Hot Stamping Experience and Tech Tour

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Charleston, SC

Root-Cause Analysis of Hot Stamping Defects... and Best Practices for Prevention

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American Tooling Center, Diversified Tooling Group

PRODUCED BY MetalForming Magazine PMA PRECISION METALFORMING ASSOCIATION

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Superior Cam

- Prototype – Class A
  - Cold Stamp Body Panels
  - Hot Stamp Structural Parts
- Low Volume Stamping
  - Cold Stamp Body Panels
  - Large Bed Side x Side
  - 500T to 3500T Presses
  - Large Format Laser Cut
  - Extensive Aluminum
- Low Volume Assembly
  - Manual RSW, Rivet, Bond
  - Robotic RSW, Bond, Hem

Midland Design

- Engineering
  - Autoform
  - Pamstamp
  - Work NC
  - Cenit Laser, Robotic Weld, Bond, and Hem
- Die Design
  - Catia V5/V6
  - Siemens NX
  - Blank Dies
  - Large Tandem, Transfer Dies
  - Hot Stamp Dies

Bespro Pattern

- Foundry Tools
  - Polystyrene Foam
    - Single Pour
    - Multiple Pour
    - Lost Foam or Cope & Drag
    - Stamping Dies
    - Press Risers
    - Marine, Oil & Gas
    - Water, Mining
  - Wood & Composite Patterns
- Check, Laser Cut, CMM Fixtures
- Hem Anvils
- Weld & Bond Assembly Fixtures

American Tooling Center

- Tool and Die - Class A
  - Cold Stamp Body Panels
  - Hot Stamp Structural Parts
- Low Volume Stamping
  - Cold Stamp Body Panels
  - Hot Stamp Structural Parts
  - (2) 180” Tandem Press Lines
  - (2) 120” Tandem Press Lines
  - (1) Hot Stamp Press & Laser
- Defense, Mining, Oil & Gas
  - Heavy Fabrication
  - Large Shot Blast, CARC Paint
  - Heavy CNC Machining
  - Heavy & Large Assemblies
  - Complete Assemblies

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Michigan Sites: Grass Lake, Jackson, Lansing, Madison Hts.

Superior Cam, Midland Design, Bespro Pattern - Madison Hts. – 235,000 sq. ft.


ATC Grass Lake – 165,000 sq. ft.


ATC Jackson – 125,000 sq. ft.


ATC Lansing – 270,000 sq. ft.

425 Highly Skilled Workers
49 Large Stamping Presses
39 Large CNC Machines/Cells
775,000 Sq. Ft. – (13) Facilities

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ATC Grass Lake – Automated Hot Stamp Press Cell

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Root-Cause Analysis of Hot Stamping Defects… and Best Practices for Prevention

- How Do Hot Stamped Part Defects Compare to Cold Stamped?
- What Unique Challenges Does the Hot Stamp Process Have? How Are They Managed?
- Can the Heat Treatment Process Impact Part Geometry and Tolerances, or Secondary Operations?
- How Do You Determine the Root Cause of a Hot Stamped Defect?
- What Are the Best Ways to Control Defects Once Root Causes Are Identified and Correlated to Hot Stamp Process Variables?

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How Do Hot Stamped Part Defects Compare to Cold Stamped?

Quench Rate Soft Spots

- Hot Stamping Combines Stamping and Heat Treatment (Press Hardening)
- Heat Treatment Uses Austenitizing Furnaces and Dry Press Quench
  - Steel Mill Supplied Incoming Material is Ferritic & Pearlitic Microstructure – 600 MPa
  - Austenitizing Transforms Ferritic-Pearlitic Microstructures to Austenitic – 200 MPa
  - Quenching Transforms Austenitic Microstructures to Martensitic – 1500 MPa
- Quench Rates (Time Taken To Cool) Must Exceed Material Specifications To Transform Austenitic Microstructure to Martensitic Microstructure
- Failure to Achieve Required Quench Rates Can Create “Soft Spots” Due To Bainite Formations and “Autotempered” Martensite/Carbides
- If Soft Spots Are In Critical Areas Where Strength Is Needed In A Crash Event, the Part May Not Provide Expected Occupant Protection

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How Do Hot Stamped Part Defects Compare to Cold Stamped?

Quench Rate Soft Spots

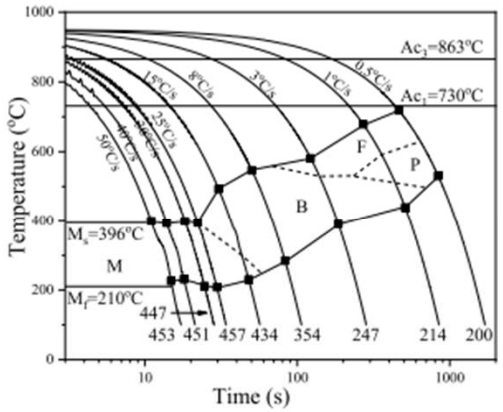


Figure 5. The CCT diagram of hot-stamped 22MnB5 steel.

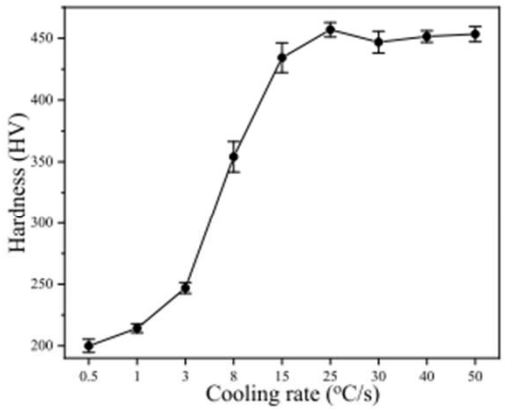
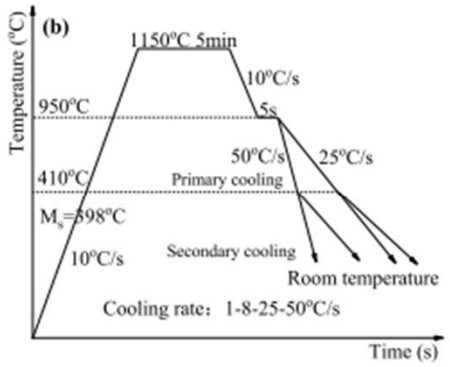


Figure 4. Vickers hardness of the samples with different continuous cooling rates.



1. Effect of Cooling Path on Microstructures and Hardness of Hot-Stamped Steel
https://www.researchgate.net/publication/347790368
Yaowen Xu, Qiumei Ji, Gengwei Yang, Siqian Bao, Gang Zhao, Xiaodong Miao and Xinping Mao
The State Key Laboratory of Refractories and Metallurgy, Wuhan University of Science and Technology, Wuhan 430081, China

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How Do Hot Stamped Part Defects Compare to Cold Stamped?

Quench Rate Soft Spots

- Heat Treatment Has No Moving Parts To See, Control and Inspect
- Cold Stamped Part Quality Control Is Usually Focused On Visible Characteristics - Tool Surface, Forming Velocities, Geometry, Trims, Holes
- Quench Rates and Time Are the Primary Hot Stamp Variables to Control
- To Accomplish Control, the Part Must Be Completely Formed To Bottom of Press Stroke Prior to Phase Transformation from Austenite to Martensite
- This Requires High Blank Temperatures and Fast Forming Process
  - High Blank Temperatures Require Quick Transfer From Furnace
  - Fast Forming Process Requires Fast Slide Close, Pad Set, Form to Bottom

How Do Hot Stamped Part Defects Compare to Cold Stamped?

Quench Rate Soft Spots

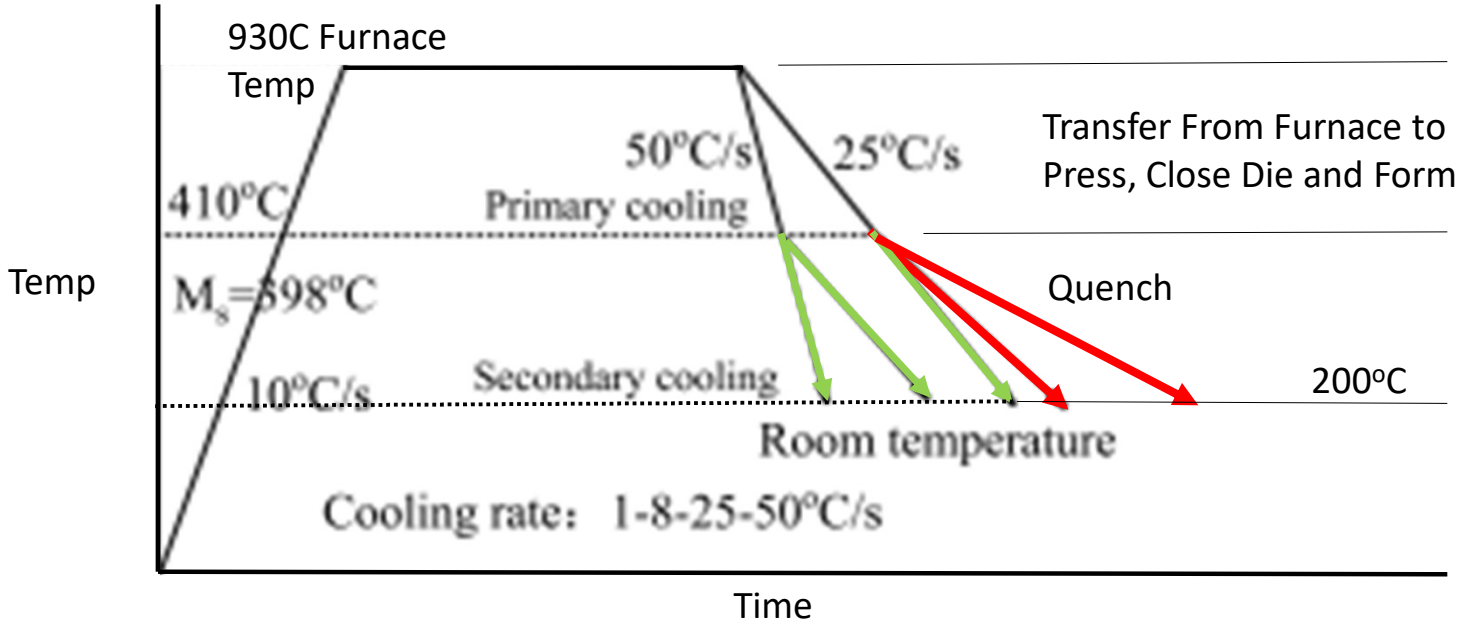
Fast Furnace Unloading, Transfer, Press Loading

Rapid Press Closing

Quick Pressure Buildup and Forming To Bottom

How Do Hot Stamped Part Defects Compare to Cold Stamped?

Quench Rate Soft Spots



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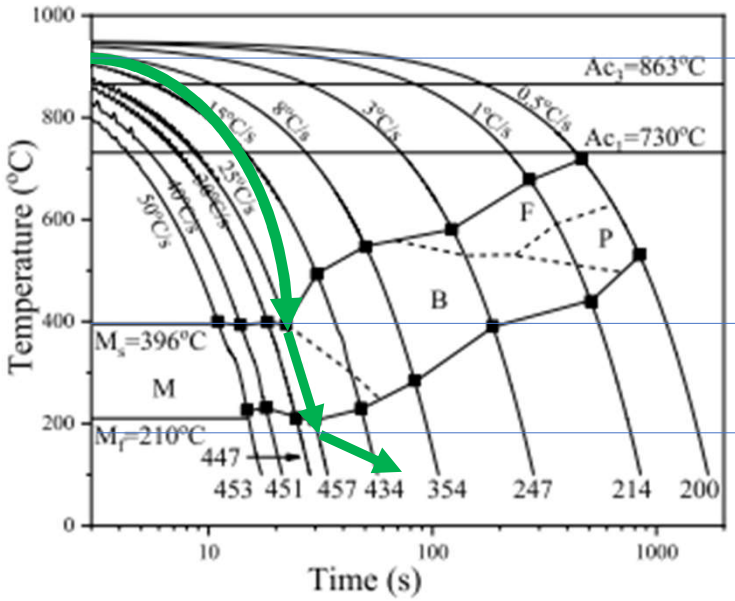

Figure 5. The CCT diagram of hot-stamped 22MnB5 steel.

Transfer From Furnace to Press, Close Die and Form

Quench Below 200 C

Air Quench Until Racked

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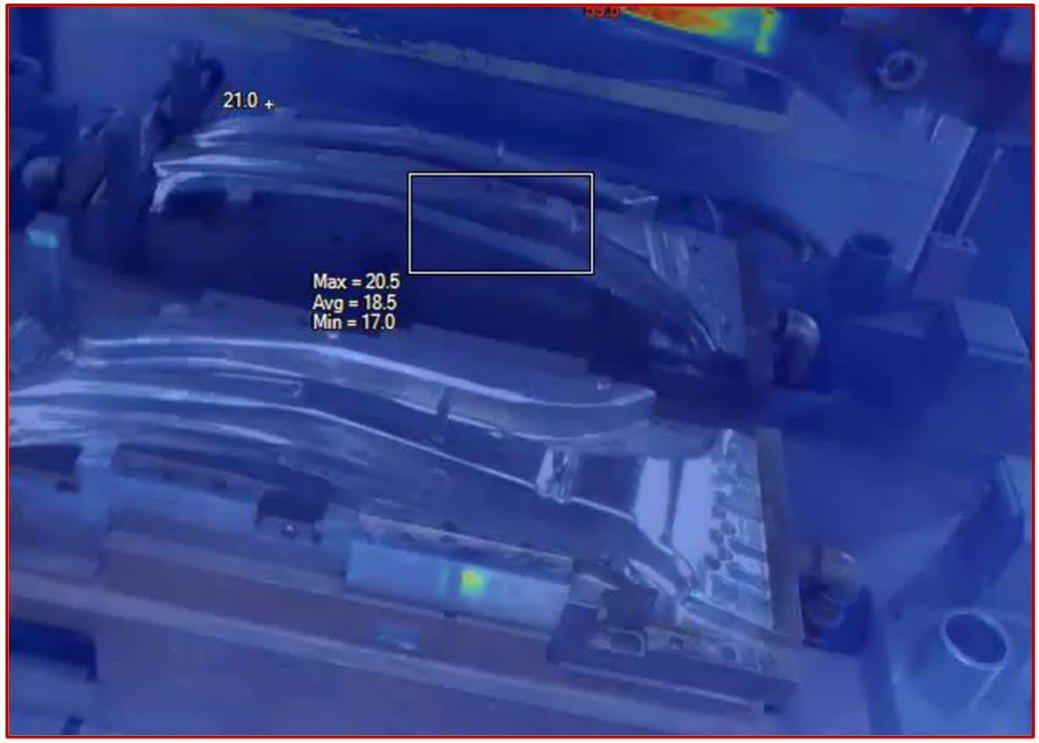

Excessive Side Wall Part Temp and Die Temp

To Learn Root Cause, Need To Inspect Die Punch and Cavity For Eroded Side Walls or Blocked Water Channels

Parts Need To Be Quarantined And Inspected For Soft Side Walls In These Hot Areas

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How Do Hot Stamped Part Defects Compare to Cold Stamped?

AlSi Coatings

- Both Cold and Hot Stamped Part Coatings Must Provide Required Corrosion Protection and Weldability/Paintability
- The Majority of Hot Stamped Parts Use 22MnB5 Boron Steel With An Aluminum Silicate Coating That Protects Against Scale and Decarburization During Heating, and Also Provides Corrosion Protection
- Extreme Furnace “Soak” Times and Temps Can Create Surface Conditions With Aluminum Silicate Coatings Which May Reduce Corrosion Prevention and Weldability/Paintability, Process Limits For Furnace Temperatures and Soak Times Control the Coating Growth
- Inter Diffusion Layer (IDL) Thickness Growth During Austenitization May Need To Be Controlled To Prevent Undesirable IDL Characteristics

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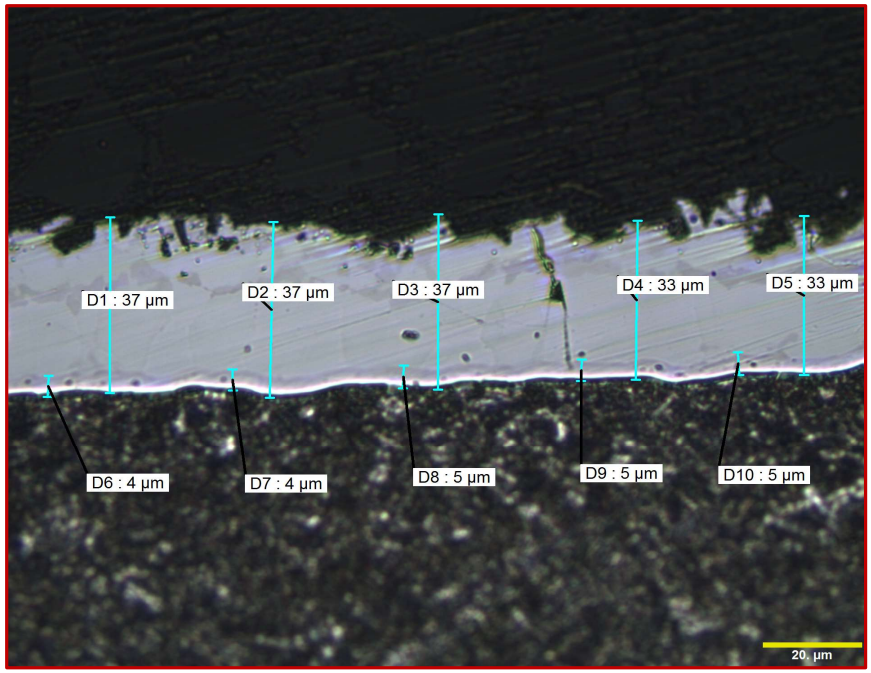
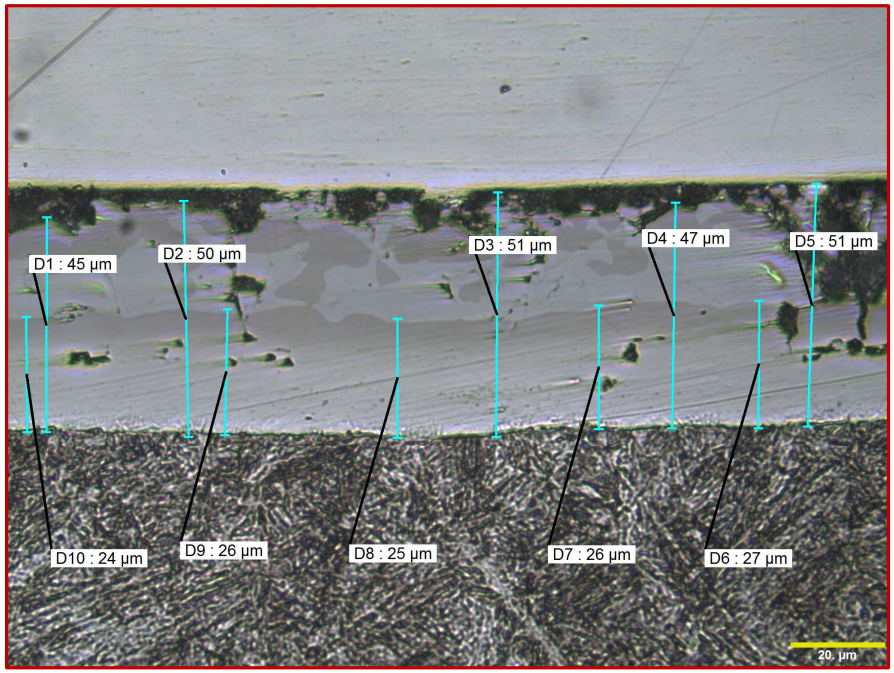
AlSi Coatings



Nominal Furnace Temp and Minimal Soak Time - IDL Does Not Grow, Remains at 4 to 5 micron



High Furnace Temp and Excessive Soak Time Increases IDL Thickness to 24 to 27 micron

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What Unique Challenges Does the Hot Stamp Process Have? How Are They Managed? Gap Pads

- Heated 22MnB5 Has Very High Coefficient of Friction (40-45%), Material is Very Soft and Pliable (100-200 MPa), Similar To a Stick Of Chewing Gum
- The Soft Sticky Material Tends to Wrinkle, These Cannot Be Controlled With Draw Beads/Pressure Pads Like Cold Stamp (friction varies, material is too soft)
- Wrinkle Control For Hot Stamped Steel Uses Gapped Pads & No Draw Beads
  - Crash Form When Possible Without Wrinkling (open ended rails)
  - Crash Form + Pressure Pad for Blank Control (for developed trim on open ended rails)
  - Crash Form + Local Gap Pad For Wrinkle Control (better material utilization than full pads)
  - Full Gap Pad For Best Wrinkle Control
- Gap Pads Allow Minor Wrinkles, Ironed Out At Bottom, Allow Good Matl. Flow
- If Form Is Too Slow, Wrinkles Can Harden, Causing Sidewall Thinning/Splits

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What Unique Challenges Does the Hot Stamp Process Have? How Are They Managed? Gap Pads

- Gap Pads Use Conventional Nitrogen Cylinder Actuated Force Pads, But Separate Higher Force Cylinders Prevent the “Gapped” Pad From Touching the Blank Until the End Of Stroke
- This Holds the Gap Pad Slightly Off the Surface Of the Blank, Not Touching the Blank Until the Separate Forming Steels Start To Form
- As the Part Starts To Form, Wrinkles Are Developed Which Contact the Gap Pad, Creating Friction To Control Material Flow Into the Cavity.
- When the Die Is Nearly Bottomed, the Gap Pad Slide Bottoms Out And the Moving Die Overcomes the Gap Pad Force, Ironing Out Wrinkles

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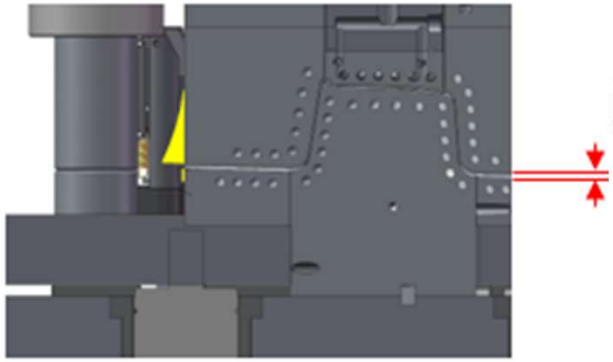

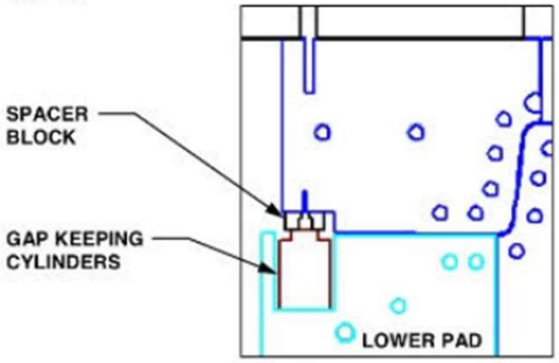

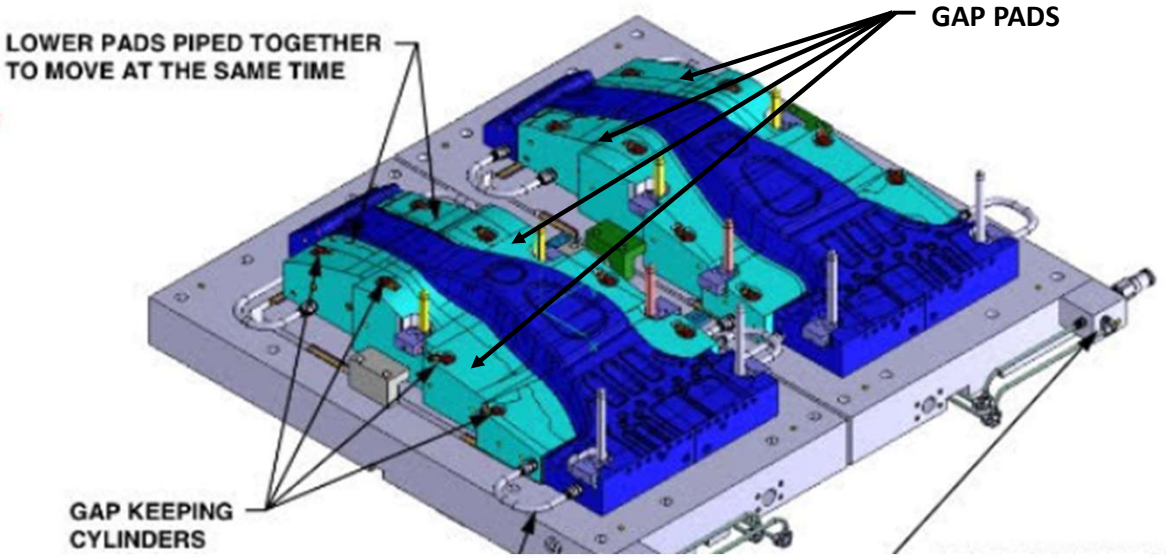

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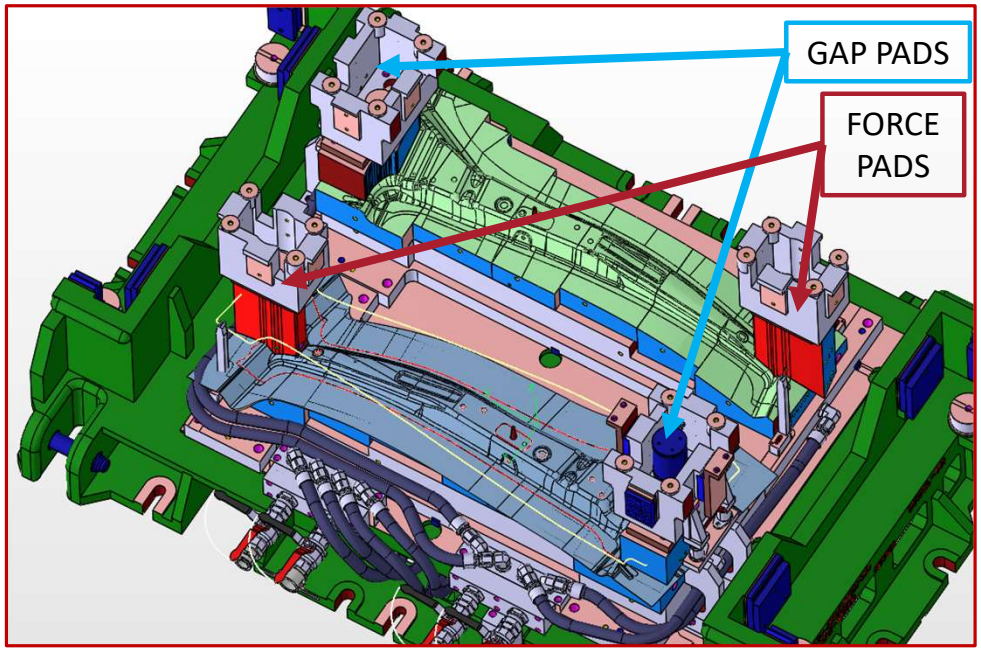
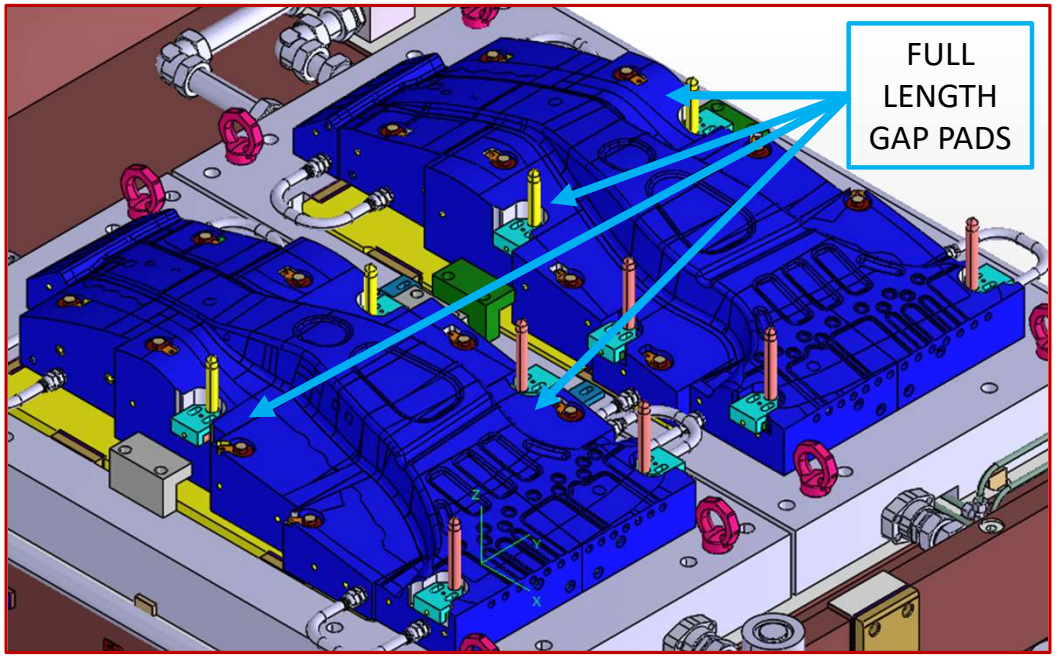


LOCAL FORCE PADS AND GAP PADS REDUCE CONTROL BUT SAVE ON PART MATERIAL COST



FULL GAP PADS PROVIDE THE MOST CONTROL BUT REQUIRE ADDED MATERIAL

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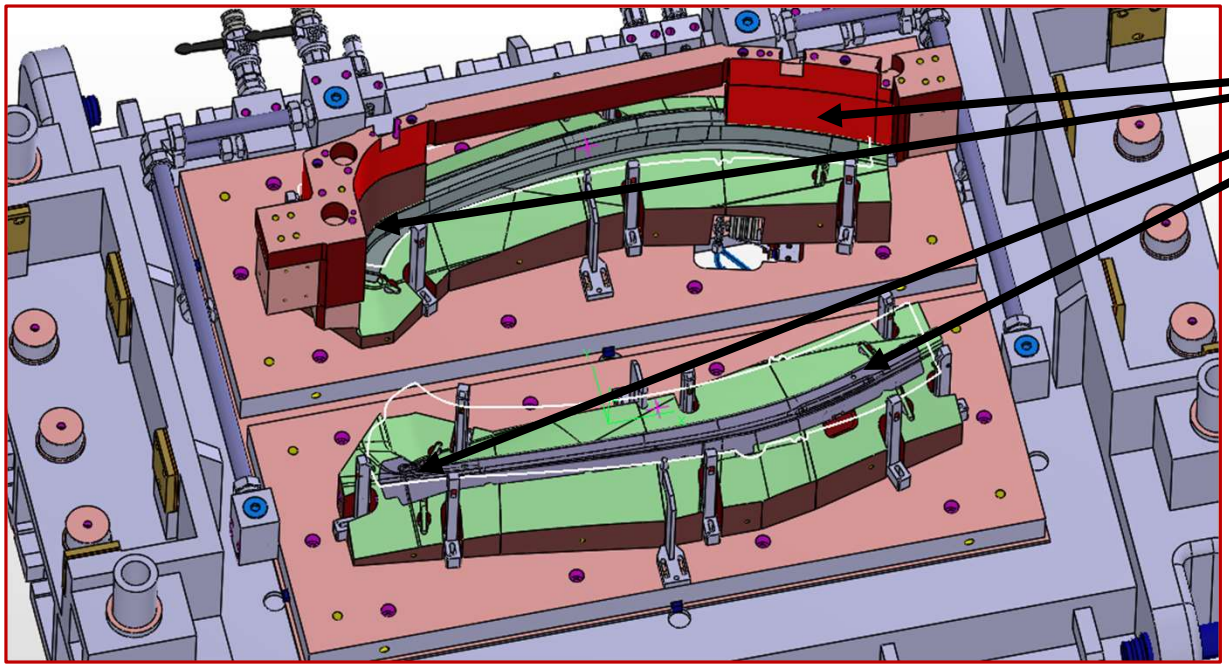

LOCAL FORCE PADS REQUIRED ON CRITICAL PARTS SUBJECT TO TWIST, OR TO FORM EMBOSSMENTS PRIOR TO FORMING BALANCE OF PART

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What Unique Challenges Does the Hot Stamp Process Have? How Are They Managed? Secondary Datums

- Hot Stamped Steel Parts Typically Are Too Hard To Trim or Pierce In Secondary Stamping Dies
- Secondary Laser Cutting Is Used To Add Holes and Trim Addenda That Was Needed For Part Forming, Or Excess Material Used To Compensate For Variation In Draw Shell Edges
- Datums Are Needed To Locate the Draw Shell When Laser Trimming
- The Datums Can Use the General Shape Of the Draw Shell, Or Can Use Features Such As Holes/Embossments Stamped Into Blanks Prior To Forming, Or Holes/Embossments That Are Hot Stamped Into Sacrificial Material On the Draw Shell

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What Unique Challenges Does the Hot Stamp Process Have? How Are They Managed? Secondary Datums

- Hot Pierce Of PLP Hole(s) Typically Is Performed At Bottom Of Stroke Before the Surface Hardens Using Hydraulic Cylinders
- Holes Must Be On Flat Surface To Avoid Side Loads
- Hot Pierced PLP Holes Are Often Put Inside Slug Of A Larger Hole/Slot Or Into Addenda Being Trimmed Off, Or Can Be In Part
- Slug Removal Is Critical, Punch Must Retract Before Hole Shrinks
- Hot Form Of Sacrificial Embossments Typically Is Done At Start Of Forming, And Used During Forming To Control Blank Position
- Embossments Provide Better Part Control Than Holes In Blank

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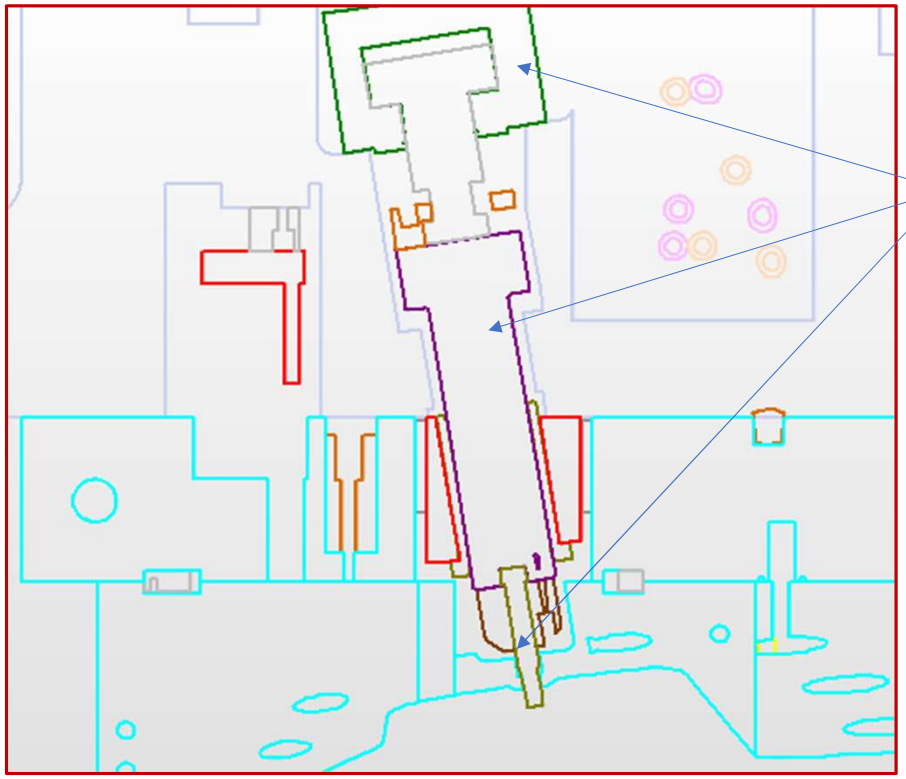
What Unique Challenges Does the Hot Stamp Process Have? How Are They Managed? Secondary Datums



Hydraulic Cylinder Actuated Yoke Drives Punch Holder Guided By Special Bushing Carrying Punch With Slug Stripper, Normal To Part Surface

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Can the Heat Treatment Process Impact Part Geometry and Tolerances, or Secondary Operations?

- Austenitizing Relieves Mill Stresses, But Expands/Contracts Material, Introducing New Residual Stresses Into Part That Can Release During Laser Trim or Paint Bake, Causing Distortion
- Springback Very Low Compared to Cold Stamp AHSS or UHSS
- Once Part Has Quenched To Full Martensitic Microstructure (Below 200 C), Part Can Be Removed From Die, Provided Subsequent Non-Fixtured Air Quench Does Not Produce Excessive Form Variation
- Critical Shape Parts May Need An Assessment of Secondary Residual Stress Impact On Geometry From Laser Cutting, Welding, Paint Bake

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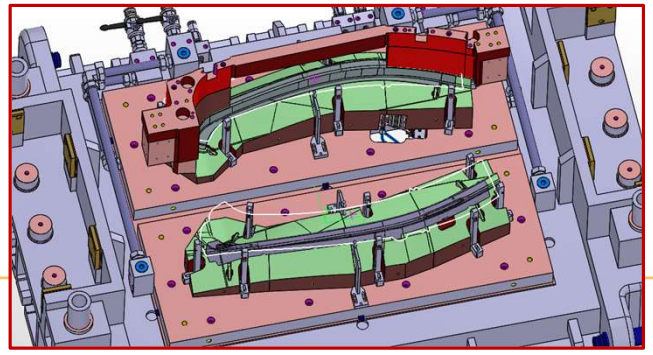
Can the Heat Treatment Process Impact Part Geometry and Tolerances, or Secondary Operations?

- Residual Stresses Are Caused When the Part Shrinks During Quenching
- Certain Shapes Of Parts Will Cause More Stresses Than Others
- Long Parts Locked At Ends In Tool Will Impart More Strains Than Open Ended Cross Sections Which Allow the Part To Shrink
- Primary Methods of Resolving Stresses Are Morphing Tool Surfaces To Compensate For Twist, Change Product Shape To Allow Shrinkage Without Stresses, Or Form All Locking Features First Prior To Forming Part



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How Do You Determine the Root Cause of a Hot Stamped Defect?

- Finding the Root Cause Of A Hot Stamped Part Defect Can Be More Challenging Than For Cold Stamped Due to the Added Complexities Of Heat Treatment, Sticky Material, And Extremely Shaped Hot Stamp Product Designs
- Using a Typical Fishbone Diagram To Identify Process Steps Which Could Contribute to the Defect Is Usually Helpful.
- Comparing Press Cell Datalogs Against Master Process Variables Is Normally One Of the Best Places To Start, Assuming Data Collection Is Monitoring the Important Variables In the Process (Temps, Times, Forces, Speeds)

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How Do You Determine the Root Cause of a Hot Stamped Defect?

- Infrared Thermal Checks Of Blanks, Parts, Die Upper/Lower, Water Flows Is Also A Great Place To Start
- Swapping Out Material Heats Usually Helps Rule Out Material Issues
- A Pareto Chart Is Absolutely Critical To Help Manage Defects With Causes and Effects, for example:
  - Progressively Worse Hot Spots Over Time Indicate Slow Quench Rates Likely Caused By Gradual Erosion Or Buildup Of Material Coatings In Die
  - Suddenly Occuring Hot Spots Indicate Die Failure, Possibly Double Blank Hit, Plugged Water Line?
  - Troubles Initially Seen After Die Set Often Related To Improper Setups Or Die Conditions Not Being Corrected After the Last Production Run

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What Are the Best Ways to Control Defects Once Root Causes Are Correlated to Hot Stamp Process Variables?

- Datalogging Should Trigger Warnings When Data Exceeds Threshold Indicating A Significant Process Change Has Happened, and Alarms Which Shut Down Operation When Absolute Limits Are Exceeded
- Data Collection and Analysis and Parametric Models Can Help Predict Failures, Especially With Good Tool and Furnace Monitoring

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Root-Cause Analysis of Hot Stamping Defects… and Best Practices for Prevention

1. Manage Hot Spots In the Part and Tooling, Inspect Parts Frequently To Insure They Are Quenching Quickly Enough To Obtain Full Martensite
2. Avoid Excessive Furnace Temperatures and Times, Inspect Coatings Frequently To Insure Parts Are Weldable, Paintable, And Have Good Corrosion Protection
3. Manage Excessive Thinning and Thickening With Controlled Material Flow In Tools (Pad Selection Can Be Critical)
4. Dimensional Variation Control Is Highly Dependent on Forming Tool and Laser Cutting, Use Best Practice For Material Control in Form, Datum and Clamp Strategy In Cutting
5. Minimize Residual Stresses In Parts That Cause Issues In Assembly or Paint
6. Collect and Manage Data, Establish Simple Explanations of Defect Causes/Effects, Analyze Data and Consider Parametric Modeling of Process

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Thank You!

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