

Simulation, Design and Manufacture of A Friction Test Apparatus Suitable For Deep Drawing Process

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Abstract— To investigate the friction and lubrication conditions of steel sheets, a friction test apparatus is designed and manufactured. Both ordinary and colour coated steel sheets are experimentally evaluated in these tests. Various die materials and die coatings are used to obtain optimum tribological conditions. Two types of die coatings i.e. 1-PVD coating (TiN) and 2-Plasma Nitridated coating and also three types of lubricants i.e. oil, nylon and dry conditions are used in the friction tests. An analytical closed form equation is used to obtain friction coefficient for each friction test. Experiments show that combination of PVD coating and oil yields the best tribological conditions as compared with the other combinations.

Index Terms—Friction test, Colour coated steel sheet, Die coating, Lubricant, Deep Drawing.

I. INTRODUCTION

Several friction test apparatuses have been proposed to measure the friction coefficient between sheet and die. Mostly in these tests, the sheet is bent around a roll (or two rolls) and forces are exerted on two sides of the sheet. Two common apparatuses are shown in Fig. 1 and 2 [1], [2]. These test apparatuses are called “bending-under-tension apparatus” and “tensile strip friction testing apparatus”. Although various lubrication conditions can be compared by these two tests, none of these apparatuses are similar to deep drawing dies since they do not have any blank-holder or draw beads. Therefore the friction coefficient cannot be accurately evaluated by these methods for deep drawing process.

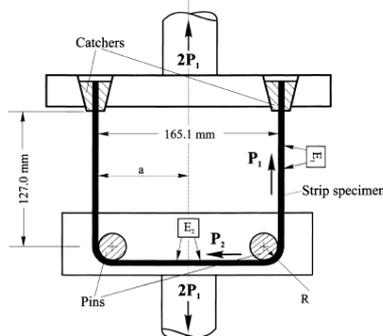


Fig. 1. Tensile strip friction testing

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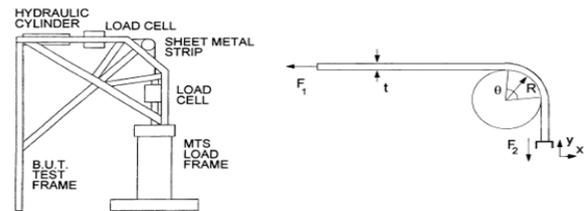


Fig. 2. Bending under tension

There are several researches performed on colour pre-coated steel sheets. Ueda [3] et. al. has investigated the colour layer mechanical properties and its effect on the formability of these sheets in deep drawing. Ueda also has done a series of tensile tests on different common colour layers and has studied the integrity of the colour layer in forming processes like bending and deep drawing [4]. In this research the main mechanical properties of the colour layer that influence the damage are separately determined for bending and deep drawing. The main research area on the colour pre-coated steel sheets is the corrosion resistance of these sheets, which is studied by [5-9]. No research work could be found about the effect and measurement of friction between the colour pre-coated steel sheets and forming dies.

Hence in this research an apparatus is designed and made which is very similar to a deep drawing die, as shown in Fig. 3. In this apparatus the punch and holder forces are measured using three load cells and by an analytical closed form equation, the friction coefficient is evaluated. Also two draw beads are included in this apparatus since these draw beads are usually used in rectangular deep drawing dies.

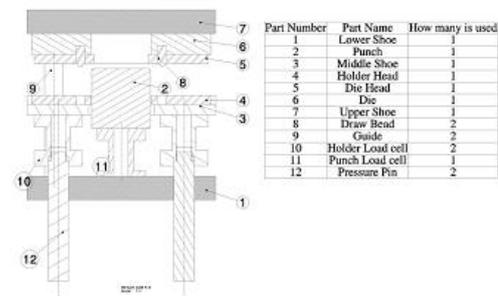


Fig. 3. Schematic view of the test apparatus

A main objective of this research is to obtain the optimum tribological conditions for polyester colour coated steel sheets. The optimum tribological conditions are vital in practice since inappropriate conditions can reduce the quality of colour coatings. Therefore it was essential to rank various lubrication conditions. To the author's knowledge there is no report on the optimum lubrication conditions for the polyester colour coated steel sheets.

II. TEST APPARATUS:

Several friction testing apparatuses have been introduced so far. Although these apparatuses are helpful, previous investigations on sheet metals show that friction forces in stamping processes are a complicated function of material properties, process parameters and contact conditions so that it is difficult to set up a single experimental test that realistically represents the frictional behaviour of a sheet metal forming process [1]. Therefore, an apparatus is designed and built which is very similar to the actual deep drawing process. Two draw beads are also involved in this apparatus. Main contacting surfaces are removable and exchangeable in this apparatus. Hence various surface and lubrication conditions can be easily obtained and investigated.

III. DESIGN OF THE APPARATUS:

Fig. 3 shows a schematic view of the apparatus. In this apparatus, the sheet is drawn by the punch 2 into the die 5. The parts 5, 4 and 8 are exchangeable and are fastened to the apparatus by means of screws. Parts 10 and 11 are load cells that measure the holder and punch forces respectively. Parts 7, 3 and 1 are shoe blocks, which are guided by two frictionless diagonal ball bushing posts. The pressure pins 12, transfer the press cushion force to the blank holder plate.

When a sheet is pulled into a bending die, two major forces are involved: The bending force, and the friction force. Figure 4 illustrates a bent sheet on the apparatus containing a draw bead. According to this figure, the sheet is successively bent and unbent from position 1 to position 6.

To calculate the bending force, the following assumptions are made:

- 1- At each position, the bending radius is equal the tool radius i.e. the holder slot, draw bead or die.
- 2- Swift work hardening equation is assumed as: .
- 3- The sheet is an isotropic material.
- 4- The strain rate has no effect on the work hardening.
- 5- The bending and unbending of the sheet have plain strain conditions.

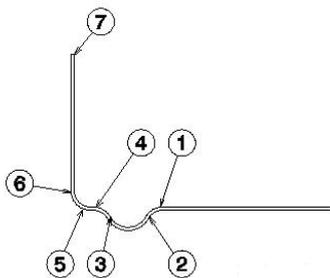


Fig. 4 A deformed sheet in the apparatus

Tensile tests were performed to determine the mechanical properties of the sheet. The mechanical properties of the sheet are presented in Table 1.

TABLE I
MECHANICAL PROPERTIES OF THE COLOUR COATED STEEL SHEETS AND GALVANIZED STEEL SHEETS

	Yield Strength (N/mm ²)	Tensile Strength (N/mm ²)	Elongation (%)	n
Colour coated steel sheet	350	362	25	0.124
Galvanized steel sheet	304	395	30	0.144

At each position in figure 4, the strip force is calculated using the following analytical equations. To determine the effect of work hardening, at each point the bending strain is calculated and added to the amount of previous strain, causing the yield strength to increase due to strain hardening.

The method for calculating the bending force is based on the previous works of Nine [10] and later Foroutan M. et al [11]. At position 1 we have:

$$\sigma_{b1} = \frac{F}{R_C \cdot t} \tag{1}$$

where R_C is the radius of the middle axis, t is the thickness of the sheet and σ_{b1} is the bending stress at position 1. F is calculated by the following equation [10]:

$$F = \frac{2KC_b^{n+1}}{R_N^n(n+2)(n+1)} \left(\frac{t}{2}\right)^{n+2} \tag{2}$$

where k is the work hardening coefficient, R_N is the radius of neutral axis of the bent sheet. C_b is calculated by the following equation:

$$C_b = \left[\frac{2(2+R)(1+R)}{3(2R+1)} \right]^{\frac{1}{2}} \tag{3}$$

in which R is the bending radius.

At position 2, the unbending stress σ_{ub2} is calculated as:

$$\sigma_b = \frac{Mt_b}{R_C} \tag{4}$$

in which M is calculated by the following equation [4]:

$$M = \left\{ \frac{C_b \bar{\sigma}_o}{4} \left[1 + y^2 + 2 \frac{z_n}{R_N} \left(1 + \frac{y^2}{3} \right) \right] + \frac{SC_b^2 t_b}{24R_N} \left[1 + 3y^2 + \frac{3z_n}{R_N} (1 + y^2) \right] \right\} \tag{5}$$

where z_n is:

$$z_n = \frac{\sigma_{mo} t_o}{2C_b \bar{\sigma}_o + SC_b^2 \frac{t_b}{R_N}} \tag{6}$$

and y is $y = 2Z_n/t_b$.

The sheet slides over the holder slot radius, between positions 1 and 2. Therefore the amount of stress at position 2 is calculated as:

$$\sigma_2 = \sigma_{b1} e^{\mu\theta} + \sigma_{ub2} \tag{7}$$

Where θ is the bending angle.

Also the reaction force of sheet on the holder corner is:

$$F_c = N_{av} 2RW \tag{8}$$

In the above equation, F_c is the reaction force, R is holder corner radius, w is the width of the sheet and N_{av} is the average normal force on the holder surface which is calculated by following equation:

$$N_{av} = \frac{\sigma t}{R\theta} [e^{\mu\theta} - 1] \tag{9}$$

Where σ is the current yield stress, θ is the angle of the round surface and R is the bending radius. By calculation and

accumulation of all stresses from position 1 to 6 the final strip stress, is obtained.

For simplicity R , R_N and R_C are assumed to be equal, since the sheet thickness in comparison with the above radii is negligible and also the friction force between positions 4 and 5 is neglected because this friction force is very small.

Manufacturing of the apparatus:

The main parts of the apparatus were built by CNC milling machines, manual milling machines, lathes and drilling machines. All the parts were produced accurately and with a good surface finish, especially those which were in contact with the sheet which were ground and polished. The load cells were capable to measure about 7 tons of axial load. The output of each load cell was connected to a data acquisition card and was connected to a computer. To read and analyze the data, the LabView 7.0 software was used. To calibrate the load cells a ZWICK universal testing machine was used. Finally, to eliminate the effect of noise, all the wires were shielded and the signals were filtered in the LabView program. The apparatus and a test specimen are shown in Fig. 5.



Fig. 5 test apparatus assembled on a press and a tested specimen

IV. PERFORMING THE TESTS:

For each pair of lubricant and die material two specimens were tested. The forces were measured by the calibrated load cells and the averages of the results were taken into account.

The punch and holder forces as well as the calculated friction coefficients for various types of die and/or material coatings and lubricants are listed in Table 2.

TABLE II
THE PUNCH AND HOLDER FORCES AND CALCULATED FRICTION COEFFICIENTS FOR VARIOUS TYPES OF DIE AND/OR MATERIAL COATINGS AND LUBRICANTS

Sheet	Friction condition	Punch force (N)	Holder force (N)	Friction coefficient
0.5 mm thickness Colour coated steel sheet	TiN PVD coated die with oil as lubricant,	16700	4150	0.184
	TiN PVD coated die with oil and nylon as lubricant	14800	4150	0.15
	Nitrated steel die with oil as lubricant	31100	4150	0.352
	Nitrated steel die with oil and nylon as lubricant	27100	2300	0.328
	Heat treated steel	37800	2000	0.414

0.8 mm thickness galvanized steel sheet	die with oil as lubricant			
	Heat treated steel die with oil and nylon as lubricant	22220	4200	0.262
	TiN PVD coated die with oil as lubricant,	33600	2950	0.155
	TiN PVD coated die with oil and nylon as lubricant	30500	2950	0.125
	Nitrated steel die with oil as lubricant	47400	4500	0.25
	Nitrated steel die with oil and nylon as lubricant	51900	5900	0.269
	Heat treated steel die with oil as lubricant	71400	2950	0.362
	Heat treated steel die with oil and nylon as lubricant	35800	2950	0.173

V. RESULTS AND DISCUSSION:

The resulted forces along with the calculated coefficient of friction are presented in Table 2.

Experimental results of the two colour coated and galvanized steel sheets investigated in this research show almost the same trend. The friction coefficients of the colour coated steel sheets are clearly larger than those of galvanized steel sheets. As it is seen, regardless of the effect of lubricants, coating the die surface with TiN has decreased the coefficient of friction significantly. This is true both in the case of colour coated steel sheets and galvanized steel sheets.

Generally, the combination of hardened die with no additional coating and using oil as lubricant led to the worst friction condition in all the experiments. Comparing oil and combination of oil and nylon, it seems that combination of oil and nylon is better than the oil. However there is one exception when galvanized steel sheets and a nitrated die is used.

Comparing the die coatings, it was realized that the TiN coating significantly reduces the friction coefficient. While in the case of nitrated steel and heat treated steel, friction coefficient depends on the type of lubricant as well. In the case of combination of oil and nylon as lubricant, heat treated steel shows better results than nitrated steel while in the case of oil, nitrated steel showed smaller coefficients of friction.

A set of experiments were also performed on sheets without any lubricant. In all of these tests, the specimens were torn at point 6, (Fig. 4), where maximum tension exists. Also using lubricant on only one side of the sheet was not adequate and the sheets were also torn. It should be mentioned that previous researchers stated that the colour coating layer on the sheet acts as a lubricant and it is also mentioned that these sheets do not need any lubricant [12]. However this is not in agreement with performed tests in this research. This might be due to different types of colour coatings used in these experiments.

These tests show the importance of lubricants as well as die coatings in forming of colour coated sheets.

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