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Workshop on Forming of Advanced High Strength Steels (AHSS), April 29th, 2009
Columbus, Ohio

Tool Materials, Coatings and Lubricants To Reduce Tool Wear in Forming AHSS

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Edison Welding Institute (EWI)

Outline

- ❑ Background
- ❑ Objectives
- ❑ FEA of forming AHSS example part
- ❑ Twist compression test (TCT)
- ❑ Cup drawing / ironing tests
- ❑ Strip drawing / strip ironing tests
- ❑ Recommendations for future work

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Background

Impact of AHSS on Stamping Tools

- Advanced/Ultra High Strength Steels (A/UHSS) are increasingly used in forming auto body structures to improve vehicle safety and fuel economy
- Forming of A/UHSS generates unfavorable tribological conditions (high pressure and temperature) resulting in failure of commonly used lubricants, leading to galling which significantly reduces tool life and affects the high scrap rate in production

A technical diagram of a car body structure with various parts labeled. The labels include: Front L&R Axle, A pillar, B pillar, C pillar, D pillar, E pillar, F pillar, G pillar, H pillar, I pillar, J pillar, K pillar, L pillar, M pillar, N pillar, O pillar, P pillar, Q pillar, R pillar, S pillar, T pillar, U pillar, V pillar, W pillar, X pillar, Y pillar, Z pillar, AA pillar, AB pillar, AC pillar, AD pillar, AE pillar, AF pillar, AG pillar, AH pillar, AI pillar, AJ pillar, AK pillar, AL pillar, AM pillar, AN pillar, AO pillar, AP pillar, AQ pillar, AR pillar, AS pillar, AT pillar, AU pillar, AV pillar, AW pillar, AX pillar, AY pillar, AZ pillar, BA pillar, BB pillar, BC pillar, BD pillar, BE pillar, BF pillar, BG pillar, BH pillar, BI pillar, BJ pillar, BK pillar, BL pillar, BM pillar, BN pillar, BO pillar, BP pillar, BQ pillar, BR pillar, BS pillar, BT pillar, BU pillar, BV pillar, BW pillar, BX pillar, BY pillar, BZ pillar, CA pillar, CB pillar, CC pillar, CD pillar, CE pillar, CF pillar, CG pillar, CH pillar, CI pillar, CJ pillar, CK pillar, CL pillar, CM pillar, CN pillar, CO pillar, CP pillar, CQ pillar, CR pillar, CS pillar, CT pillar, CU pillar, CV pillar, CW pillar, CX pillar, CY pillar, CZ pillar, DA pillar, DB pillar, DC pillar, DD pillar, DE pillar, DF pillar, DG pillar, DH pillar, DI pillar, DJ pillar, DK pillar, DL pillar, DM pillar, DN pillar, DO pillar, DP pillar, DQ pillar, DR pillar, DS pillar, DT pillar, DU pillar, DV pillar, DW pillar, DX pillar, DY pillar, DZ pillar, EA pillar, EB pillar, EC pillar, ED pillar, EE pillar, EF pillar, EG pillar, EH pillar, EI pillar, EJ pillar, EK pillar, EL pillar, EM pillar, EN pillar, EO pillar, EP pillar, EQ pillar, ER pillar, ES pillar, ET pillar, EU pillar, EV pillar, EW pillar, EX pillar, EY pillar, EZ pillar, FA pillar, FB pillar, FC pillar, FD pillar, FE pillar, FF pillar, FG pillar, FH pillar, FI pillar, FJ pillar, FK pillar, FL pillar, FM pillar, FN pillar, FO pillar, FP pillar, FQ pillar, FR pillar, FS pillar, FT pillar, FU pillar, FV pillar, FW pillar, FX pillar, FY pillar, FZ pillar, GA pillar, GB pillar, GC pillar, GD pillar, GE pillar, GF pillar, GG pillar, GH pillar, GI pillar, GJ pillar, GK pillar, GL pillar, GM pillar, GN pillar, GO pillar, GP pillar, GQ pillar, GR pillar, GS pillar, GT pillar, GU pillar, GV pillar, GW pillar, GX pillar, GY pillar, GZ pillar, HA pillar, HB pillar, HC pillar, HD pillar, HE pillar, HF pillar, HG pillar, HH pillar, HI pillar, HJ pillar, HK pillar, HL pillar, HM pillar, HN pillar, HO pillar, HP pillar, HQ pillar, HR pillar, HS pillar, HT pillar, HU pillar, HV pillar, HW pillar, HX pillar, HY pillar, HZ pillar, IA pillar, IB pillar, IC pillar, ID pillar, IE pillar, IF pillar, IG pillar, IH pillar, II pillar, IJ pillar, IK pillar, IL pillar, IM pillar, IN pillar, IO pillar, IP pillar, IQ pillar, IR pillar, IS pillar, IT pillar, IU pillar, IV pillar, IW pillar, IX pillar, IY pillar, IZ pillar, JA pillar, JB pillar, JC pillar, JD pillar, JE pillar, JF pillar, JG pillar, JH pillar, JI pillar, JJ pillar, JK pillar, JL pillar, JM pillar, JN pillar, JO pillar, JP pillar, JQ pillar, JR pillar, JS pillar, JT pillar, JU pillar, JV pillar, JW pillar, JX pillar, JY pillar, JZ pillar, KA pillar, KB pillar, KC pillar, KD pillar, KE pillar, KF pillar, KG pillar, KH pillar, KI pillar, KJ pillar, KK pillar, KL pillar, KM pillar, KN pillar, KO pillar, KP pillar, KQ pillar, KR pillar, KS pillar, KT pillar, KU pillar, KV pillar, KW pillar, KX pillar, KY pillar, KZ pillar, LA pillar, LB pillar, LC pillar, LD pillar, LE pillar, LF pillar, LG pillar, LH pillar, LI pillar, LJ pillar, LK pillar, LL pillar, LM pillar, LN pillar, LO pillar, LP pillar, LQ pillar, LR pillar, LS pillar, LT pillar, LU pillar, LV pillar, LW pillar, LX pillar, LY pillar, LZ pillar, MA pillar, MB pillar, MC pillar, MD pillar, ME pillar, MF pillar, MG pillar, MH pillar, MI pillar, MJ pillar, MK pillar, ML pillar, MM pillar, MN pillar, MO pillar, MP pillar, MQ pillar, MR pillar, MS pillar, MT pillar, MU pillar, MV pillar, MW pillar, MX pillar, MY pillar, MZ pillar, NA pillar, NB pillar, NC pillar, ND pillar, NE pillar, NF pillar, NG pillar, NH pillar, NI pillar, NJ pillar, NK pillar, NL pillar, NM pillar, NN pillar, NO pillar, NP pillar, NQ pillar, NR pillar, NS pillar, NT pillar, NU pillar, NV pillar, NW pillar, NX pillar, NY pillar, NZ pillar, OA pillar, OB pillar, OC pillar, OD pillar, OE pillar, OF pillar, OG pillar, OH pillar, OI pillar, OJ pillar, OK pillar, OL pillar, OM pillar, ON pillar, OO pillar, OP pillar, OQ pillar, OR pillar, OS pillar, OT pillar, OU pillar, OV pillar, OW pillar, OX pillar, OY pillar, OZ pillar, PA pillar, PB pillar, PC pillar, PD pillar, PE pillar, PF pillar, PG pillar, PH pillar, PI pillar, PJ pillar, PK pillar, PL pillar, PM pillar, PN pillar, PO pillar, PP pillar, PQ pillar, PR pillar, PS pillar, PT pillar, PU pillar, PV pillar, PW pillar, PX pillar, PY pillar, PZ pillar, QA pillar, QB pillar, QC pillar, QD pillar, QE pillar, QF pillar, QG pillar, QH pillar, QI pillar, QJ pillar, QK pillar, QL pillar, QM pillar, QN pillar, QO pillar, QP pillar, QQ pillar, QR pillar, QS pillar, QT pillar, QU pillar, QV pillar, QW pillar, QX pillar, QY pillar, QZ pillar, RA pillar, RB pillar, RC pillar, RD pillar, RE pillar, RF pillar, RG pillar, RH pillar, RI pillar, RJ pillar, RK pillar, RL pillar, RM pillar, RN pillar, RO pillar, RP pillar, RQ pillar, RR pillar, RS pillar, RT pillar, RU pillar, RV pillar, RW pillar, RX pillar, RY pillar, RZ pillar, SA pillar, SB pillar, SC pillar, SD pillar, SE pillar, SF pillar, SG pillar, SH pillar, SI pillar, SJ pillar, SK pillar, SL pillar, SM pillar, SN pillar, SO pillar, SP pillar, SQ pillar, SR pillar, SS pillar, ST pillar, SU pillar, SV pillar, SW pillar, SX pillar, SY pillar, SZ pillar, TA pillar, TB pillar, TC pillar, TD pillar, TE pillar, TF pillar, TG pillar, TH pillar, TI pillar, TJ pillar, TK pillar, TL pillar, TM pillar, TN pillar, TO pillar, TP pillar, TQ pillar, TR pillar, TS pillar, TT pillar, TU pillar, TV pillar, TW pillar, TX pillar, TY pillar, TZ pillar, UA pillar, UB pillar, UC pillar, UD pillar, UE pillar, UF pillar, UG pillar, UH pillar, UI pillar, UJ pillar, UK pillar, UL pillar, UM pillar, UN pillar, UO pillar, UP pillar, UQ pillar, UR pillar, US pillar, UT pillar, UY pillar, UZ pillar, VA pillar, VB pillar, VC pillar, VD pillar, VE pillar, VF pillar, VG pillar, VH pillar, VI pillar, VJ pillar, VK pillar, VL pillar, VM pillar, VN pillar, VO pillar, VP pillar, VQ pillar, VR pillar, VS pillar, VT pillar, VU pillar, VV pillar, VW pillar, VX pillar, VY pillar, VZ pillar, WA pillar, WB pillar, WC pillar, WD pillar, WE pillar, WF pillar, WG pillar, WH pillar, WI pillar, WJ pillar, WK pillar, WL pillar, WM pillar, WN pillar, WO pillar, WP pillar, WQ pillar, WR pillar, WS pillar, WT pillar, WU pillar, WV pillar, WW pillar, WX pillar, WY pillar, WZ pillar, XA pillar, XB pillar, XC pillar, XD pillar, XE pillar, XF pillar, XG pillar, XH pillar, XI pillar, XJ pillar, XK pillar, XL pillar, XM pillar, XN pillar, XO pillar, XP pillar, XQ pillar, XR pillar, XS pillar, XT pillar, XU pillar, XV pillar, XW pillar, XX pillar, XY pillar, XZ pillar, YA pillar, YB pillar, YC pillar, YD pillar, YE pillar, YF pillar, YG pillar, YH pillar, YI pillar, YJ pillar, YK pillar, YL pillar, YM pillar, YN pillar, YO pillar, YP pillar, YQ pillar, YR pillar, YS pillar, YT pillar, YU pillar, YV pillar, YW pillar, YX pillar, YY pillar, YZ pillar, ZA pillar, ZB pillar, ZC pillar, ZD pillar, ZE pillar, ZF pillar, ZG pillar, ZH pillar, ZI pillar, ZJ pillar, ZK pillar, ZL pillar, ZM pillar, ZN pillar, ZO pillar, ZP pillar, ZQ pillar, ZR pillar, ZS pillar, ZT pillar, ZU pillar, ZV pillar, ZW pillar, ZX pillar, ZY pillar, ZZ pillar.

D2 PUNCH - GALLING

[Courtesy for GDIS 2007]






[Courtesy for SSAB]

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Background

Failure Mechanisms in Stamping

5

	Wear	Abrasive-adhesive or mixed	Sliding contact
	Plastic deformation	Exceeding of yield strength locally	Contact pressure
	Chipping	Cracking at cutting edges and surfaces	Fatigue
	Cracking	Total cracking of the tool	Fatigue
	Galling	Material pick up-The same type of mechanism as adhesive wear	Sliding contact

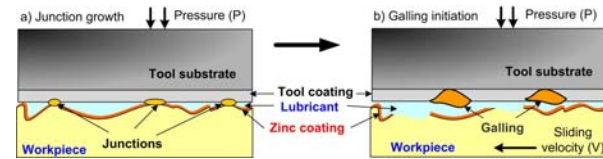
[Courtesy for Uddeholm Steels]

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Background

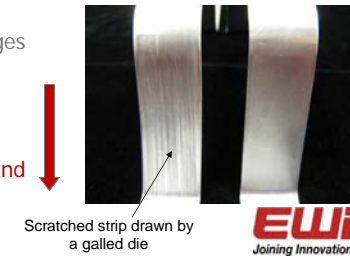
Galling Mechanism in Stamping

6



o Galling can be developed in three stages

- Lubricant film breakdown
- Junction formation and growth
- Material pick-up on the tool surface and scratching the incoming sheet



Scratched strip drawn by a galled die

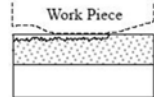
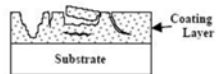
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Background

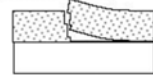
Failure Mechanisms in Tool Coating

7

Coating internal fracture Substrate fracture Wear (adhesive or abrasive)



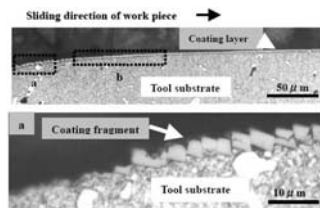
Delamination



Intrusion



[Courtesy of Katagiri et al. 2007]



Cross section of TiC coated tool after 50 sliding with Al_2O_3 in drawing of 780 MPa steel

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Evaluation of Die Coatings and Stamping Lubricants in Forming Galvanized Advanced/Ultra High Strength Steels (A/UHSS)

1. CIRP 2008 published paper - Hyunok Kim, Soosik Han, Qingguang Yan and Taylan Altan
2. IDDRG 2009 paper - Hyunok Kim, Soosik Han, Frank Goodwin, Kyungbo Kim, Taylan Altan

Objectives

9

The overall objective is to develop reliable guidelines to select optimum combination of tribological parameters (i.e. die material, coating and lubricant) in stamping AHSS for automotive structural parts.

The specific objectives are to:

- develop a methodology to investigate the effect of process parameters (interface pressure, temperature and relative sliding speed) on galling during forming galvanized AHSS.
- determine critical pressures and temperatures for the initiation of galling at the tool-workpiece interface for selected lubricants and sheet / tool characteristics (material properties, surface finish and coating).

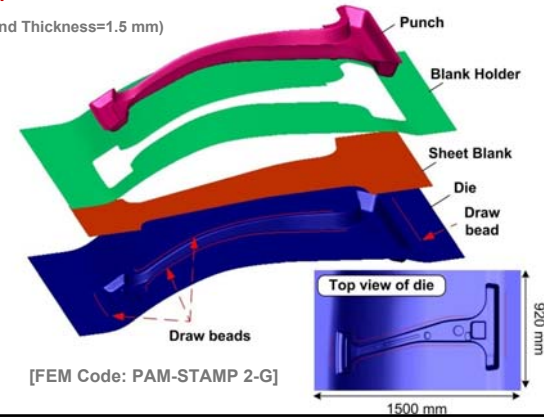


FE Simulation of Forming a B-pillar part: Determination of Critical Interface Conditions

10

B-pillar Simulation Model

(TRIP600 and Thickness=1.5 mm)



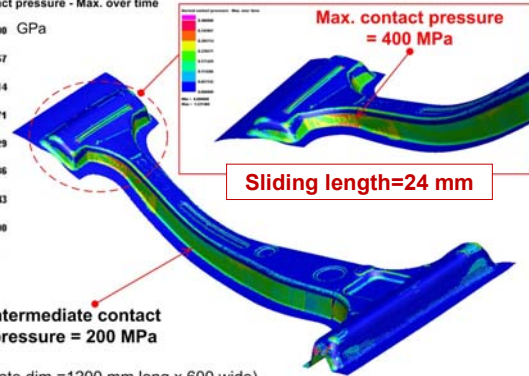
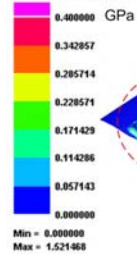
[FEM Code: PAM-STAMP 2-G]



FE Simulation of Forming a B-pillar part: Determination of Critical Interface Conditions

11

Normal contact pressure - Max. over time

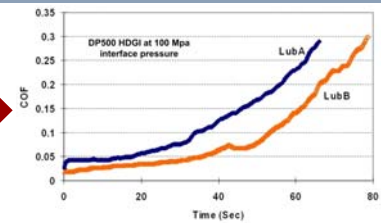
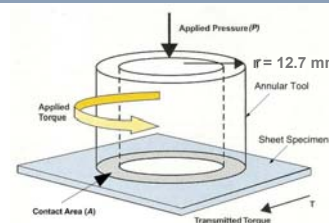


(Approximate dim.=1200 mm long x 600 wide)



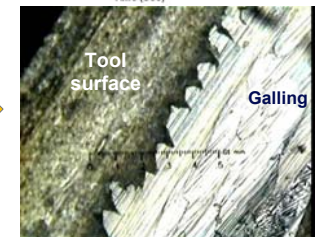
The Twist Compression Test (TCT)

12



Galling 0

Galling 3



The Twist Compression Test (TCT) - Qualitative Evaluation of Galling at 170 MPa

13

Pressure (Mpa)	Sheet Material – Galvanize Coating	Lube	Severity of Galling								
			0	0.5	1	1.5	2	2.5	3		
170	DP600 – Bare (No coating)	A									
		B									
	DP600 – HDGI (Hot Dip Galvanized)	A									
		B									
	DP500 – HDGI (Hot Dip Galvanized)	A									
		B									
	DDS – HDGA (Hot Dip Galvanneal)	A									
		B									
	AKDQ – HDGA (Hot Dip Galvanneal)	A									
		B									

- TCT was conducted for 50, 100 and 170 MPa interface pressures.
- No galling was observed in TCT at 50 MPa, however galling became severe as the contact pressure was increased to 170 MPa.
- DP600 GI with Lub B showed the best effectiveness in reducing galling compared with other sheet materials.



Surface Analyses of Galling

14

a) Galled tool surface caused by GA coating

b) Galling structure caused by GA coating

c) Galled tool surface caused by GI coating

d) Galling structure caused by GI coating

EDS Analyses Results

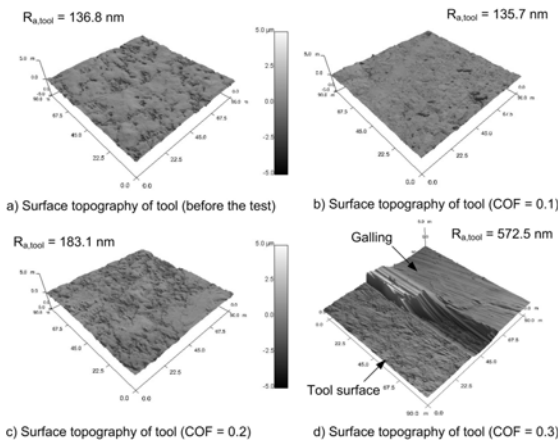
Element	Weight%	Atomic%
C	0.60	2.77
O	4.13	14.31
Fe	14.94	14.83
Zn	80.32	68.09
Totals	100.00	

Element	Weight%	Atomic%
C	0.46	2.34
O	1.45	5.56
Zn	98.09	92.10
Totals	100.00	



Topography Change of Tool Surface as the COF increases

15



Cup Drawing and Ironing Tests

16

Deep drawing test

CL (Center Line)

R_i (Initial radius of blank)

P_i (Blank holder pressure)

τ (Frictional shear stress)

Ironing Test

Stationary ← Punch

Ironing Die

Moving with press ram

Evaluation criteria:

- Max. punch force
- Max. BHF without fracture
- Flange draw-in length
- Flange perimeter

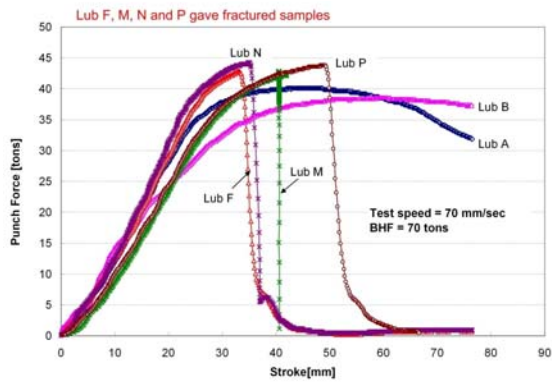
Drawn cup

Ironed cup



Test Results of Cup Drawing

17



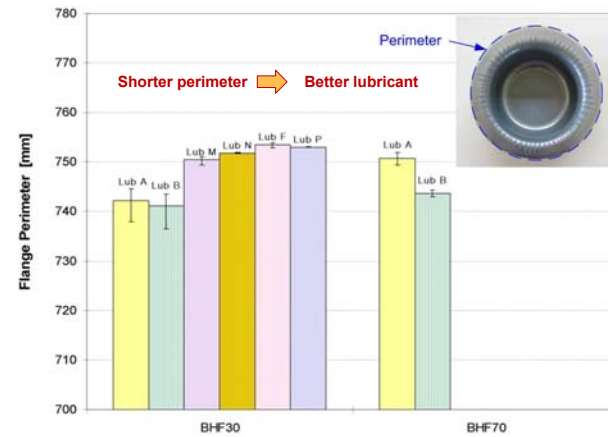
Sheet material: DP590 GA (thickness=1.24 mm)

Die material: D2 tool steel (uncoated and polished to Ra = 0.1 μm)

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Test Results of Cup Drawing

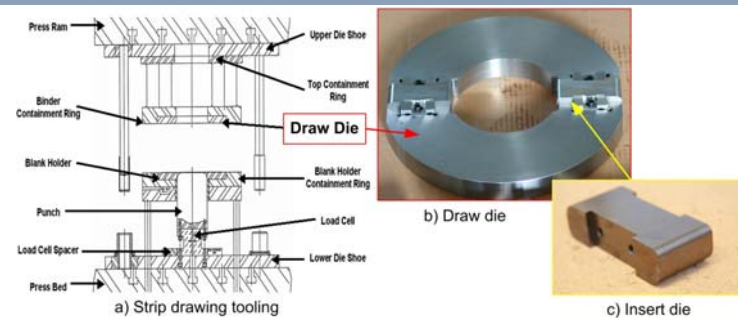
18



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Strip Drawing Test (SDT)

19

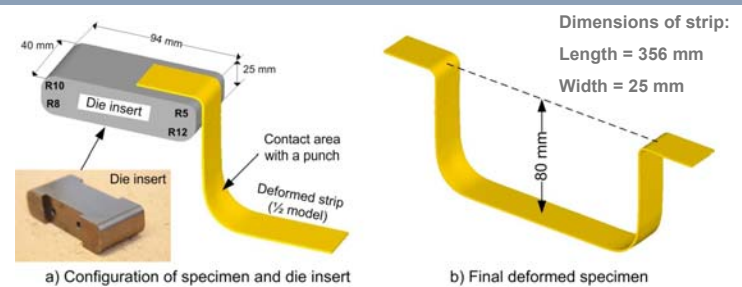


The strip drawing test (SDT) was developed to test the higher grades of AHSS (DP780, TRIP780 and DP980), because the limited formability of these steels makes the deep drawing test difficult to conduct.

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Strip Drawing Test (SDT)

20



With preliminary FE simulations of SDT, four different die radii of 5, 8, 10 and 12 mm were determined to change the contact pressure in the range of 110 ~ 260 MPa without any necking of strip.

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Strip Drawing / Strip Ironing Tests - Die Coating Evaluation Test Conditions

21

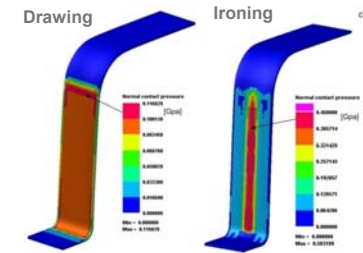
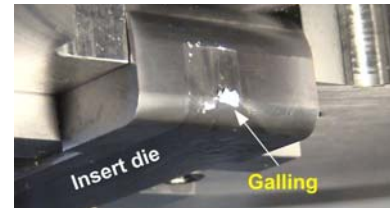
Testing parameters	Descriptions
Sheet materials	DP 980GI (Hot-Dip Galvanized), 1.4 mm (initial thickness)
Tool material (total 4 matls.)	DC53 uncoated ($R_a=0.19 \mu\text{m}$) DC53 PVD coating of CrN ($R_a=0.16 \mu\text{m}$) DC53 PVD coating of TiCN ($R_a=0.34 \mu\text{m}$) DC53 PVD coating of XNP ($R_a=0.25 \mu\text{m}$)
Die corner radius	5 mm
Testing conditions	20 strip drawings ($P=110 \text{ Mpa}$) 20 strip ironings at 14% ironing ratio ($P=450 \text{ Mpa}$)
Tested lubes	Straight oil coated in a range of 2.0~3.0 g/m ²

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Test Results of SDT / SIT

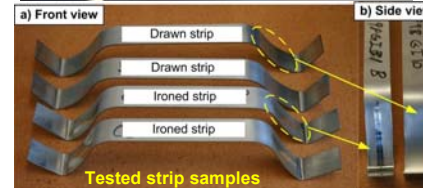
22

Galled die surface after testing 40 specimens
(20 drawings and 20 ironings)



$P_{\text{max}}=116 \text{ MPa}$ $P_{\text{max}}=450 \text{ MPa}$

[FEM Code: PAM-STAMP 2G]

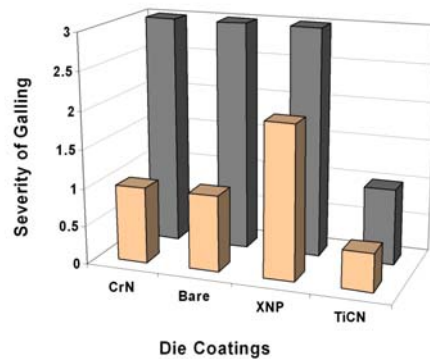


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Strip Drawing and Strip Ironing Tests - Ranking of Galling after SDT/SIT

23

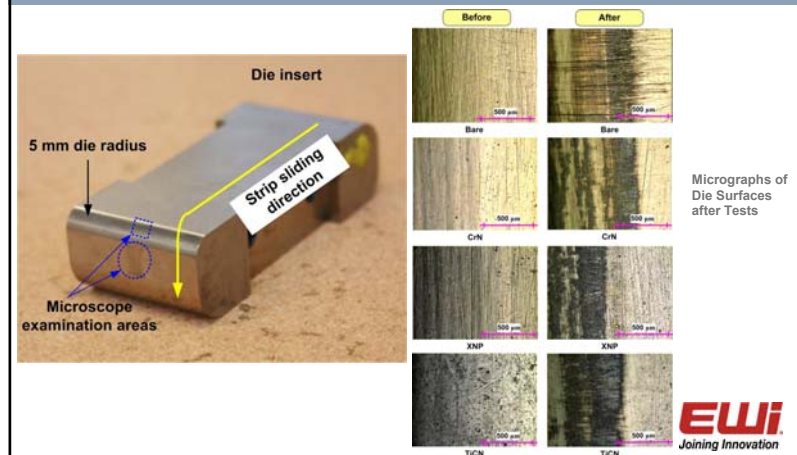
■ Galling after drawing 20 samples ■ Galling after ironing 20 samples



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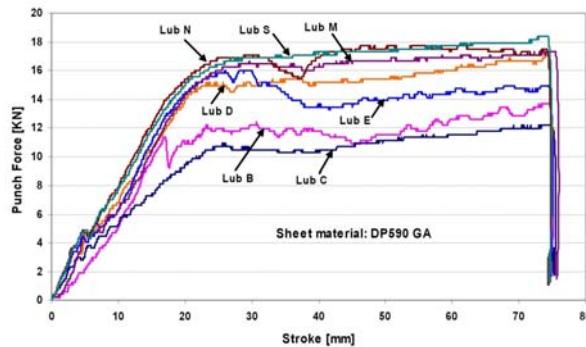
Examinations of Tool Surface

24



Strip Drawing Test (SDT) - Load vs. Stroke Curves

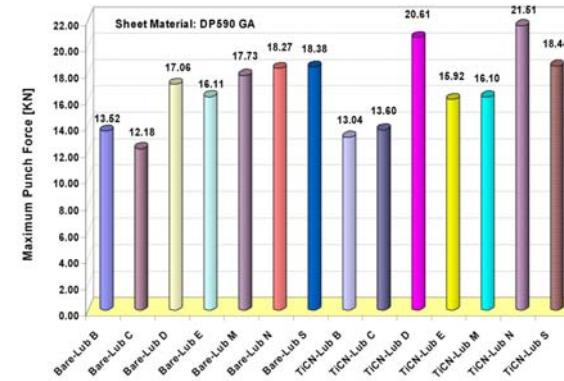
25



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Strip Drawing Test (SDT) - Maximum Punch Force from SDT

26



A smaller punch force indicates better lubricants !

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Recommendations for Future Work

1. Laser hardening for **stamping tools and dies**
2. Laser cladding for **stamping tools and dies**
3. Advanced simulation model for **tool wear**

Advantages of Laser Hardening & Cladding Technologies

28

- Saving of time and costs by selective hardening
- Minimal distortion due to low thermal load
- No need for additional quenching media (i.e. water)
- Reducing maintenance time of worn-out tools
- High quality process control with robots and CAD/CAM interface
- High degree of flexibility (hardening/cladding process control, re-cladding and easiness to access complex geometry)

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Laser Hardening for Stamping Tools and Dies

29



Laser hardening with Laser and robot for a car body deep drawing tool

[Courtesy of LBBZ GmbH]



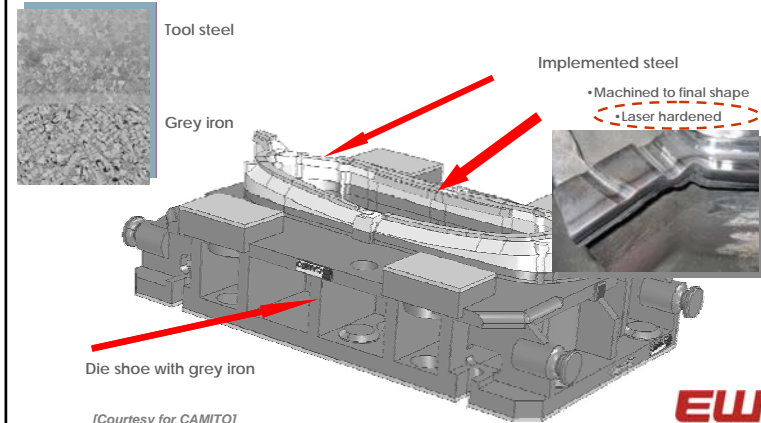
Laser hardening of cutting edges and complicate geometry

[Courtesy of hwg-inductionheat]



Laser Hardened Die Surfaces

30



[Courtesy for CAMITO]

Laser Hardening of Trimming Tools and Dies

31

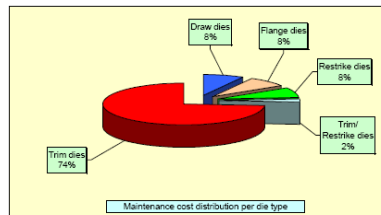


Figure 1. Annual maintenance cost distribution per die type.

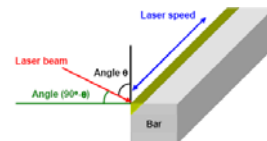
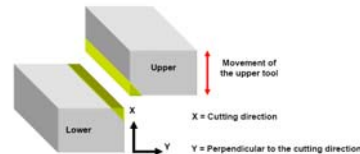
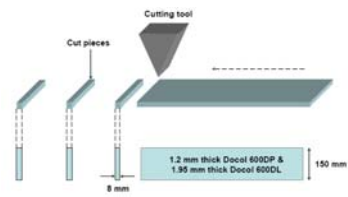


Figure 2. Schematic illustration of the laser speed and laser beam angle.

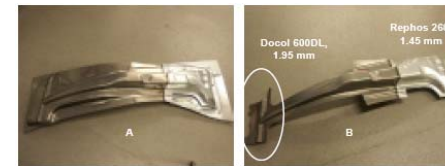


[Courtesy for Asnafi et al. 2004]

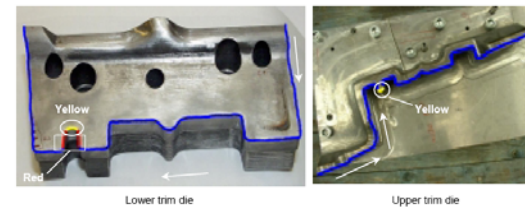


Laser Hardening of Trimming Tools and Dies

32



The B-pillar before (A) and after (B) trimming a tailor-welded blank of Docol 600DL (1.95 mm thickness) and Rephos 260 (1.45 mm) [Courtesy for Asnafi et al. 2004]

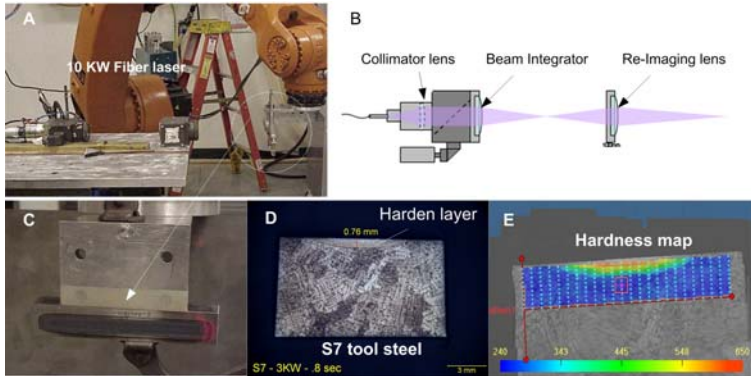


Laser surface hardening of the new trip die for V70 B-pillar (The arrow indicates the hardening direction)



Laser Hardening Technology - EWI

33

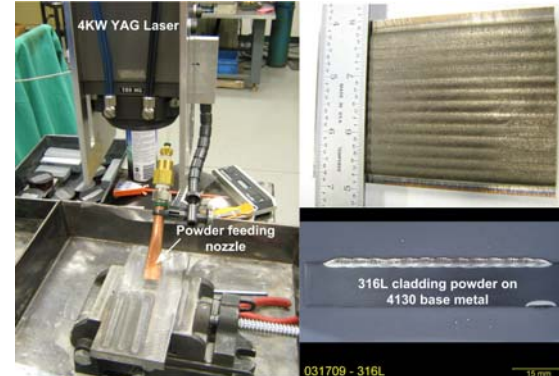


The hardness of hardened layer is about 200-300% higher than the tool metal.



Laser Cladding Technology - EWI

34



Various powder materials (Stellite 6, Inconel 718 and 316 L) were used with 4130 base metal.



Laser Cladding Technology - EWI

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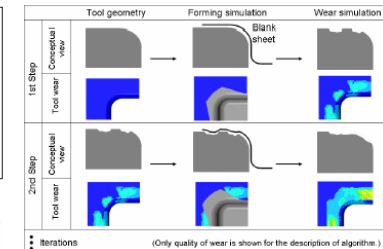
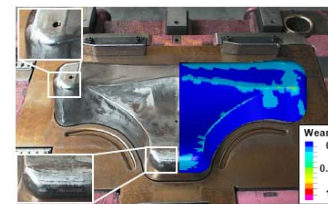
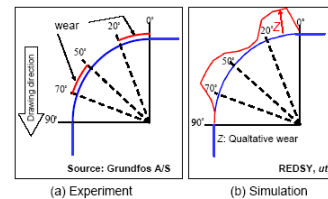


The hardness of welded coating is about 300% higher than the base metal.



Advanced Simulation Models for Tool Wear

36



$$Z = \int p v dt$$

Wear work (Z) = fun (pressure and sliding velocity)

$$W_u = \frac{K}{H} Z$$

W_u = wear volume, K= a material constant, H= surface hardness

[Courtesy for Hoffmann et al., CIRP 2005]





Questions

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