure response of the material, the draw forming test is conducted until the fracture is presented in the draw forming cup part. Maximum punch force at fracture is recorded at 108 kN with 9.5 mm draw forming depth. The load-displacement S-curve illustrates the formability of the material. From Figure-8, the formability of the material can be divided into three different stages before it reaches the forming limit [8]. It characterizes the behavior of material formability into elasto-plastic, hardening and failure region.

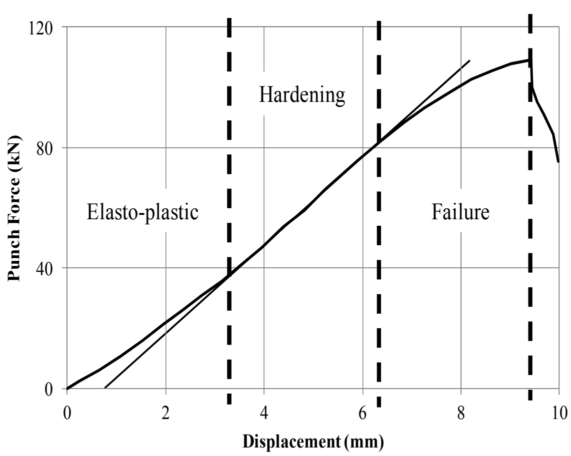

Figure-8. Load-displacement curve.

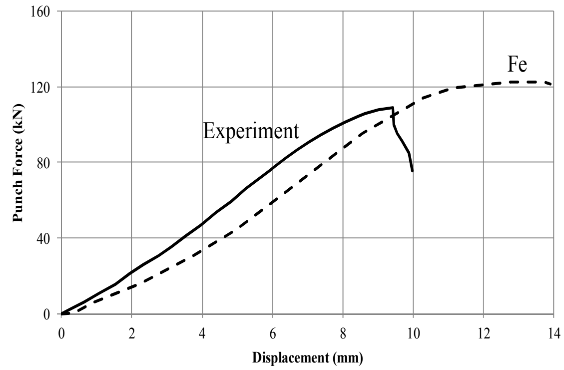

Figure-9. Comparison between FE and experimental result.

CONCLUSIONS

This study is to design and develop a test device that able to examine the formability of material in the draw forming processes. The concept of ease of assembly and disassembly design is applied to easily transform UTM into draw forming test device. Results shows that to equally apply BHF on draw forming small parts, double action draw forming mechanism is employed. Die block is used to uniformly transmit the BHF which regulated by the external hydraulic hand pump. It is push by the pressurized hydraulic cylinder which the amount of generated force from the external hydraulic hand pump is govern by UTM's control monitor. Characteristic of assessed material formability exhibit three distinct region covering elastic-plastic, hardening and failure before reaching the forming limit.

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