

Effect of Tool Coatings and Tool Steels on Formability of Advanced High Strength Steels

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ABSTRACT

To improve the formability of advanced high strength steels, the interaction between steel sheet, tool material and tool coating was investigated. Square cup drawing experiments were conducted to determine the range of binder forces for forming good cups without wrinkling or splitting. Binder Span of Control (BSC) tests were conducted for DP590, TRIP590, DP780, DP780 EG and DP980 using three uncoated tool steels and two coatings on a standard tool steel substrate. The experimental results indicate that the binder span for forming good cups is sensitive to the choice of tool material and tool coating and the effect of lubricant on formability also varies with tooling material and coating. The obtained binder spans were compared and the best coating plus tool steel combinations for steels of different grades were identified. In addition, roughness of the tooling surface was measured before and after stamping. The tooling behavior during stamping and the roughness change after stamping depend not only on steel grades and coating but also tooling material and coating. The ranking of surface roughness of different tooling is consistent with their overall performance on binder span. The understanding on the effects of tool material and coating will help to provide solutions to formability issues in the application of advanced high strength steels.

INTRODUCTION

The increased use of advanced high strength steels (AHSS) has caused concerns in die wear, galling, chipping, cracking, scratching, etc., because of high contact stress and friction. One of the solutions is to use advanced die materials and die coatings in stamping dies. A variety of cast, cold worked, and powder metallurgical tool steels have been introduced to counter die wear and galling by changing the chemical composition and the manufacturing process of the tool steel. Recently, some research has been conducted to compare the wear resistance on a variety of advanced die materials when

stamping advanced high strength steels [1, 5, 7]. In addition to advanced tooling materials, coating technologies such as Physical Vapor Deposition (PVD), Chemical Vapor Deposition (CVD) and Thermal Diffusion (TD) die coatings are proving helpful in solving die wear and galling problems [2, 3, 4, 6]. To reduce friction between work piece and tooling, lubricants are applied in the stamping process. Various stamping lubricants were tested by strip draw test (SDT) to evaluate performance with uncoated and coated dies [2, 3]. Punch force measurement for different lubricants on coated and uncoated dies was used to evaluate the interaction between lubricant, die coating and the protective Zn coating on the sheet steel. The advanced tooling material and coating does offer the potential to counteract die wear and galling caused by AHSS. The above study showed approaches to reduce die wear and die galling by die material, die coating and lubricant selection based on the strength, coating and gauge of the AHSS.

Another challenge in the application of AHSS is formability during the stamping process. While making die material decisions based on abrasive and adhesive wear resistance of the tooling, the influence of die material and die coating on the formability of AHSS should not be neglected. Depending on the sheet material and coating, the effect of die material on formability could be significant. Experience obtained from stamping tryouts have shown that soft tool trials cannot always be used to predict performance in the hard tool stage. LDH tests and draw beads tests on cold rolled and zinc coated materials also showed that soft tool and D2 hard tool material were clearly shown to have influence on LDH value, level of draw bead forces and friction coefficients [9, 10, 11]. The die material effects persist when various lubricants were used to offset the frictional difference due to tool material changes. Moreover, Draw bead tests were conducted with four different automotive sheet steels (CR, HDG, HDGA and EG DQSK) and five different tool materials (Kirksite, untreated Gray cast iron, flame hardened cast iron, ion nitrided cast iron and D2 tool steel) [13]. The results showed that the coefficients of

friction from drawbead tests depend on the type of die material/treatment utilized for the fixed bead.

For the application of AHSS, it would be necessary and interesting to study the effects of die material and die coating on the formability.

Presented in this work are square cup drawing experiments conducted to determine the range of binder forces (binder span of control) for forming good cups without wrinkling or splitting. The binder span of control (BSC) test method [16] is described in Sec. 2. BSC tests were conducted for DP590, TRIP590, DP780, DP780 EG and DP980 using three uncoated tool steels (D2, Caldie, and Vancron 50) and two coatings (Alcrona and Lumena) on a standard D2 tool steel substrate with and without lubrication. The testing materials and test matrix are listed in Sec. 3. Since surface roughness of tool is one of the factors to influence frictional behavior related to the formability [8, 9, 14 and 15], tooling roughness was measured, as shown in Sec. 4, before and after stamping to help to understand the performance of various tooling materials. The tooling behavior during stamping and the roughness change after stamping depend not only on steel grades and coating but also tooling material and coating. The effect of lubricant on formability also varies with tooling material and coating. The BSC results are compared in Sec. 5. The binder spans for forming good cups were found to be sensitive to the choice of tool material and tool coating. The best coating plus tool steel combinations that offer the best formability for steels of different grades were identified. The rankings of surface roughness and tooling surface hardness are found consistent with overall performance ranking on binder span. The details of result correlation are discussed in Sec. 6. The understanding on effects of tool material and coating will help to provide solution to formability issues in the application of advanced high strength steels.

BINDER SPAN OF CONTROL TEST

Binder Span of Control is a procedure frequently used in stamping plants where for a given press condition, the binder

pressure is varied to determine the safe operating window (wrinkle-free and split-free parts) for production. The procedure is a very good indicator of the formability of a steel grade and robustness of the stamping process, whereby the sensitivity to variations in incoming material, lubricant, and die condition can be evaluated. [Figure 1](#) shows square cup draw samples, which were formed with low, middle and high binder forces resulting in wrinkled, safe or split part. [Figure 1](#) shows the effect of the binder pressure on forming a cup of the same depth using the same material and same tooling.

For a cup of a certain depth, about 10-20 samples were formed using a number of binder forces. After forming, the samples were examined for splits (or incipient necking) and perceptible wrinkling. The binder force limit for splitting is the lowest binder force causing necking or splitting and below which the resulting sample is free from necking or splitting. The wrinkling limit is the binder force below which, perceptible wrinkling on the flange can be observed and felt by touching. The onset of perceptible wrinkling was determined using touch and the unaided eye. The splitting and wrinkling limit forces were recorded for all the tests.

[Figure 2](#) gives a more complete understanding of binder span of control as a function of the different test variables. The intersection point of the wrinkle and split lines for a given lubricant is the maximum cup depth that can be formed for the particular combination of blank size and lubricant. As seen in [Figure 2](#), use of prelube results in a significantly higher operating window than using the lighter ship oil. The maximum cup depth that could be formed with the prelube is also higher than with the ship oil. The binder span was also varied with blank size. Using blank of a reduced size will result in higher draw depth and wide binder span because of easier flow through the binder. The binder span tests in this study necessitate a much larger experimental matrix comprising of sheet material, cup heights, tooling material, tool coating and lubrications.



Figure 1. Effect of binder force on formability of the material

TOOLING, TESTING MATERIALS AND TEST MATRIX

A schematic drawing for the tooling is illustrated in [Figure 3](#). Five sets of tooling inserts were made for upper die, lower

binder and punch with D2, Caldie, Vancron50, D2 with Lumena coating and D2 with Alcrona coating as listed in [Table 1](#). The features of the above die material and coating are described as the following:

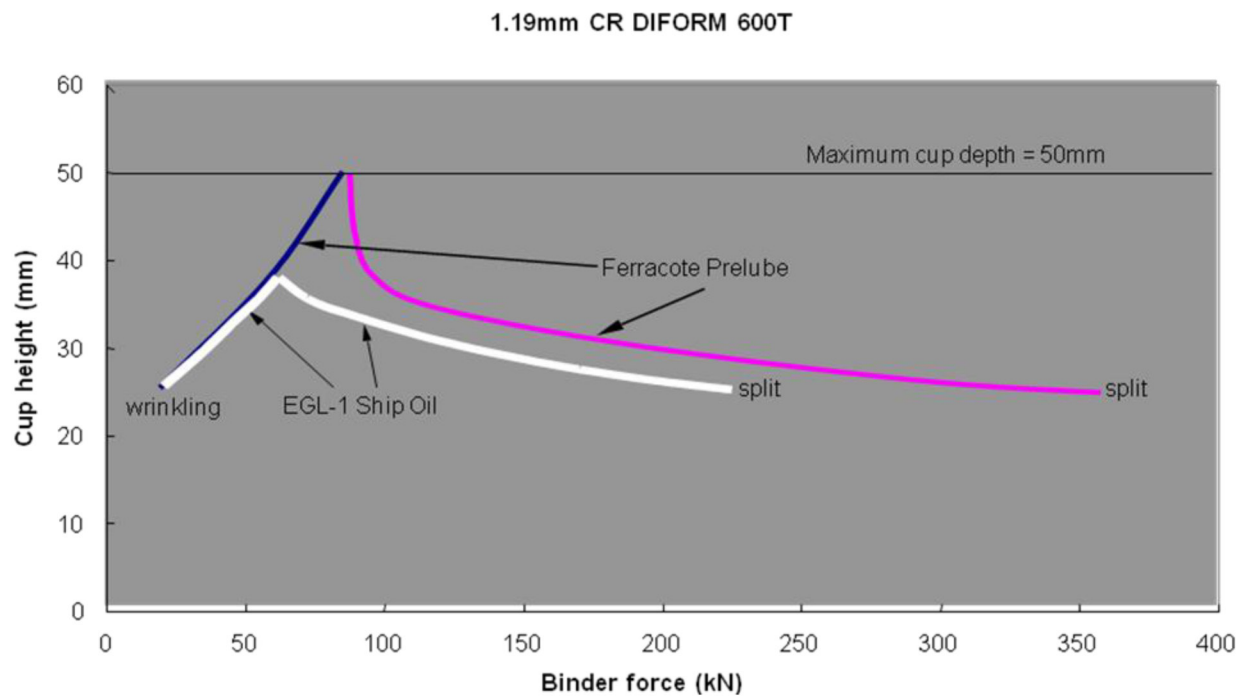
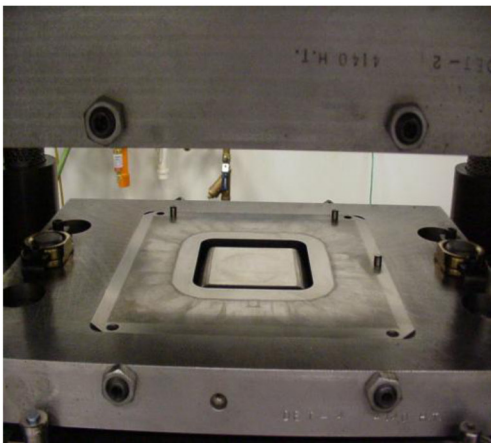
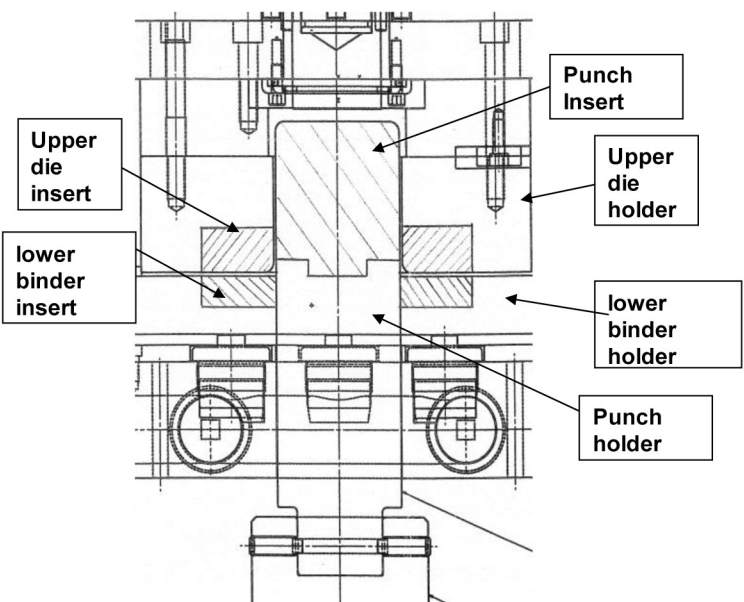


Figure 2. The binder span and its variation with different lubricants



Lower binder insert and punch

Figure 3. Binder span test tooling

- With relatively low cost, D2 has good wear resistance, through-hardening properties, resistance to tempering-back and is compatible with all coatings. The weakness of D2 is its low toughness causing die chipping and bad reparability.
- Caldie has very good chipping and cracking resistance, wear resistance, excellent polishability, dimensional stability in heat treatment and in service, excellent through-hardening properties, good machinability and grindability and good resistance to tempering back.
- Vancron50 has High galling and adhesive wear resistance, high compressive strength, good dimensional stability and through hardening properties, resistance to tempering back and very good chipping/cracking resistance.
- Both die coatings, Lumena and Alcrona offers good oxidation resistance and hot hardness. They have excellent wear resistance under conventional conditions or severe mechanical stresses. Besides, both are PVD coatings so the tooling distortion and phase change issue due to high process temperature are avoided.

The tooling hardness were measured using Rockwell hardness C scale for tooling substrate hardness and Vickers micro hardness HV scale for surface/coating as shown in [Table 1](#). The hardness reading is the average of hardness readings from many locations on the tooling. The Rockwell hardness and micro-hardness for the uncoated dies are consistent. Among uncoated dies, Vancron 50 is harder than D2, and Caldie is the relatively less harder tool. The micro hardness of coated die is much higher. The hardness of coating is much higher than the metal substrate. Therefore, the surface hardness of tooling could be the key to relate to contact pressure and also functioning of lubricants. Correlating the surface micro hardness with formability using binder span test could provide answers for AHSS regarding the need for a softer tool or harder tool for better formability.

Six sheet materials were used in the binder span tests using 5 sets of tooling as listed in [Table 2](#). They are AHSS grades with tensile strength from 590 MPa to 980 MPa. One EG coated material is involved for learning the sheet coating effects. The rest is cold rolled varied in strength level and formability. Two kinds of DP980 material, DP980-1 and DP980-2, were tested to confirm the consistency of tooling performance for AHSS of similar grade. All the materials were cut into blanks of 7.5×7.5 inch for the binder span tests.

The test matrix is listed in [Table 3](#). Tests were conducted with and without applying the Ferracote Prelube. For each of the materials on each of the 5 die material/coating combination, 2 to 5 draw depths were used in the binder span tests for plotting the binder span diagram. To find the wrinkling and splitting limits, 20 to 30 tests were needed to try binder forces from low to high. In this study, a total of around 4000 square cup draw tests were completed.

The baseline tests are ones without using prelube, which is the worst case scenario. When prelube is not applied, only ship oil remains on the blank. The test without lubricant has its industrial relevance. In fact, some automotive company has transferred to dry press shop, only rust protection oil applied by material supplier is allowed as stamping lubricant [1]. Die material selection guidelines were established based on die wear after forming 50,000 strokes [1].

To represent a condition more typically used to stamp AHSS, tests were repeated with prelube completely brushed on both side of the blank for a fully lubricated condition. Test matrix was decided based on the draw depth that a material can reach in the baseline test. For 1.2 mm DP780 (B), no test was done with lubricant due to material of the same coil run out in baseline test.

Table 1. Tooling and hardness measurement

Number	Tooling	HRC	HV 0.5
1	D2	60.6	768
2	Caldie	59.9	729
3	Vancron 50	60.9	787
4	D2 with Lumena coating	58.5	1640
5	D2 with Alcrona coating	55.8	1870

Table 2. Test materials

Test Material	Grade	Coating	Gauge (mm)	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)
A	DP780	CR, EG	1.5	491.1	835.6	16.7
B	DP780	CR, Bare	1.2	519.3	851.7	15.9
C	TRIP590	CR, Bare	1.6	450.8	633.4	32.2
D	DP590	CR, Bare	1.5	390.2	632.3	20.5
E	DP980-1	CR, Bare	1.2	685.6	1033.0	11.0
F	DP980-2	CR, Bare	1.2	707.0	1036.5	13.8

Table 3. Test Matrix

Steel Grade	Die Material	Lubrication	Draw Depth (inch)	Binder Force at Wrinkle (lbf)	Binder Force at Splitting (lbf)
A/B/C/D/E/F	1/2/3/4/5	None lube /prelube	2 to 5 depths of 1.0, 1.3, 1.5, 1.75 and 2	Maximum of 20-30 binder forces that causing wrinkling	Minimum of 20-30 binder forces causing necking/splitting

TOOLING SURFACE ROUGHNESS

Factors influencing formability of a material include part geometry, sheet material properties, forming process, restraining force (binder pressure) and frictional behavior at tool-workpiece interface. In this study, friction behavior for a material on different tooling/coating is the major variable that causes the difference in formability. The friction coefficient, although may not be a constant during forming process [9], depends on the tool-workpiece interfacial contact pressure, temperature, tooling hardness, surface roughness, tool coating, lubrication and surface chemistry. Among them, surface roughness of the stamping tool is an important factor to compare tooling performance and to explain the variation in formability. The relationship between formability and tool surface roughness has been investigated in the lab and in production [8, 10]. The frictional force was found to increase as the surface roughness increased [10]. Low friction

coefficient can only be obtained if working surface were polished to mirror sheen with roughness less than 1 micro inch Ra [4]. In this study the averaged surface roughness, Ra, was measured before and after stamping to compare die performance and also correlate the binder span test results to surface roughness of the various tooling.

Surface roughness was measured for punch and die at the radii and for binder and die in the flat areas, as shown in [Figure 4](#), before stamping and after forming ~ 500 samples without prelube (baseline tests). Binder span tests with prelube was conducted after the die was cleaned with Emery cloth to remove any material build up on the tooling face and the radii. Surface roughness was measured again after additional 300 tests with lubricants applied. [Figure 5](#) compares the surface roughness of D2, Caldie and Vancron50 before and after stamping. For D2, stamping without lubricant increases the