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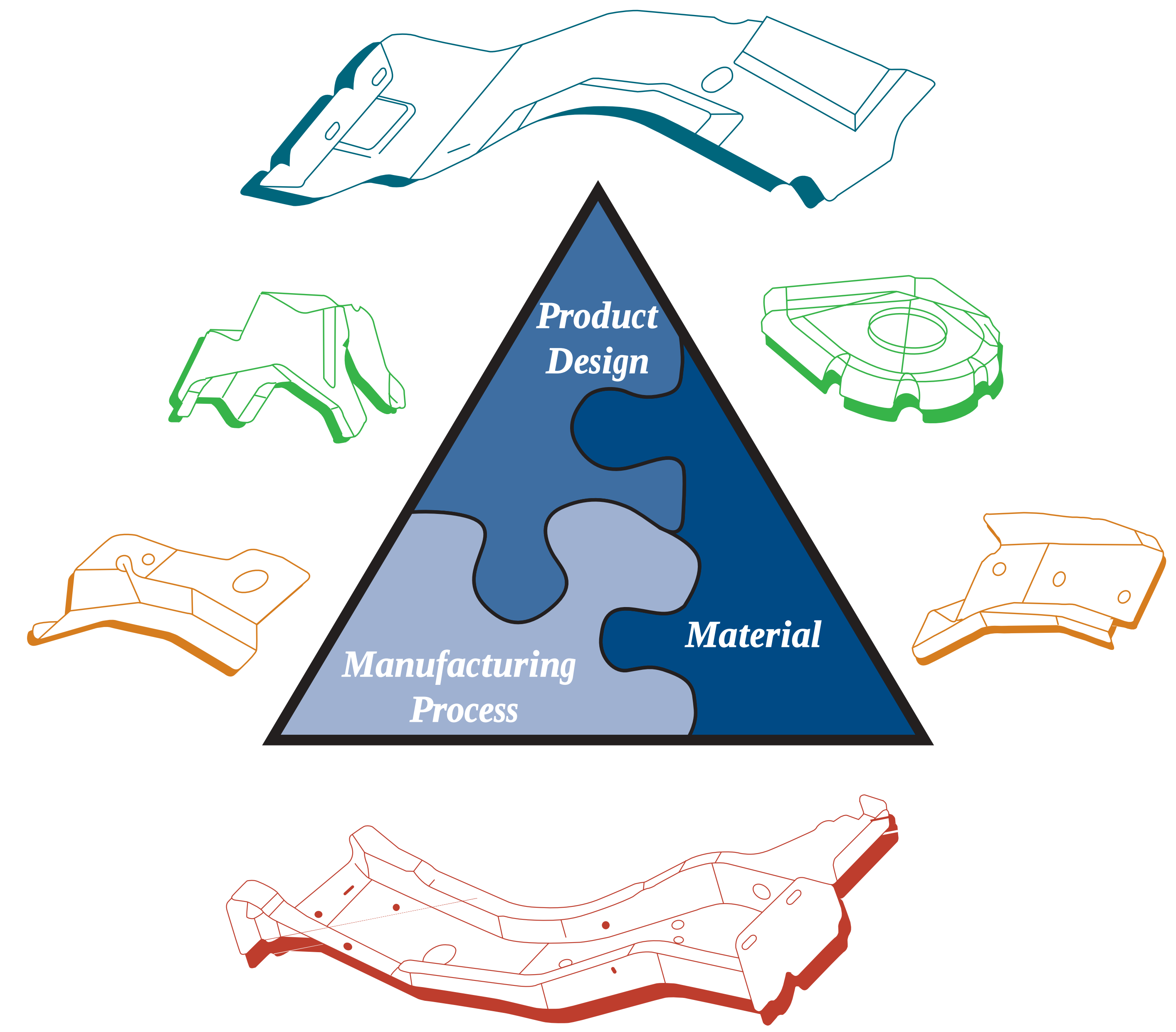

High Strength Steel Stamping Design Manual

Collaborative product - process development guidelines for high strength steel stampings.

Auto/Steel Partnership

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Introduction

This manual is intended as a practical guide for automotive material engineers, product designers and die process planners when using high strength steels for new body-in-white applications. The guidelines herein are for normal stamping operations only, with no reference to roll forming or warm forming processes. High strength steels in this context are defined as those in the range of 205 to 420 MPa yield strength (30-60 KSI). Applications for these steels and other advanced high strength steels will increase as automakers worldwide look for cost effective materials for weight reduction and improved crash energy management.

Material characteristics and die process capabilities must be understood by the product designers in order to assure practical HSS part designs. Many of the design features needed to provide ease of formability and dimensional stability in HSS stampings can be incorporated if known early on by product designers. A collaborative relationship with the die process planners must be realized at the outset of the development program.

The die process planner must communicate the required design changes to product design and plan for a stamping process that controls buckling, springback, sidewall curl and other distortions. A process that works for mild steel will not always produce acceptable results for HSS. The new steels may require new stamping processes. This manual briefly covers some of these advanced die process concepts for HSS.

The manual also provides some guidelines for die design, die construction and die tryout. In the past, die tryout has often been left with the task of trying to make an acceptable HSS part from an impossible combination of material, part design and die process. The result is either an unsatisfactory part or a lower strength material substitution, and in the process, much cost and lead-time is added to the program.

Executive Summary

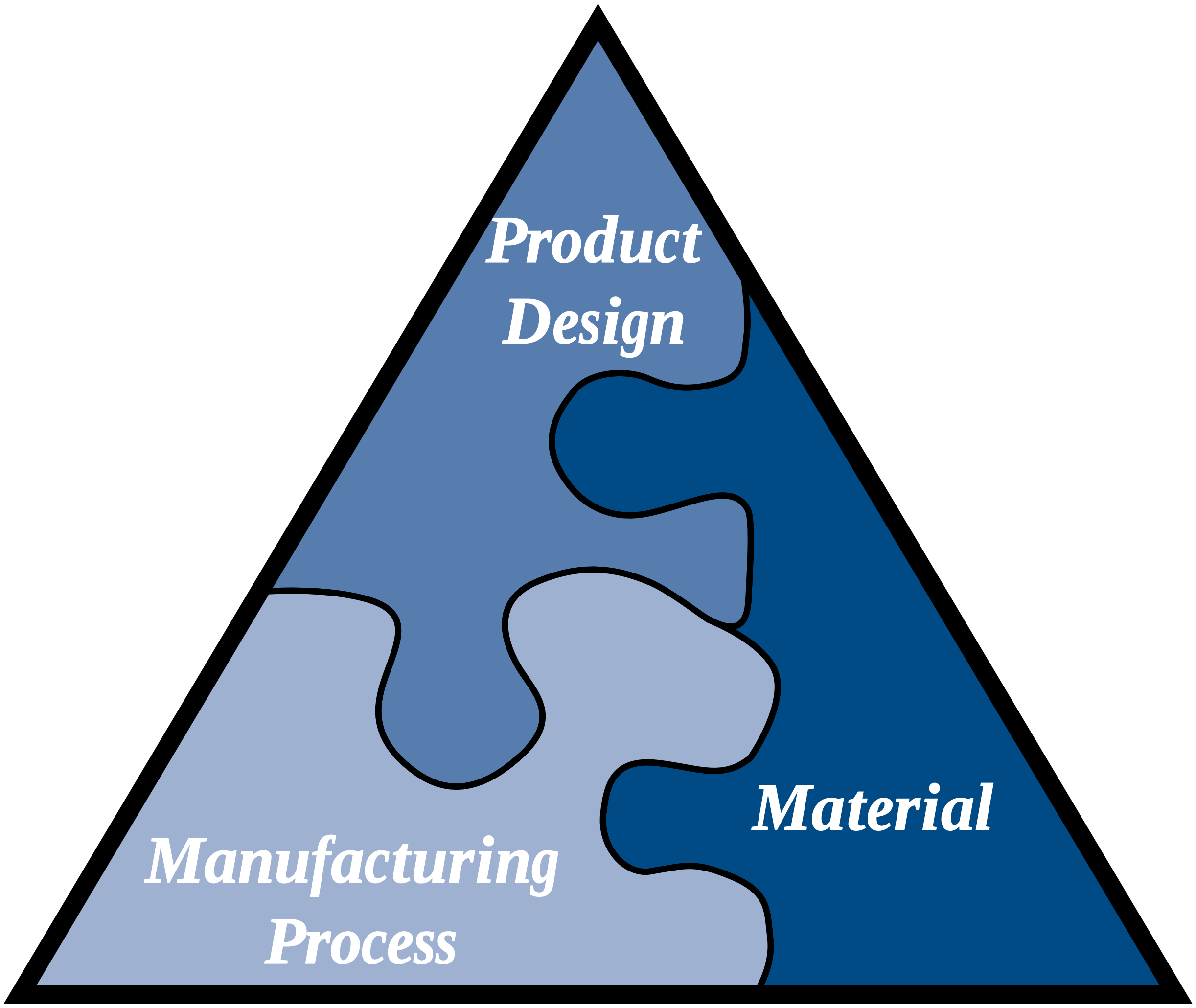
The importance of collaboration between the product designer, the materials engineer and the die process planner for cost effective mass reduction through the application of high strength steel is emphasized in this manual.

HSS often requires die processes different from those used for mild steels in order to achieve a quality stamping. Recent HSS studies at the Auto/Steel Partnership have shown that, in the range of 275 – 420 MPa (40 – 60 KSI yield strength), the wrong die process was a much greater contributor to poor part quality than material property variation. This includes the effects on wall opening angle, side-wall curl, offset flange angle and panel twist.

The product designer must understand the material characteristics and the proposed die process in order to produce a workable part design. Abrupt changes in part geometry and/or uneven depth of draw make HSS parts more difficult to produce. In general, those parts in the 275 to 420 MPa range should be designed for form die or “open-end” draw die processes.

HSS material characteristics are such that elongation potential is reduced and resistance to compression increases as tensile strength rises. Therefore splitting and buckling tendencies are increased. Residual stress can cause dimensional instability in the stamping. It is almost impossible for die tryout personnel to get an approved HSS stamping if the part design and die process are not optimized. Flange die bend radii must be small in order to minimize springback. In addition, the die process may require some form of “post-stretch” or “shape-set” in order to induce a minimum of 2% stretch in the part near the bottom of the press stroke. This has been shown to be effective in reducing residual stresses.

Several alternate die processes for HSS are being evaluated in research centers throughout the world. These are primarily focused on better process control and various means of inducing “shape-set” stretch in the stamping. Among these processes are programmable hydraulic blankholders for varying the force-stroke trajectory as the sheet is drawn and active draw beads for increasing the restraining force as the press approaches bottom dead center. Nitrogen and hydraulic cylinders have been developed with controlled return stroke for form die pressure pads. These and other developments will enhance HSS stamping process capability in the near future.


Product Design
Material
Manufacturing Process

Section 1- Material Characteristics of High Strength Steels

Flat rolled steels are versatile materials. They provide strength and stiffness with favorable mass to cost ratios and they allow high-speed fabrication. In addition, they exhibit excellent corrosion resistance when coated, high-energy absorption capacity, good fatigue properties, high work hardening rates, aging capability, and excellent paintability, all of which are required by automotive applications. These characteristics, plus the availability of high strength steels in a wide variety of sizes, strength levels, chemical compositions, surface finishes, and various organic and inorganic coatings have made sheet steel the material of choice for the automotive industry.

Sheet steels have been reclassified in recent years by the Society of Automotive Engineers (SAE), both the formable low carbon grades (SAE J2329) and the higher strength grades (SAE J2340). There are differing opinions as to what determines a high strength steel and at what strength level the classification begins.

The SAE specifies low carbon formable materials where the formability is the prime consideration in making a part, whereas in high strength steels the yield and tensile strength level is the prime consideration. Higher strength steels are desirable for dent resistance, increased load carrying capability, improved crash energy management, or for mass reduction through a reduction in sheet metal thickness, or gauge.

An increase in strength generally leads to reduced ductility or formability. Care must be taken in designing parts, tooling, and fabrication processes to obtain the greatest benefit from the higher strength sheet steels.

Strength in these steels is achieved through chemical composition, or alloying, and special processing. Special processing includes mechanical rolling techniques, temperature control in hot rolling, and time/temperature control in the annealing of cold reduced steel.

Types of high strength steels and grades available are shown in Table 1 below:

Table 1: High and Ultra High Strength Steel Grades Available to Automotive

Steel Description	SAE Grade	Available Strengths Yield or Tensile MPa
Dent Resistant Non Bake Hardenable	A	180, 210, 250, 288 (YS)
Dent Resistant Bake Hardenable	B	180, 210, 250, 280 (YS)
High Strength Solution Strengthened	S	300, 340 (YS)
High Strength Low Alloy	X&Y	300, 340, 380, 420, 490, 550 (YS)
High Strength Recovery Annealed	R	490, 550, 700, 830 (YS)
Ultra High Strength Dual Phase	DN & DL	500, 600, 700, 800, 950, 1000 U(TS)
Transformation-Induced Plasticity (TRIP)	None	600, 700, 800, 1000 U(TS)
Ultra High Strength Low Carbon Martensite	M	800, 900, 1000, 1100, 1200, 1300, 1400, 1500 U(TS)

DENT RESISTANT BAKE HARDENABLE AND NON-BAKE HARDENABLE SHEET STEELS

There are two types of dent resistant steels, non bake-hardenable and bake-hardenable. SAE has classified them as Type A and Type B, both of which are available in grades with minimum yield strengths of 180 MPa. Dent resistant steels are cold reduced low carbon (0.01-0.08%), typically deoxidized and continuous cast steel made by basic oxygen, electric furnace, or other processes that produce a material that satisfies the requirements for the specific grade. The chemical composition must be capable of achieving the desired mechanical and formability properties for the specified grade and type. For grades 180 and 210, using an interstitial free (IF) base metal having a carbon content less than 0.01%, an effective boron addition of <0.001% may be required to minimize secondary work embrittlement (SWE) and to control grain growth during welding.

Dent Resistant Type A steel is a non bake-hardenable dent resistant steel achieving the final strength in the part through a combination of initial yield strength and the work hardening imparted during forming. Solid solution strengthening elements such as phosphorus, manganese and/or silicon are added to increase strength. Work hardenability depends upon the amount of carbon remaining in solution, which is controlled through chemistry and thermo-mechanical processing. Small amounts of columbium,vanadium, or titanium are sometimes used, but are limited because they reduce ductility.

Dent Resistant Type B steel is a bake-hardenable dent resistant steel that makes up a relatively new class of sheet steel products. They offer a combination of formability in the incoming steel and high yield strength in the application that is not attained in conventional high strength steels. They can potentially be substituted for drawing quality sheet at the stamping plant without requiring major die modifications. The combination of formability and strength makes bake hardenable steels good options for drawn or stretched applications where resistance to dents and palm printing is important in applications such as hoods, doors, fenders, and deck lids. Bake hardenable steels may also assist in vehicle mass reduction through downgaging.

The forming operation imparts some degree of strain hardening which increases yield strength in bake hardening Type B steels. The paint baking cycle, typically 175°C (350°F) for 20 to 30 minutes, provides another increase in yield strength due to moderate “carbon strain aging”. Material properties are generally stable, depending on the process. Figure 1 illustrates the hardening process with bake hardening steels.

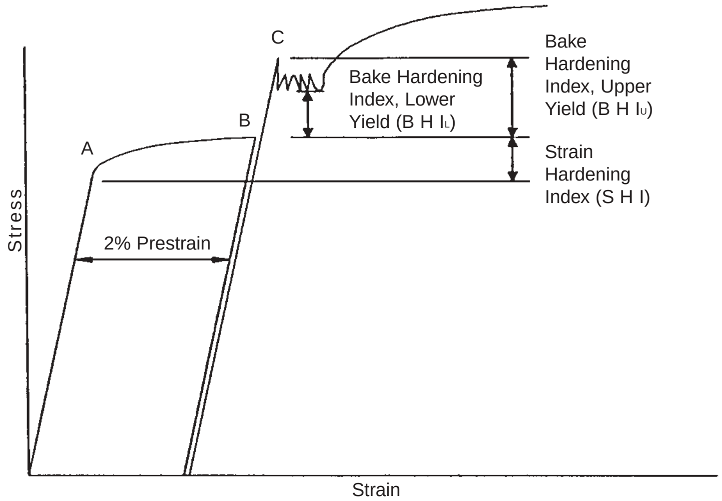


Figure 1 Schematic Illustration Showing Strain Hardening and Bake Hardening Index and the Increase in Yield Strength that Occurs During The Bake Cycle.

Table 2 below shows the required mechanical properties for the Type A and Type B bake-hardenable and non bake-hardenable dent resistant steels as described in the SAE J2340 specification.

Mechanical property requirements of dent resistant, cold reduced, uncoated and coated sheet steel grades are based on the minimum values of as-received yield strength (180, 210, 250, and 280 MPa) and the n value of the sheet steel, the minimum yield strength after strain and bake, and tensile strength.

Table 2 Required Minimum Mechanical Properties of Type A and Type B Dent Resistant Cold Reduced Sheet Steel

SAE J2340 Grade Designation and Type	As Received Yield Strength MPa	As Received Tensile Strength MPa	As Received n value	Yield Strength After 2% Strain MPa	Yield Strength After 2% Strain and Bake Mpa
180 A	180	310	0.20	215	
180 B	180	300	0.19		245
210 A	210	330	0.17	245	
210 B	210	320	0.18		275
250 A	250	355	0.16	285	
250 B	250	345	0.16		315
280 A	280	375	0.16	315	
280 B	280	365	0.15		345

SOLUTION STRENGTHENED, HIGH STRENGTH LOW ALLOW (HSLA), AND HIGH STRENGTH RECOVERY ANNEALED HOT ROLLED AND COLD REDUCED SHEET STEEL

High strength, HSLA, and high strength recovery annealed categories include steel grades with yield strengths in the range of 300 to 830 MPa. Steel made for these grades is low carbon, deoxidized and continuous cast steel made by basic oxygen, electric furnace, or other process that will produce a material that satisfies the requirements for the specific grade. The chemical composition must be capable of achieving the desired mechanical and formability properties for the specified grade and type.

Several types of high strength steel based on chemistry fall in the above group. Solution strengthened high strength steels are those that contain additions of phosphorus, manganese, or silicon to conventional low carbon (0.02-0.13% carbon) steels. HSLA steels have carbide formers such as titanium, niobium (columbium), or vanadium added to conventional low carbon steels along with solid solutions strengthening from P Mn and Si. High strength recovery annealed steels have chemistries similar to the above varieties of steel, but special annealing practices prevent recrystallization in the cold-rolled steel.

Classification is based on the minimum yield strength of 300 to 830 MPa. Several categories at each strength level are defined as follows:

Type S: High strength solution strengthened steels use carbon and manganese in combination with phosphorus or silicon as solution strengtheners to meet the minimum strength requirements. Carbon content is restricted to 0.13% maximum for improved formability and weldability. Phosphorus is restricted to a maximum of 0.10%. Sulfur is restricted to a maximum of 0.02%.

Type X: High Strength Low Alloy steels, typically referred to as HSLA, are alloyed with carbide and nitrite forming elements, commonly niobium (columbium), titanium, and vanadium, either singularly or in combination. These elements are used with carbon, manganese, phosphorus, and silicon to achieve the specified minimum yield strength. Carbon content is restricted to 0.13% maximum for improved formability and weldability. Phosphorus is restricted to a maximum of 0.06%. The specified minimum for niobium (columbium), titanium, or vanadium is 0.005%, while sulfur is restricted to a maximum of 0.015%. A spread of 70 MPa is specified between the required minima of the yield and tensile strengths.

Type Y: Same as Type X, except that a 100 MPa spread is specified between the required minimum of the yield and tensile strengths.

Type R: High strength recovery annealed or stress-relief annealed steels achieve strengthening primarily through the presence of cold work. Alloying elements mentioned under Types S and X may also be added. Carbon is restricted to 0.13% maximum for improved formability and weldability. Phosphorus is restricted to a maximum of 0.10%. Sulfur is restricted to a maximum of 0.015%. These steels are best suited for bending and roll-forming applications since their mechanical properties are highly directional and ductility and formability are limited.

Table 3 below shows the required mechanical properties for the Type SA, Type X, and Type Y of the High Strength Low alloy steels. The SAE Specification of these properties are described in SAE specification J-2340.

Table 3 Required Mechanical Properties of High Strength and HSLA Hot Rolled and Cold Reduced, Uncoated and Coated Sheet Steel

SAE J2340 Grade Designation and Type	**Yield Strength MPa**		**Tensile Strength MPa**	**%Total Elongation Minimum (ASTM.L)**	
	Minimum	Maximum	Minimum	Cold Reduced	Hot Rolled
300 S	300	400	390	24	26
300 X	300	400	370	24	28
300 Y	300	400	400	21	25
340 S	340	440	440	22	24
340 X	340	440	410	22	25
340 Y	340	440	440	20	24
380 X	380	480	450	20	23
380 Y	380	480	480	18	22
420 X	420	520	490	18	22
420 Y	420	520	520	16	19
490 X	490	590	560	14	20
490 Y	490	590	590	12	19
550 X	550	680	620	12	18
550 Y	550	680	650	12	18

Table 4 below shows the required mechanical properties for the Type R, Recovery Annealed steels. The SAE Specification of these properties are described in SAE specification J-2340.

Table 4 Required Mechanical Properties of Type R, High Strength Recovery Annealed Cold Reduced Sheet Steel

SAE J2340 Grade Designation and Type	Yield Strength MPa		Tensile Strength MPa	%Total Elongation (ASTM.L)
	Minimum	Maximum	Minimum	Minimum
490 R	490	590	500	13
550 R	550	650	560	10
700 R	700	800	710	8
830 R	830	960	860	2

ULTRA HIGH STRENGTH COLD ROLLED STEELS; DUAL PHASE, TRANSFORMATION INDUCED PLASTICITY, AND LOW CARBON MARTENSITE

The ultra high strength dual phase (DP), transformation induced plasticity (TRIP), and low carbon martensite (LCM) categories include steel grades with minimum tensile strengths in the range of 500 to 1500 MPa. These sheet steels may be ordered and supplied as uncoated or zinc coated. Coating availability differs among the various steel suppliers.

Special heat treating practices that involve quenching and tempering treatments are used to generate a martensite phase in the steel microstructure. The volume fraction and carbon content of the martensite phase determines the strength level. These steels are primarily alloyed with carbon and manganese. Boron may be added in some cases.

Specification of chemical limits for low carbon martensitic grades may be found in ASTM A980 “Standard Specification for Steel, Sheet, Carbon, Ultra High Strength Cold Rolled”.

The typical mechanical properties of ultra high strength sheet steels are specified in Tables 5 thru 7 on pages 11-13. Classification is based on the minimum tensile strength of the sheet steel: 500 to 1500 MPa. The formability and weldability requirements of these ultra high strength steels are determined upon agreement between purchaser and supplier.

Dual Phase (Type D)

The ultra high strength dual phase steel microstructure is composed of ferrite and martensite, with the volume fraction of low-carbon martensite primarily determining the strength level. Two types of dual phase steels are available; a high yield ratio (YS/TS) product designated DH and a low yield ratio product designated DL. Table 5 shows the required mechanical properties for the Type D, Dual Phase High Strength steels. The SAE Specification for these properties is included in SAE J-2340.

Table 5 Required Mechanical Properties of Ultra High Strength Dual Phase Hot Rolled and Cold Reduced Sheet Steel

SAE J2340 Grade Designation and Type	Yield Strength MPa Minimum	Tensile Strength MPa Minimum	Total Elongation in 50 mm % Minimum (ASTM.L)
500 DH	300	500	22
600 DH	500	600	16
600 DL1	350	600	16
600 DL2	280	600	20
700 DH	550	700	12
800 DH	500	800	8
950 DH	650	950	8
1000 DH	700	1000	5

Martensite (Type M)

Martensitic high strength steel is a low carbon deoxidized steel made by basic oxygen, electric furnace, or other process that will produce a material that satisfies the requirements for the specific grade. This steel is continuously cast. The chemical composition is capable of achieving the desired mechanical and formability properties for the specified grade and type. The steel supplier must define the chemical composition range that will be furnished on a production basis. The microstructure is low carbon martensite, with the carbon content determining the strength level. These materials have limited ductility. Table 6 below shows the required mechanical properties for the Type M, Martensitic Ultra High Strength steels. The SAE Specification for these properties is included in SAE J-2340.

Table 6 Required Mechanical Properties of Low Carbon Martensite Hot Rolled and Cold Reduced Sheet Steel

SAE J2340 Grade Designation and Type	Yield Strength MPa Minimum	Tensile Strength MPa Minimum	Total Elongation in 50 mm % Minimum (ASTM.L)
800 M	600	800	2
900 M	750	900	2
1000 M	750	1000	2
1100 M	900	1100	2
1200 M	950	1200	2
1300 M	1050	1300	2
1400 M	1150	1400	2
1500 M	1200	1500	2

Transformation Induced Plasticity Steels (TRIP) (Typically 600-1000 MPa Tensile):

Trip steels have improved ductility by virtue of special alloying and thermal treatment, or annealing after rolling. The microstructure of TRIP steels contains residual austenite in a ferritic-bainitic matrix that transforms into martensite during forming. Availability of these steels is currently very limited in the U.S.

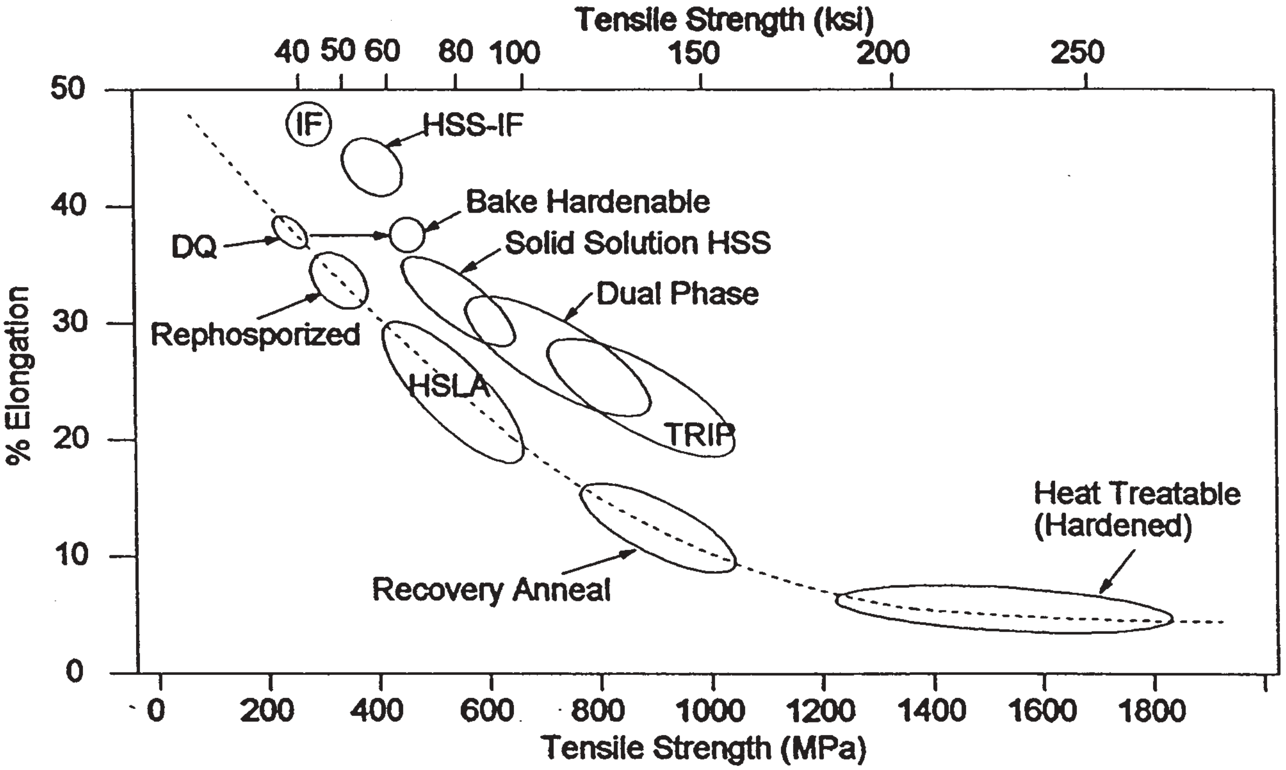
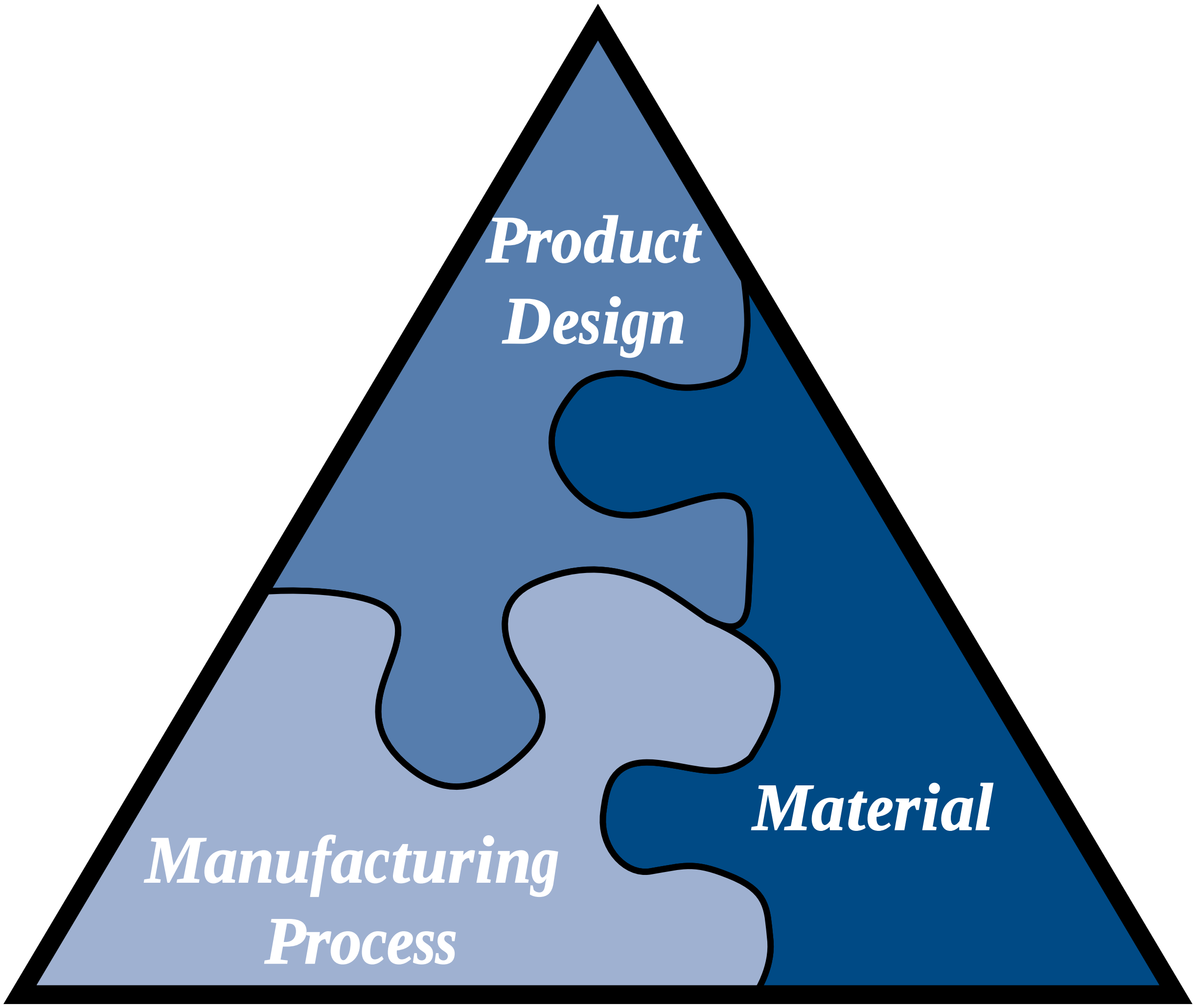


Figure 2: A Comparison of Tensile Strength and % Elongation for Various Grades of Automotive Sheet Steels (Reprinted from Auto-Steel Design Manual)

Table 7 below shows the typical mechanical property values and available width and thickness of numerous dent resistant, high strength, and ultra high strength grades of sheet steel used in the automotive industry.

Table 7 Compilation of Typical Mechanical Property Values and Limited Steel Sheet Thickness and Width Availability

Material	SAE Class.	Grade		Yield Strength	Tensile	Elon	r value n		Hard	Width Range		Thickness
		SAE	OLD	MPa/ksi	MPa/ksi	%	R	n	Rb	(mm)	(in)	(mm)
CR	SAE J2340	180A	Dent Resist	200/29	350/50	40	1.7	0.22	63	610 - 1829	24 - 72	0.64 - 2.79
CR	SAE J2340	210A	Dent Resist	210/30	375/54	39	1.6	0.21	65	610 - 1829	24 - 72	0.64 - 2.79
CR	SAE J2340	250A	Dent Resist	270/39	400/58	36	1.5	0.20	68	610 - 1829	24 - 72	0.64 - 2.79
CR	SAE J2340	280A	Dent Resist	300/43	430/62	36	1.4	0.18	70	610 - 1829	24 - 72	0.64 - 2.79
CR	SAE J2340	180B	Bake Hard	200/29	320/46	39	1.7	0.20	52	610 - 1829	24 - 72	0.64 - 2.79
CR	SAE J2340	210B	Bake Hard	221/32	352/51	41	1.6	0.20	54	610 - 1829	24 - 72	0.64 - 2.79
CR	SAE J2340	250B	Bake Hard	255/37	379/55	39	1.4	0.17	58	610 - 1829	24 - 72	0.64 - 2.79
CR	SAE J2340	280B	Bake Hard	324/47	421/61	37	1.1	0.16	67	610 - 1829	24 - 72	0.64 - 2.79
HR	SAE J2340	300S	HSS	331/48	407/59	35	N/A	0.17	72	610 - 1829	24 - 72	0.64 - 3.75
CR	SAE J2340	300S	HSS	303/44	379/55	37	1.0	0.17	63	610 - 1829	24 - 72	0.64 - 2.79
HR	SAE J2340	340S	HSS	407/59	483/70	31	N/A	0.17	75	610 - 1829	24 - 72	0.64 - 3.75
CR	SAE J2340	340S	HSS	379/55	455/66	30	1.3	0.16	76	610 - 1575	24 - 62	0.64 - 2.79
HR	SAE J2340	300X	HSLA	350/51	407/59	35	N/A	0.17	72	610 - 1829	24 - 72	0.64 - 3.75
CR	SAE J2340	300X	HSLA	350/51	469/68	28	1.1	0.16	70	610 - 1829	24 - 72	0.38 - 3.30
CR	SAE J2340	300Y	HSLA							610 - 1829	24 - 72	0.38 - 3.30
HR	SAE J2340	340X	HSLA	407/59	483/70	31	N/A	0.17	75	610 - 1829	24 - 72	0.64 - 3.75
CR	SAE J2340	340X	HSLA							610 - 1524	24 - 60	0.76 - 3.18
CR	SAE J2340	340Y	HSLA							610 - 1524	24 - 60	0.76 - 3.18
CR	SAE J2340	380X	HSLA							610 - 1524	24 - 60	0.76 - 3.18
CR	SAE J2340	380Y	HSLA							610 - 1524	24 - 60	0.76 - 3.18
HR	SAE J2340	420X	HSLA	476/69	531/77	27	N/A	0.15	87	610 - 1542	24 - 60	0.76 - 3.18
CR	SAE J2340	420X	HSLA							610 - 1524	24 - 60	0.76 - 3.18
CR	SAE J2340	420Y	HSLA							610 - 1524	24 - 60	0.76 - 3.18
HR	SAE J2340	490X	HSLA	531/77	600/87	26	N/A	0.13	90	610 - 1524	24 - 60	0.76 - 3.18
CR	SAE J2340	490X	HSLA							610 - 1524	24 - 60	0.76 - 3.18
CR	SAE J2340	490Y	HSLA							610 - 1524	24 - 60	0.76 - 3.18
HR	SAE J2340	550X	HSLA	586/85	676/98	22	N/A	0.12	96	610 - 1524	24 - 60	0.76 - 3.18
CR	SAE J2340	550X	HSLA							610 - 1524	24 - 60	1.27 - 3.18
HR/CR	SAE J2340	550Y	HSLA							610 - 1524	24 - 60	1.27 - 3.18
CR	SAE J2340	490R	Rec Anneal	490/71	500/72	13	N/A	N/A	N/A	610 - 1524	24 - 60	1.27 - 3.18
CR	SAE J2340	550R	Rec Anneal	550/80	560/81	10				610 - 1524	24 - 60	1.27 - 3.18
CR	SAE J2340	700R	Rec Anneal	700/101	800/115	8				610 - 1524	24 - 60	1.27 - 3.18
CR	SAE J2340	830R	Rec Anneal	830/120	960/139	2				610 - 1524	24 - 60	1.27 - 3.18
HR/CR	SAE J2340	500DH	Dual Phase	340/49	550/80	28	N/A	N/A	N/A	610 - 1524	24 - 60	1.27 - 3.18
HR/CR	SAE J2340	600DH	Dual Phase	550/80	710/103	20	N/A	N/A	N/A	610 - 1524	24 - 60	1.27 - 3.18
HR/CR	SAE J2340	600DL1	Dual Phase	390/57	650/94	22	N/A	N/A	N/A	610 - 1524	24 - 60	1.27 - 3.18
HR/CR	SAE J2340	600DL2	Dual Phase	340/49	660/96	27	N/A	N/A	N/A	610 - 1524	24 - 60	1.27 - 3.18
HR/CR	SAE J2340	700DH	Dual Phase	600/87	760/110	16	N/A	N/A	N/A	610 - 1524	24 - 60	1.27 - 3.18
HR/CR	SAE J2340	800DL	Dual Phase	580/84	860/125	14	N/A	N/A	N/A	610 - 1524	24 - 60	1.27 - 3.18
HR/CR	SAE J2340	950DL	Dual Phase	680/98	1050/152	12	N/A	N/A	N/A	610 - 1524	24 - 60	1.27 - 3.18
HR/CR	SAE J2340	1000DL	Dual Phase	810/117	1070/155	9	N/A	N/A	N/A	610 - 1524	24 - 60	1.27 - 3.18
HR/CR	SAE J2340	800M	Martensite	N/A	N/A	N/A	N/A	N/A	N/A	610 - 1575	24 - 62	0.51 - 1.52
HR/CR	SAE J2340	900M	Martensite	900/130	1025/149	5	N/A	N/A	N/A	610 - 1575	24 - 62	0.51 - 1.52
HR/CR	SAE J2340	1000M	Martensite	N/A	N/A	N/A	N/A	N/A	N/A	610 - 1575	24 - 62	0.51 - 1.52
HR/CR	SAE J2340	1100M	Martensite	1030/149	1180/171	4	N/A	N/A	N/A	610 - 1575	24 - 62	0.51 - 1.52
HR/CR	SAE J2340	1200M	Martensite	1140/165	1340/184	6	N/A	N/A	N/A	610 - 1575	24 - 62	0.51 - 1.52
HR/CR	SAE J2340	1300M	Martensite	1200/174	1400/203	5	N/A	N/A	N/A	610 - 1575	24 - 62	0.51 - 1.52
HR/CR	SAE J2340	1400M	Martensite	1260/183	1480/214	5	N/A	N/A	N/A	610 - 1575	24 - 62	0.51 - 1.52
HR/CR	SAE J2340	1500M	Martensite	1350/196	1580/229	5	N/A	N/A	N/A	610 - 1575	24 - 62	0.51 - 1.52


Product Design
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Manufacturing Process

Section 2 – Product Design Guidelines for High Strength Steel Applications

GENERAL PRODUCT DESIGN GUIDELINES

Cost effective weight savings for automotive applications are readily achievable with high strength steel. However, the potential offered by these steels can be only be realized to full advantage if there is planned coordination of material characteristics, part design geometry and die process capability.

As steel strength is increased, the n value, or the work hardening exponent, a coefficient of stretchability is decreased in comparison to the mild steel grades. The lower n value of higher strength steels creates a sharper strain gradient and more localized thinning. The product designer and the manufacturing engineer must recognize that high strength steels have different forming characteristics. On this basis, a part design and manufacturing process can be developed to accommodate the HSS formability parameters to produce satisfactory stampings.

To effectively utilize the automotive structural grades of HSS in the 275 to 420 Mpa (yield strength) range (40 to 60 KSI), most parts should be designed for fabrication in form and flange dies, “draw-action” form dies or open end draw dies. These die processes require the metal to bend and stretch but minimize the metal compression common to closed corners of conventional draw die processes. Structural parts, such as longitudinal rails, motor compartment rails and roof rails can be designed to allow an open-end draw die operation. It is important that the product designers work closely with the die process planners and the steel suppliers when parts are being designed to avoid improper material/part design/die process combinations.

For structural parts such as rails and crossbars, springback on flanges will increase as compared to mild steel. The manufacturing process will therefore require overbend of flanges to allow for springback compensation. The part design should be such that overbend of flanges is possible, particularly for “hat section” parts with opposing sidewalls. Smaller bend radii will minimize springback, but the part design should also allow for a die overbend of at least 6 degrees for HSS parts.

When part geometry is such that a draw die or stretch-form die is required, the reduced formability of the HSS must be accommodated through optimization of product design, material specification and/or die process. Such is the case for most major panels, such as door inner panels. For these applications, a material such as a bake-hardenable or dual-phase steel may be recommended. These steels can have lower initial strength and be more formable, but gain ultimate strength by work hardening and as the result of elevated temperatures in the paint ovens. See Section 1 for material characteristics of these steel grades.

Early involvement of the manufacturing engineers and steel suppliers will avoid typical draw die/stretch-form die problems which result when a part design is too complex for the material specified. The manufacturing engineer will usually suggest changes in the part design to keep stretch and compression of the sheet metal within acceptable limits, and keep the depth of draw to a minimum to avoid splits. Gentle shape transitions will avoid wrinkles in the part. More generous part radii are recommended where metal must flow in the die, as in draw dies. Conversely, smaller part radii will reduce springback where the die action is a fold or bend, as in form and flange dies.

The product designer must also consult the manufacturing engineer on those product design features that may cause undesirable residual stresses after forming. Residual stress is the primary cause of distortion in stamped parts. These stresses must be reduced to minimums by part design changes and proper die process planning in order to produce acceptable stamped parts when using HSS.

Careful consideration of these design guidelines will assure a more robust manufacturing process.

SELECTING THE CORRECT MATERIAL FOR THE PART

The selection of the correct material for a particular application should be a balance of performance and manufacturing criteria. For a typical door outer panel evaluation, see Table 8 and Figure 3.

In addition to good formability, outer panel material must provide good surface quality, dent resistance, and, in the case of closure panels, good hemming ability. Inner panel material should provide good formability, weldability and superior strength characteristics.

Bending or folding processes will not produce a uniform strength increase over the entire panel for those steels that achieve their ultimate strength by strain hardening. HSS grades that have the proper initial strength level may be a better choice for form and flange die processes.

For draw or stretch processes, bake hardenable steels (BHS) can achieve an increase in yield strength of 30 to 40 Mpa after the stamping process. Similar results can be expected with dual-phase steels. These steel grades require strain to gain the strengthening effect. BHS will demonstrate a further increase in strength during the paint oven bake cycle.

PART DIMENSIONAL TOLERANCES AND PROCESS CAPABILITY

For information on dimensional tolerances and the impact of the measurement system on dimensional evaluation processes, refer to the Auto/Steel Partnership publication “Automotive Body Measurement System Capability.”

For information on stamping process capability and sources of process variation, refer to the Auto/Steel Partnership publication “Automotive Sheet Steel Process Variation,” – an analysis of stamping process capability and implications for design, die tryout and process control.

	Cpt Requirement	Carbon Manganese								Dual Phase				HSLA					
		DR 210[1]		240Y		390T		440T		500T		600T		40		50		60	
		Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product
Manufacturing Criteria																			
Formability	7	7	49	6	42	3	21	2	14	4	28	2	14	3	21	2	14	1	7
Surface Quality	10	7	90	8	80	6	60	4	40	7	70	6	60	4	40	2	20	1	10
Cost	5	9	45	8	40	7	35	7	35	6	30	6	30	8	40	7	35	7	35
Weldability	6	9	54	8	48	7	42	5	30	5	30	5	30	7	42	6	36	5	30
Hemming Ability	10	9	90	8	80	6	60	5	50	6	60	5	50	7	70	6	60	4	40
Total, Manufacturing	380	86%	328	76%	290	57%	218	44%	169	57%	218	48%	184	56%	213	43%	165	32%	122
Performance Criteria																			
Strength	3	2	6	3	9	4	12	5	15	6	18	7	21	3	9	4	12	5	15
Stiffness	8	5	40	5	40	5	40	5	40	5	40	5	40	5	40	5	40	5	40
Energy Absorption	1	2	2	3	3	4	4	5	5	7	7	8	8	3	3	4	4	5	5
Dent Resistance	10	5	50	6	60	7	70	8	80	8	80	8	80	8	80	8	80	8	80
Total, Performance	220	45%	98	51%	112	57%	126	64%	140	66%	145	68%	149	60%	132	62%	136	64%	140
Overall Rating	600	71%	426	67%	402	57%	344	52%	309	61%	363	56%	333	58%	345	50%	301	44%	262

	Cpt Requirement	Mild		SS		Bake Hardenable										TRIP	
		Steel		N30		180		210		250		300		Sandwich		600	
		Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product	Rated Value	Product
Manufacturing Criteria																	
Formability	7	10	70	8	56	8	56	7	49	5	35	3	21	3	21	3	21
Surface Quality	10	10	100	8	80	9	90	8	80	6	60	5	50	3	30	5	50
Cost	5	10	50	2	10	9	45	9	45	8	40	8	40	3	15	4	20
Weldability	6	10	60	7	42	9	54	9	54	8	48	7	42	1	6	4	24
Hemming Ability	10	10	100	4	40	9	90	9	90	8	80	7	70	3	30	5	50
Total, Manufacturing	380	100%	380	60%	228	88%	335	84%	318	69%	263	59%	223	27%	102	43%	165
Performance Criteria																	
Strength	3	1	3	7	21	2	6	3	9	4	12	5	15	2	6	8	24
Stiffness	8	5	40	5	40	5	40	5	40	5	40	5	40	8	64	5	40
Energy Absorption	1	1	1	8	8	2	2	3	3	4	4	5	5	2	2	9	9
Dent Resistance	10	40	8	80	6	60	7	70	8	80	8	80	8	80	8	80	
Total, Performance	220	38%	84	68%	149	49%	108	55%	122	62%	136	64%	140	69%	152	70%	153
Overall Rating	600	77%	464	63%	377	74%	443	73%	440	67%	399	61%	363	42%	254	53%	318

Table 8

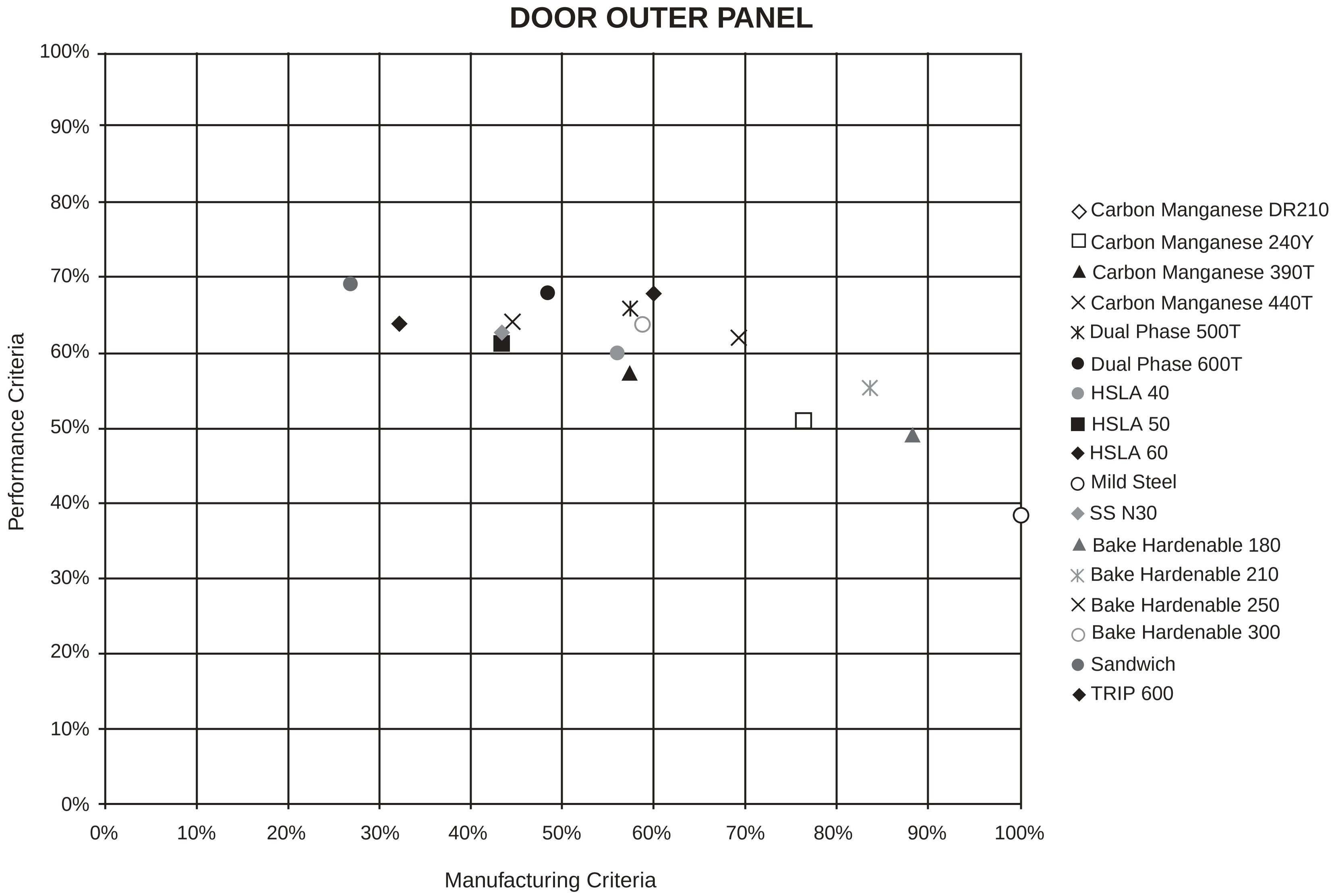

DOOR OUTER PANEL
Performance Criteria
Manufacturing Criteria
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
◇ Carbon Manganese DR210
□ Carbon Manganese 240Y
▲ Carbon Manganese 390T
✕ Carbon Manganese 440T
⚹ Dual Phase 500T
● Dual Phase 600T
● HSLA 40
■ HSLA 50
◆ HSLA 60
○ Mild Steel
◆ SS N30
▲ Bake Hardenable 180
⚹ Bake Hardenable 210
✕ Bake Hardenable 250
○ Bake Hardenable 300
● Sandwich
◆ TRIP 600

Figure 3.

Figure 4 – Typical Part Design For 60 K.S.I.-H.S.S.

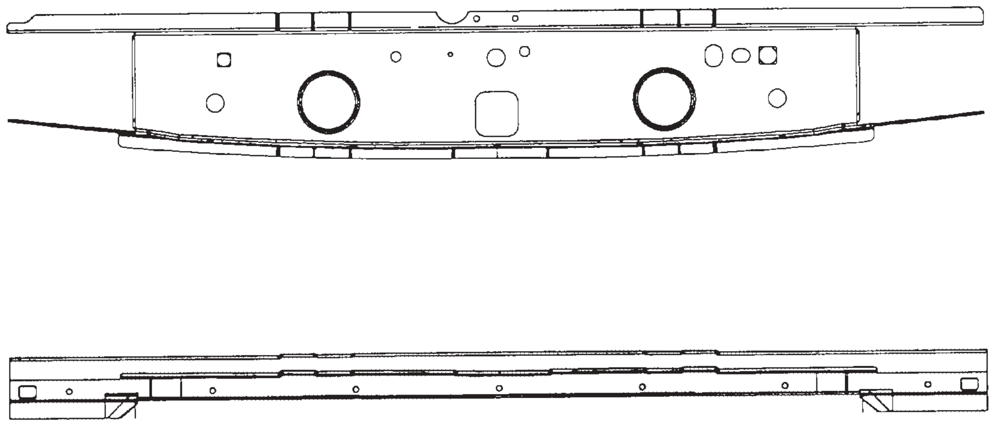


Figure 5 – Typical Part Design For 60 K.S.I.-H.S.S.

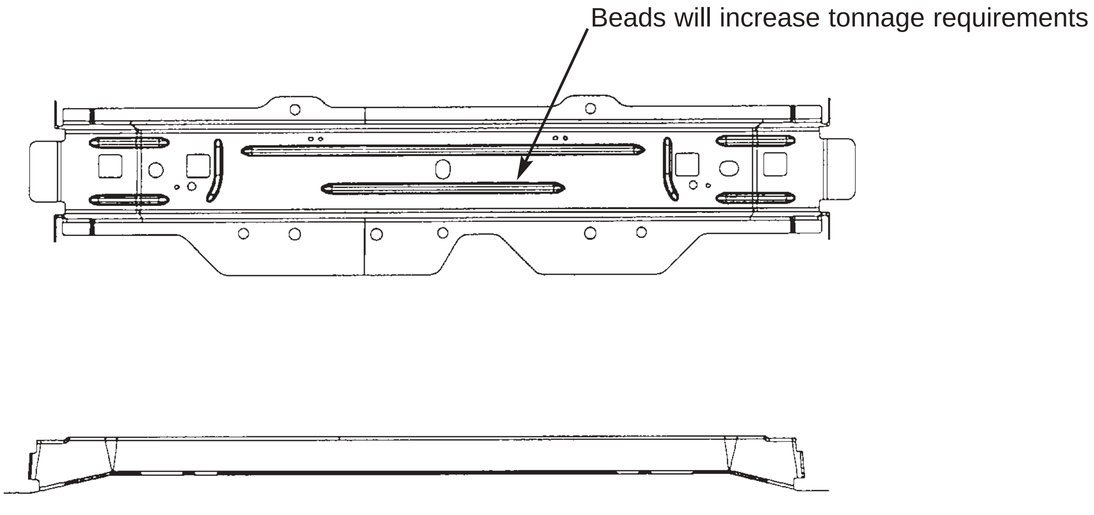


Figure 6 – Typical Part Design For 50 K.S.I.-H.S.S.

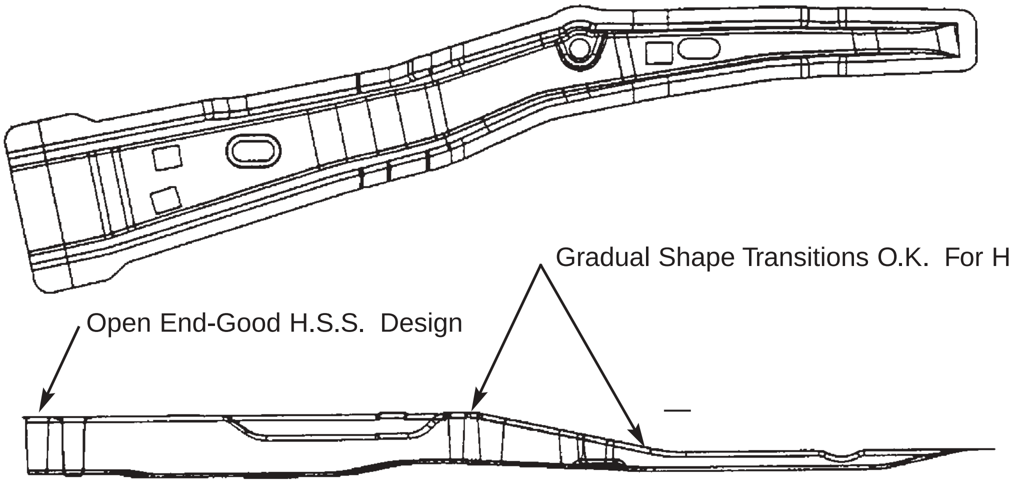


Figure 7– Typical Part Design For 40 K.S.I.-H.S.S.

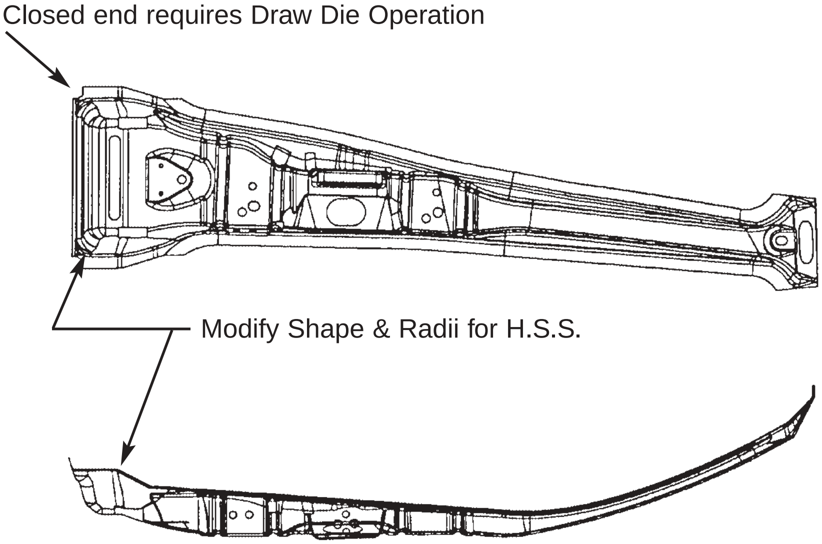


Figure 8 – Acceptable Part Design For 40 K.S.I.-H.S.S. With Appropriate Modifications

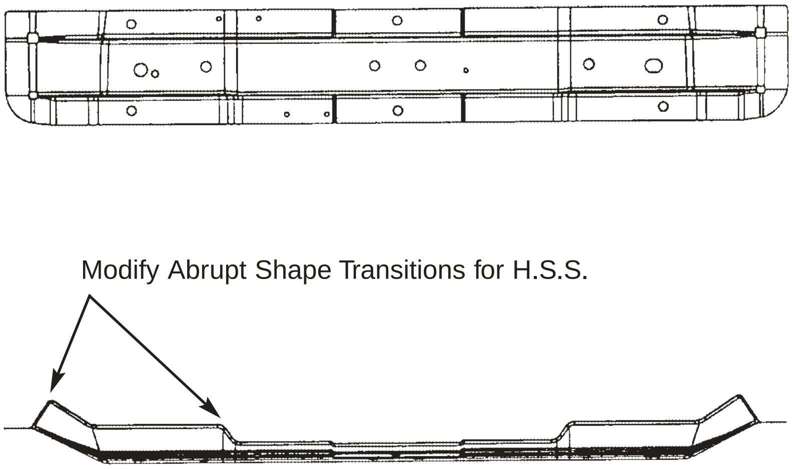


Figure 9– Acceptable Part Design For 40 K.S.I.-H.S.S. With Appropriate Modifications

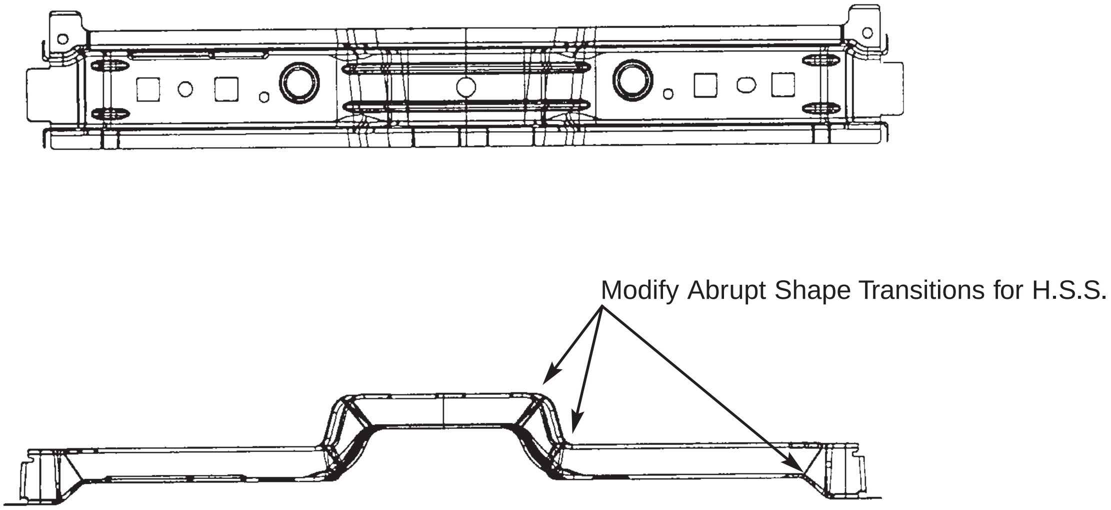


Figure 10 – Acceptable Part Design For 40 K.S.I.-H.S.S. With Appropriate Modifications

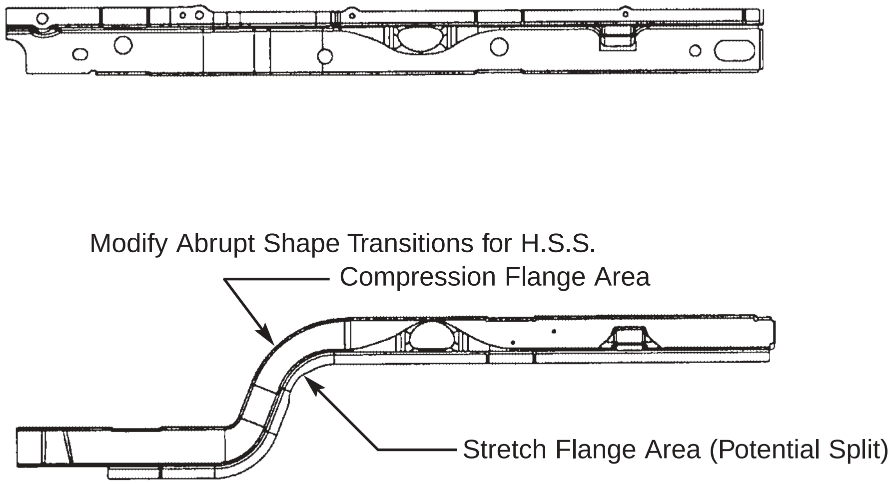


Figure 11– Marginal Part Design for H.S.S. - Part has stretch & compression flanges & Inconsistent Depth. Dimensional control will be a problem for higher strength grades. Stretch & compression stresses on opposite sides of channel shaped parts will cause part to twist.

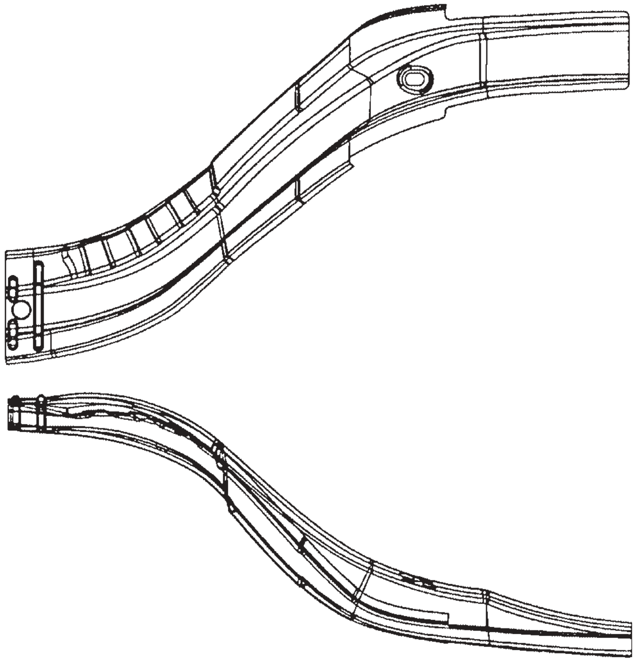
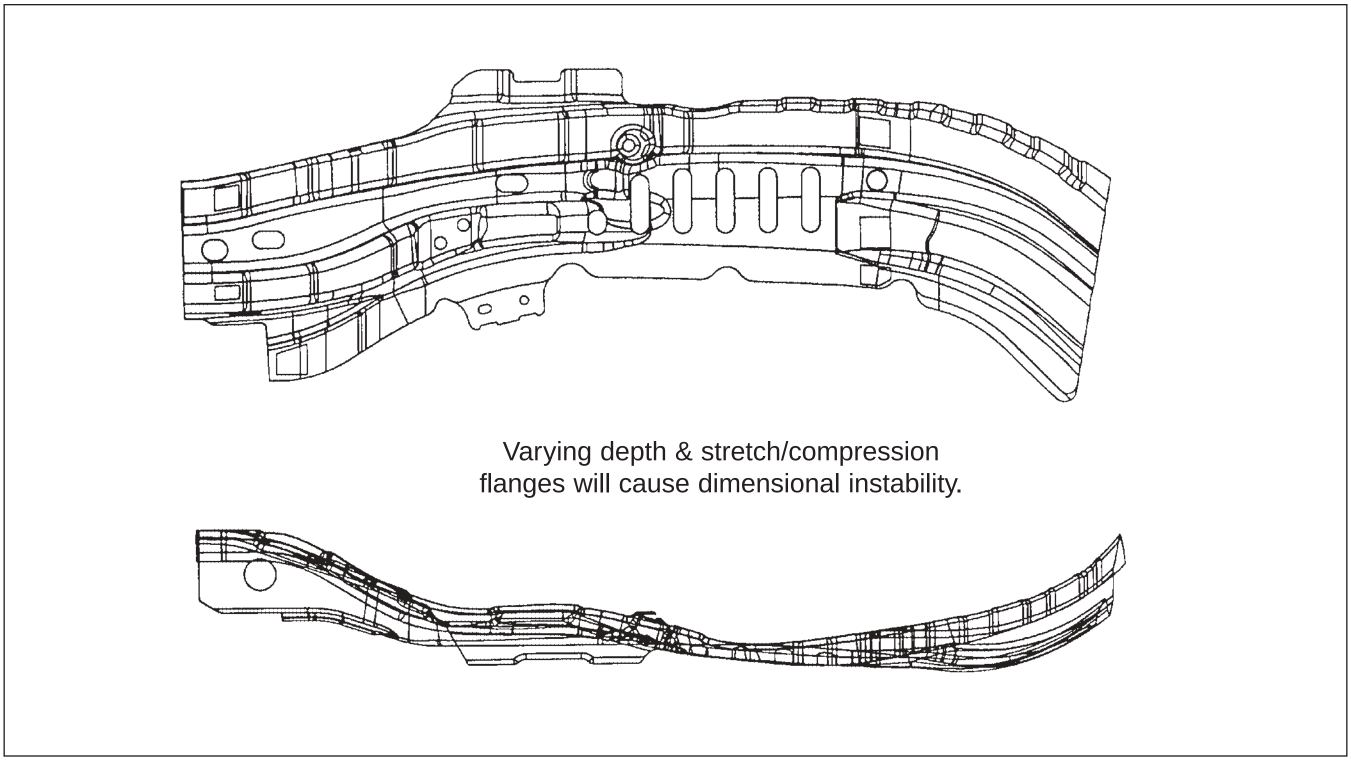
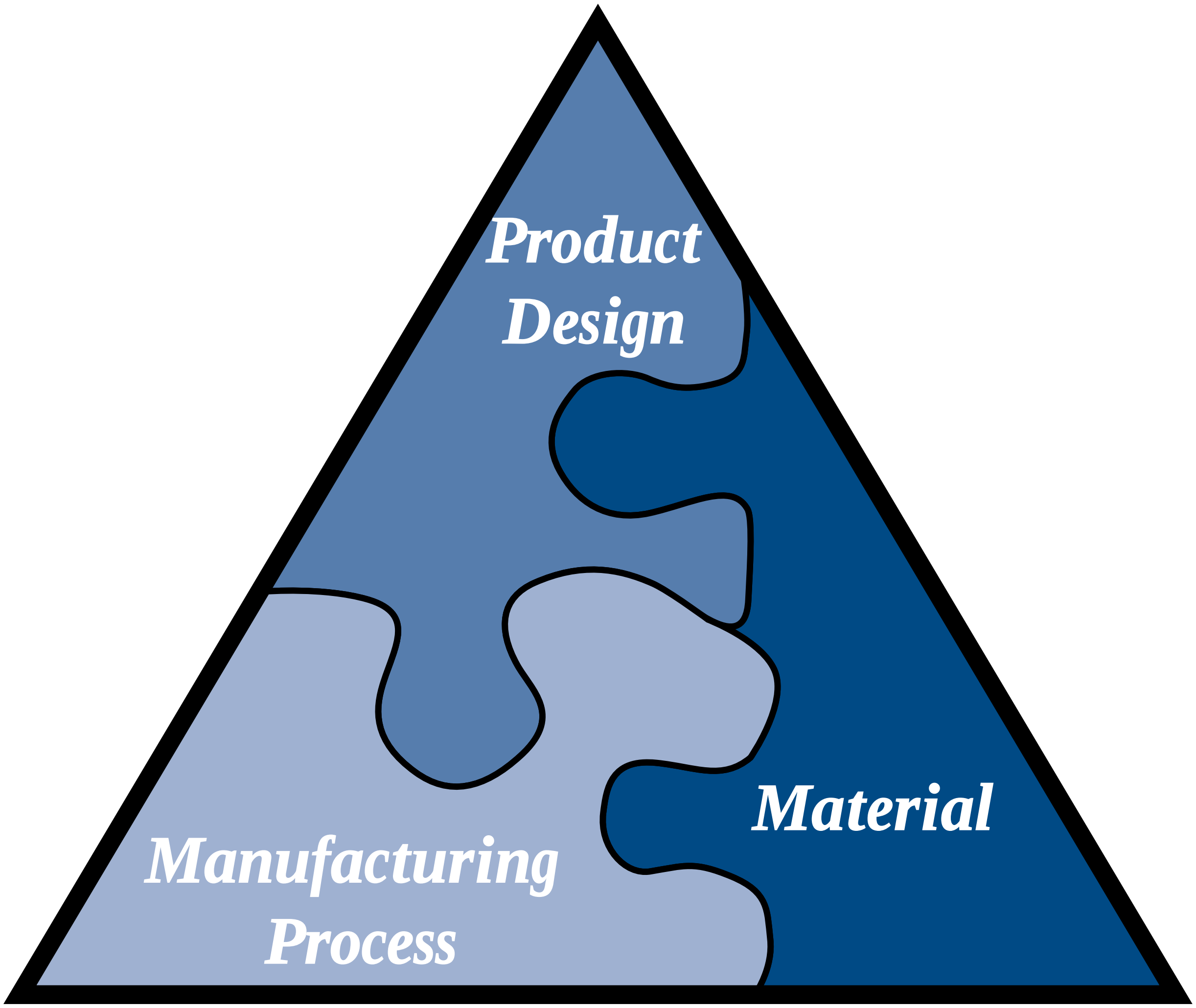


Figure 12 – Marginal Part Design. This Part Design May Be Too Complex for Most Higher Strength Grades. Part should be redesigned for consistent depth & to minimize stretch/compression.



Varying depth & stretch/compression flanges will cause dimensional instability.


Product Design
Material
Manufacturing Process

Section 3- Die Process Planning Guidelines for High Strength Steels

UNDERSTANDING THE EFFECTS OF RESIDUAL STRESS AND ELASTIC RECOVERY

In order to properly plan for operations involving HSS, the die process planner must be aware of the potential effects of residual stress and elastic recovery in stamped parts. He must try to foresee those part designs and die processes that would produce distortion in the finished stamping and plan corrective action accordingly. Part areas that will be placed in tension or compression by the forming process will develop residual stresses. Residual stress, elastic recovery and the resultant distortions are caused by a combination of material characteristics, die process and part geometry.

For structural parts, such as rails & crossbars, residual stress may result in a stamping with sidewall curl or springback. Springback is not accurately predictable through forming simulation. It is vital that the die process planner specify those part modifications and die processes which will reduce the springback phenomena resulting from residual stress. Small bend radii are an important part design element for springback reduction. Proper overbend for springback compensation is important for the die process. In addition, a die process that induces 2% or greater stretch in the part will also minimize the problem. See post-stretch form die sketches 5 & 6 on pages 36 & 37.

The die process planner must specify a forming die process that best suits the part geometry and material characteristics while keeping the stamping under control throughout the die operation. Flanges that are in compression during the forming action must be controlled with pressure pads to avoid buckling and overlapped metal.

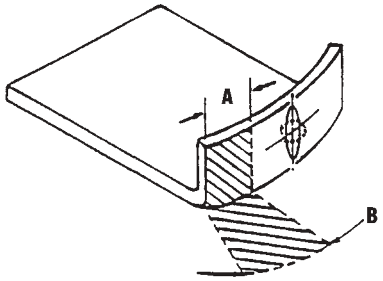
DIE PROCESS GUIDELINES FOR HIGH STRENGTH SHEET STEEL STAMPING DIES

Part Design Considerations for the Die Process Planner

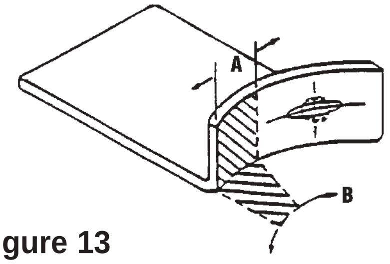
The die process planner must to have part designs modified to suit the material characteristics and the die process. Structural members such as rails, rocker panels, and center pillars, should be designed to allow a “draw-action” form die or open-end draw process. This means that the part design must not have closed ends. Product designers need to understand the importance of this requirement for successful HSS stampings. See die sketches 3, 4 & 7 on pages 34-35 & 38.

(Note: In the context of these guidelines, a “draw-action” form die is one that produces a part from a developed blank, using an external binder to control the metal flow. An open-end draw die, like a conventional draw die, produces a part from a rough blank and requires a subsequent trim die to remove the binder scrap.)

Severe shape transitions in the part geometry are more prone to distortion or splitting problems with HSS. Shape transitions must be more gradual. Of particular concern are stretch-flange areas, as these have a high potential for splits that cannot be corrected without part change concessions, as shown in figure 13 below.



1 Convex Curvature creates a shrink flange, whereby the final length of line is shorter than the initial length. The primary forming problem is buckle formation due to compression of metal.



2 Concave Curvature creates a stretch flange. All lengths must increase during the forming operation. Greater flange heights create greater elongations with danger of tensile failure. (splits)

Figure 13

Draw Dies, including open end draw dies

In draw development, it is necessary to maintain an even draw depth and length of line as much as possible. For parts with varying depth the binder may need to be higher than with mild steels at shallow cross-sections in order to match the metal flow requirement at the deeper cross-sections of the part.

The reduced elongation potential of HSS must be considered. As elongation potential decreases with higher strength material, draw and stretch-form operations become more limited. Form dies are better suited to some material/part design combinations.

HSS structural rail type parts must be processed for “draw action” form dies or open-end draw dies. Examples include motor compartment rails, rear longitudinal rails, roof rails, center pillars, cross bars, etc.

It is necessary to form as much of the part as possible to the full depth in the first forming operation. Due to the work hardening characteristics of HSS, reforming can result in splits or distortion.

Higher binder or pad pressure and press tonnage are required to maintain process control and form the part without buckles. Buckles on the binder surface can force the binder open with resultant loss of restraining force. In more severe cases, a double action draw press or hydraulic press cushion may be required.

Higher grades of die material may be necessary depending on sheet steel characteristics, the severity of the operation and production volume.

Prototype or “soft” draw dies for HSS should not be made of zinc based materials. A hard die such as boilerplate is recommended for these applications.

Form and Flange Dies

Part setup in form and flange dies must be planned to allow proper overbend on all flanges for springback compensation. Springback allowance must be increased as tensile strength increases; 3 degree allowance is typical for mild steels but 6 degrees or more is required for HSS. The product designer must allow enough open angle on side walls to permit overbending for springback in a minimum number of form and flange operations.

The punch radius also affects springback. This radius must be minimized to reduce springback, approximately 1 to 2 times metal thickness depending on strength of material. The flange steel radius affects side wall curl and springback on offset flanges. This radius must also be small to reduce springback of side flanges. Proper radii in part design must be considered as it is often difficult to change after the dies are in tryout.

Formed parts that have moderate to severe shape in the die plan view or elevation can have residual stresses after stamping. Residual stress will produce springback, twist and/or side-wall curl unless the process is planned to compensate for this characteristic of HSS. Flange steel side wall die clearances should be no more than one metal thickness. Die pressure pads that are intended to restrain metal flow must have sufficient restraining force to stretch the material at least 2%. Ideally, this elongation should take place near the bottom of the press stroke by increasing the restraining force. This will also help compensate for the effects of any HSS tensile strength variability. See sketches 5 & 6 on pages 36 & 37.

ADVANCED DIE PROCESS CONCEPTS

Recent die process research has proven the effectiveness of several unique processing techniques that address specific problems of working with HSS.

Draw Dies -

PROGRAMMABLE BLANKHOLDERS or pressure cushions are designed to provide a variable cushion pressure profile throughout the press stroke. These cushion systems usually consist of hydraulic cylinders and proportional valves connected to a programmable controller. They provide the flexibility of increasing or decreasing the pressure profile to suit the material being formed as opposed to an air or nitrogen system that can only increase pressure during the press stroke. They are also repeatable and eliminate many of the process variables associated with air and nitrogen systems.

When using this type of cushion, binder balance blocks in the draw die are not employed, as they are counterproductive to the concept of stepping the pressure profile and varying the restraining force, as shown in figure 14 below.

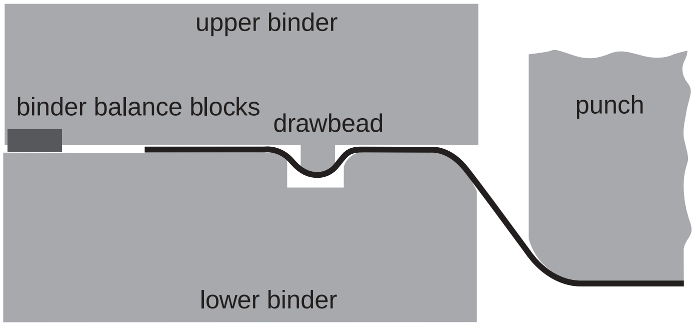
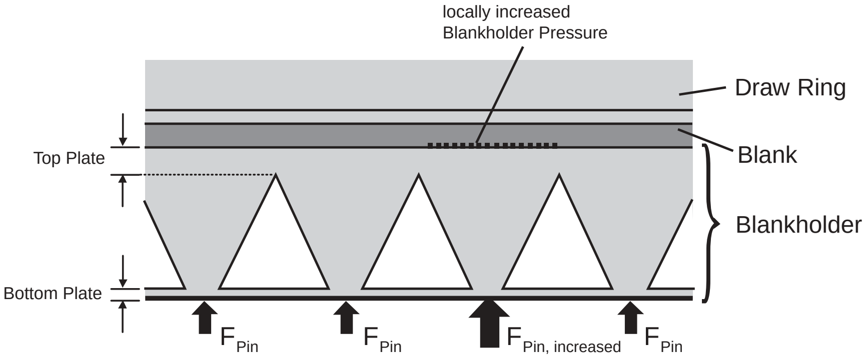


Figure 14

PULSATING BLANKHOLDERS are an extension of the programmable blankholder technology. By pulsing the proportional valves at approximately 5 to 15 hz, the binder pressures can be made to alternately increase and decrease which will allow the sheet to alternately slip and stretch. This is similar to the anti-lock brake system on automobiles. Increases in draw depth potential and reduced lubrication requirements are among the advantages.

FLEXIBLE BLANKHOLDERS are used in conjunction with programmable pressure cushions to allow pressure variations across the face of the binder. This type of blankholder requires pressure pin contact under binder areas where binder force is to be controlled. Other areas of the blankholder are of relatively thin casting, which allows the required flexibility on the binder face, as shown in figure 15 below.



Principle of the Flexible Blankholder

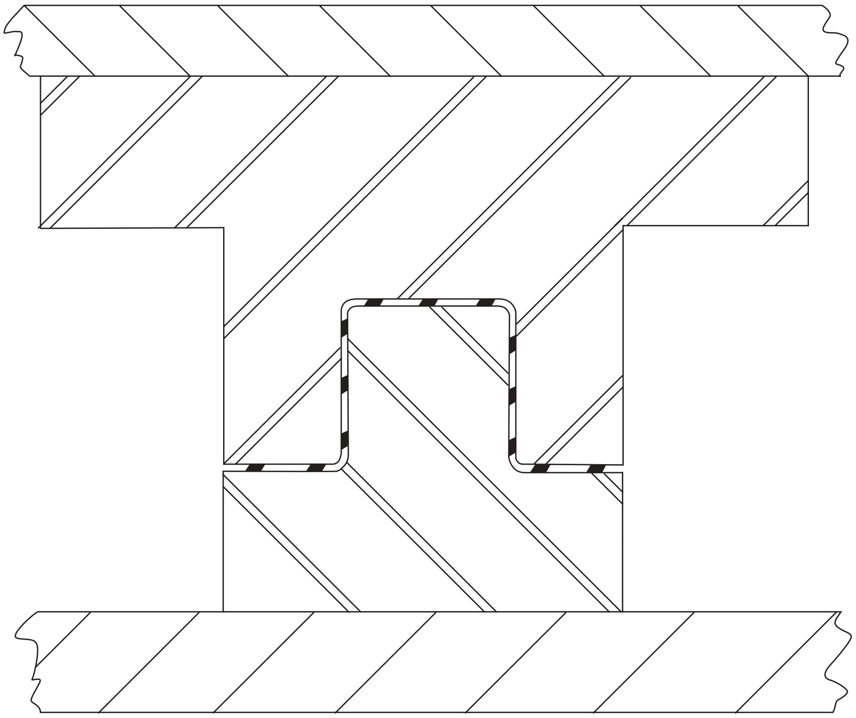
Figure 15

ACTIVE DRAW BEADS are used to increase the restraint of metal flow just prior to the press stroke reaching bottom dead center. This provides a stretching action on the stamping that will reduce residual stress and springback in the sidewall areas.

Form and Flange Dies -

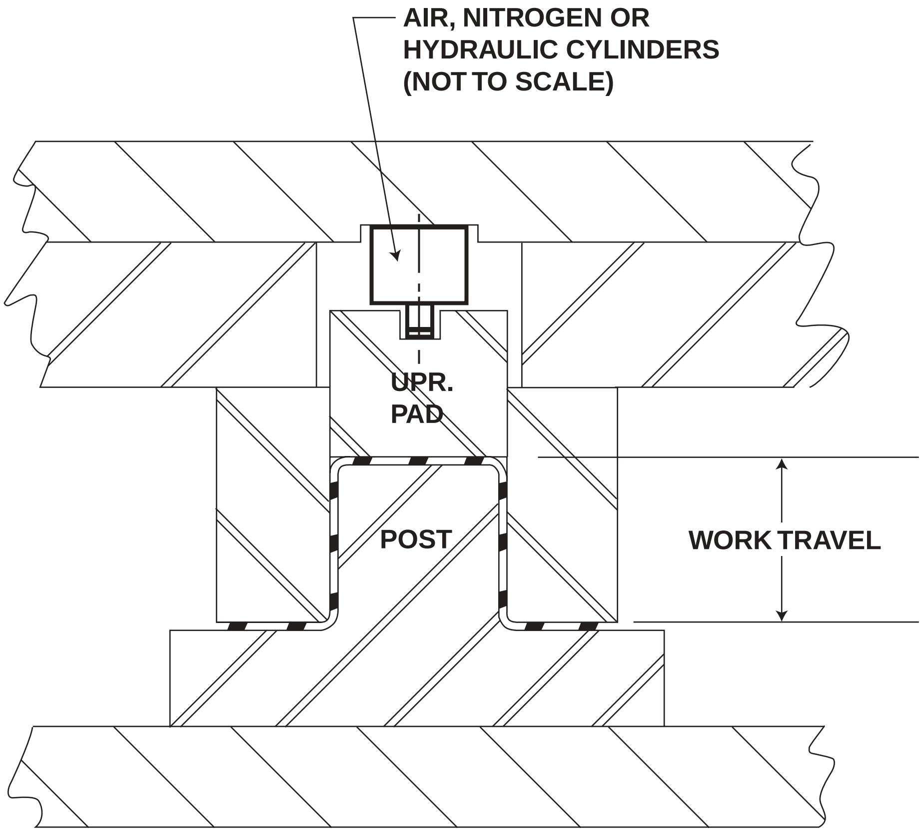
OPPOSING UPPER AND LOWER PRESSURE PADS (See Die Sketch #4) are effective in controlling distortion on channel shaped or “hat section” parts that have more severe shape in the plan view and/or elevation. These part shapes result in compression and stretching of metal during the stamping process which must be controlled in order to produce an acceptable part. This type of die has been avoided in the past due to the opposing pressure pads causing an “upstroke deformation” of the part. In order to use this process, the lower pad must be locked down during the press upstroke. Nitrogen cylinders are available with delayed return features for this purpose. A programmable hydraulic cushion system is even more effective.

POST-STRETCH OR “SHAPE SET” is a form and flange die process technique whereby the stamping is locked-up and stretched over the die post prior to the press reaching bottom dead center. A lower pressure pad with lock beads is normally designed to engage the sheet metal blank and upper die steels about 6 mm or less from bottom dead center. The resultant stretch in the part is effective in reducing residual stresses and part-to-part variation caused by non-uniform material. A lower pad lock-down device is required to avoid upstroke deformation of the part by the opposing pressure pads. See die sketches 5 and 6 and the GM #5 bar case study in section 6.



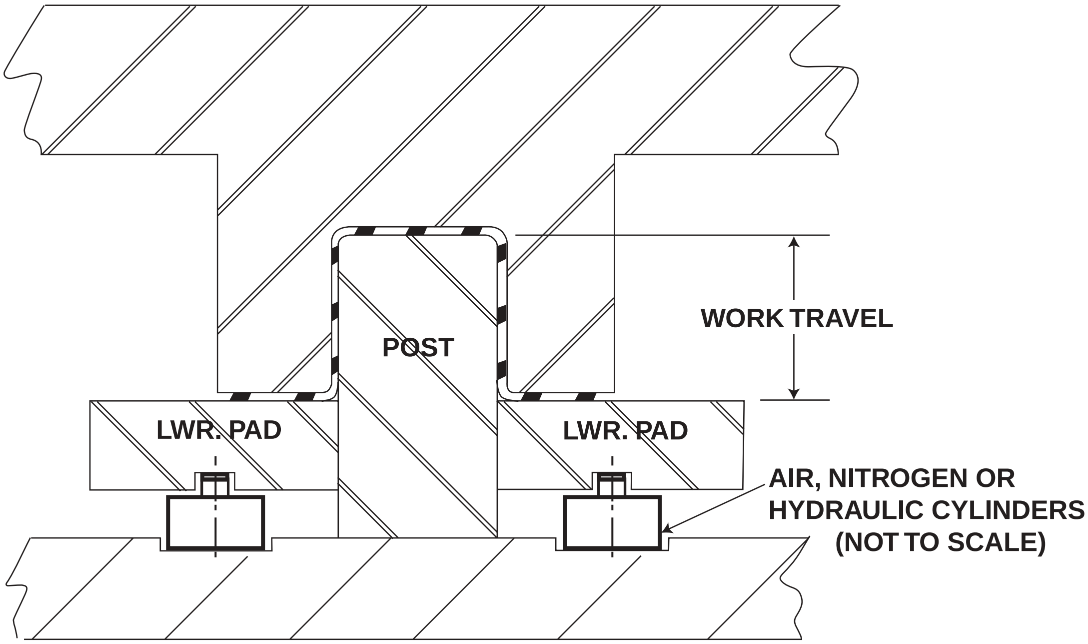
Sketch #1 – Solid Form Die (a.k.a. 2 - Piece Die)

This sketch illustrates the type of die that can be used for mild steel parts with minimal shape transitions. It is normally not an effective process for high strength materials. All part radii should be small with this process.



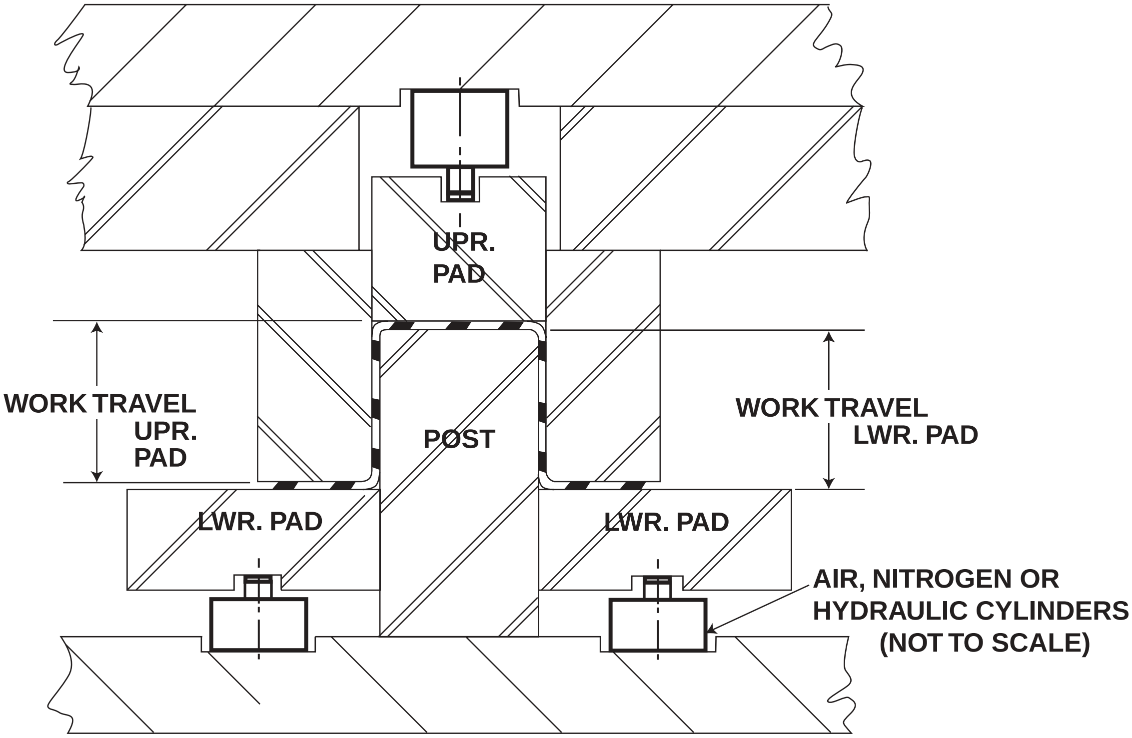
Sketch #2 – Form Die (Upper Pad)

Parts with contours in the die plan view or elevation will require an upper pressure pad. The holding pressure requirement increases with the material strength and with more complex part geometry. All part radii should be small with this process.



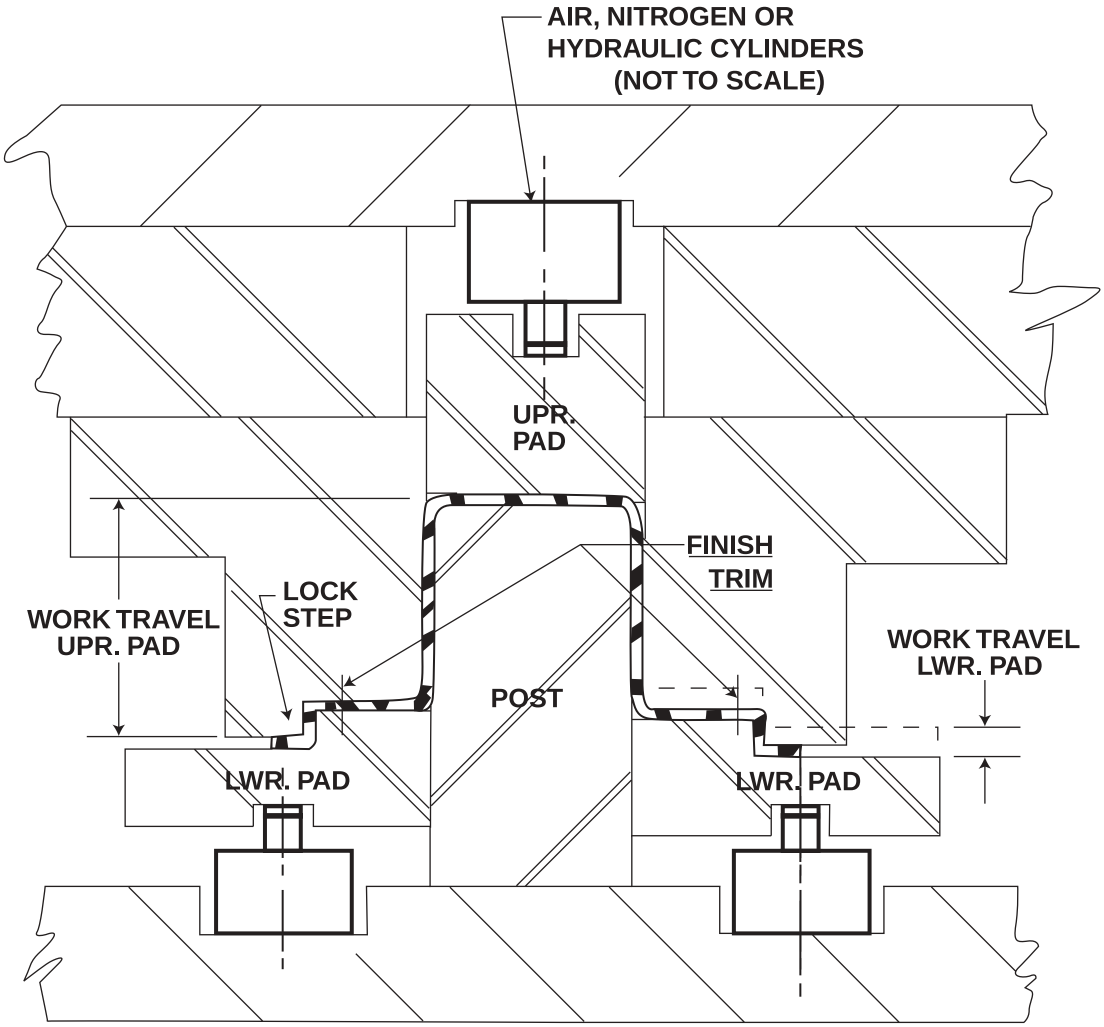
Sketch #3 – Form Die-Draw Action (Lower Pad)

Contoured parts with compression flanges will require a lower pressure pad to control buckling in areas of metal compression. Part contours in the plan view or elevation can cause metal compression during the forming process. Buckling due to metal compression increases with higher strength steels. This process is sometimes referred to as a “draw-action” form die. Post radii should be small, but flange radii may need to be slightly larger for higher strength grades when using this process. An oversized radius will increase sidewall curl.



Sketch #4 – Form Die-Draw Action (Upper and Lower Pads)

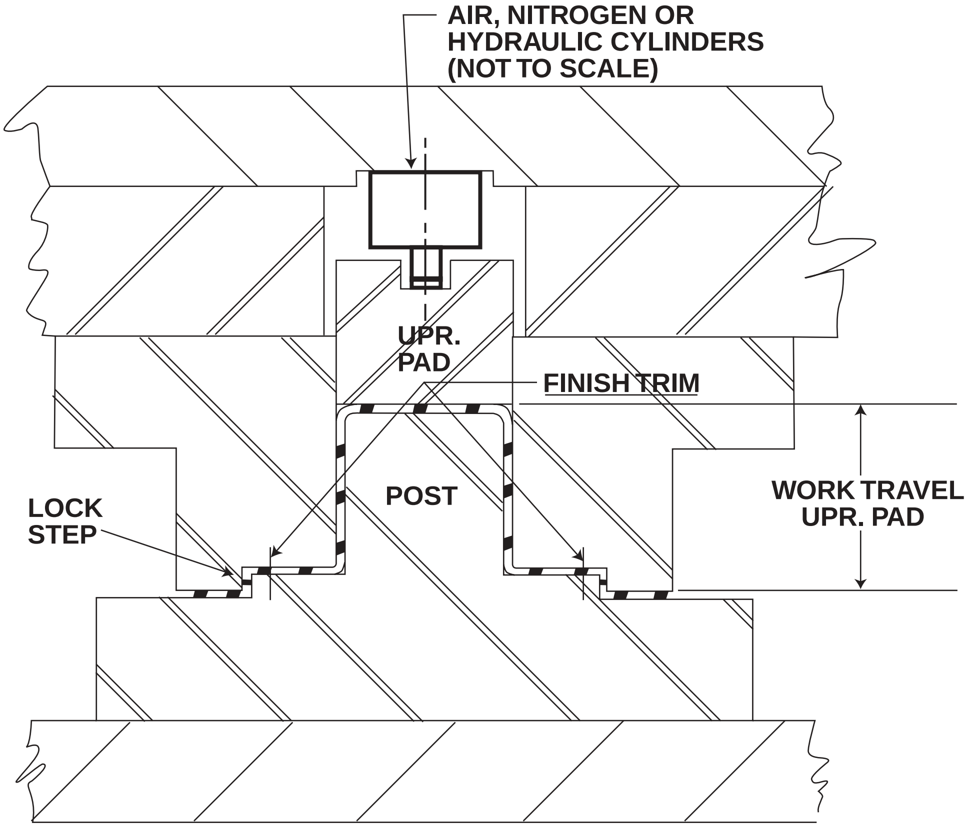
For high strength steel parts with more complex geometry, a die process using upper and lower pads may be required. A lower pad delayed return system must be employed with this two-pad process in order to avoid upstroke deformation of the part. This can be done with hydraulic cylinders, nitrogen cylinders (Delayed Return and Control or DRAC type) or a mechanical pad lock-down device. Post radii should be small to reduce spring back on walls. Flange radii may need to be slightly larger.



Sketch #5 – Post-Stretch Form Die (Upper and Lower Pads)

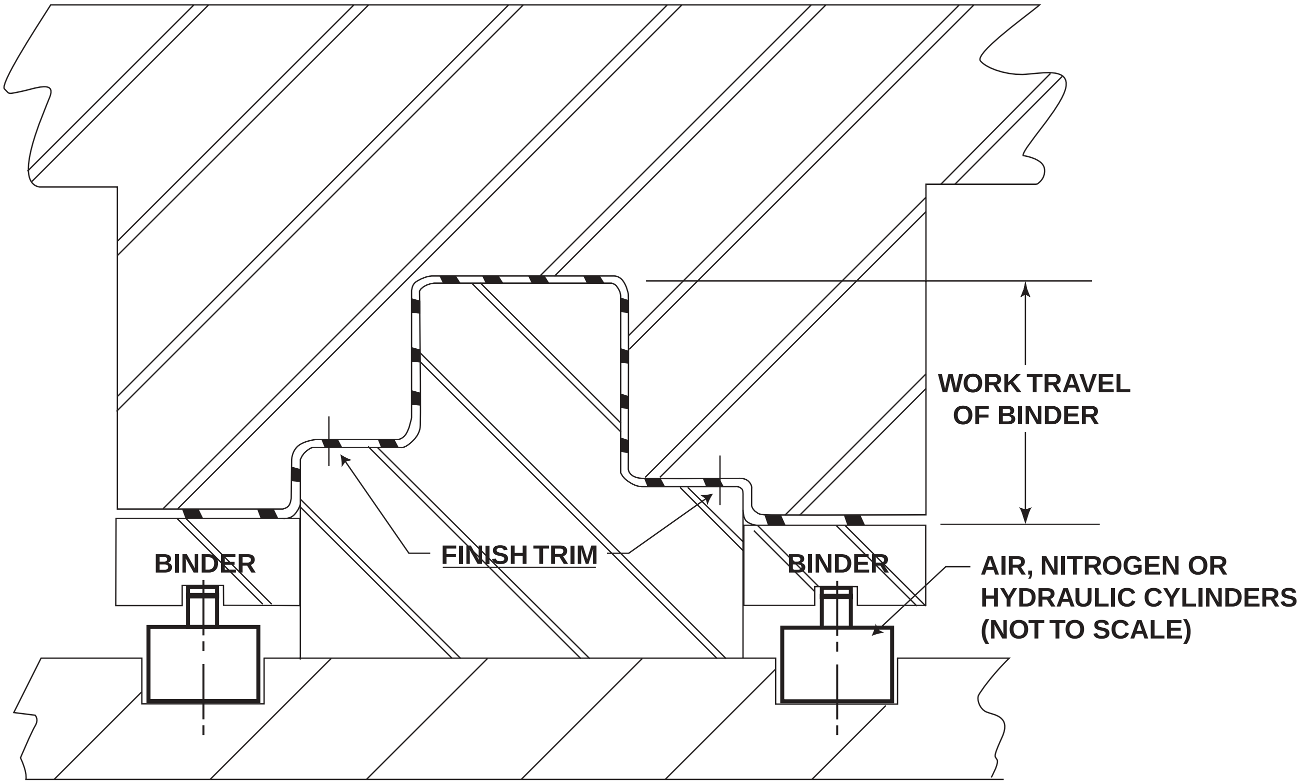
This process uses a lower pad with a lock step and high pressure to stretch the part over the die post before the die bottoms. The lower pad has only minimal travel, enough to stretch the part sidewalls at least 2%. This process can be very effective in reducing springback and sidewall curl of HSS stampings that do not have severe compression flanges. A lower pad delayed-return system is also required with this process.

Note: Parts with severe compression of metal on sidewalls or flanges will require a lower restraining pad action for the full depth of the part.



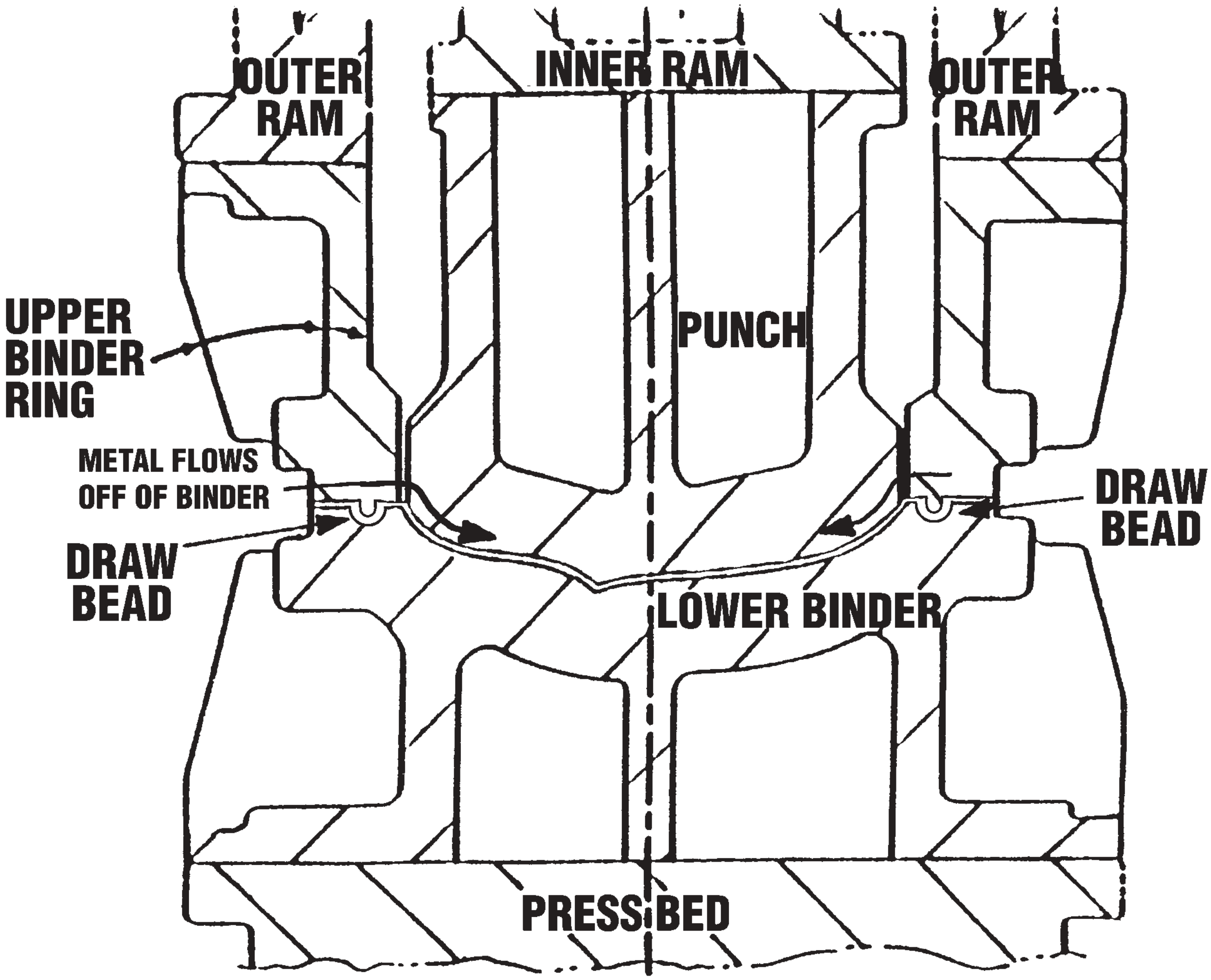
Sketch #6 – Post-Stretch Form Die (Upper Pad)

This variation of the post stretch process uses a solid lock step in place of the lower pad-mounted lock step. It also will stretch the part sidewalls. The amount of stretch will be determined by the depth of the lock step. This process is limited to those applications without compression of metal in side walls and flanges.

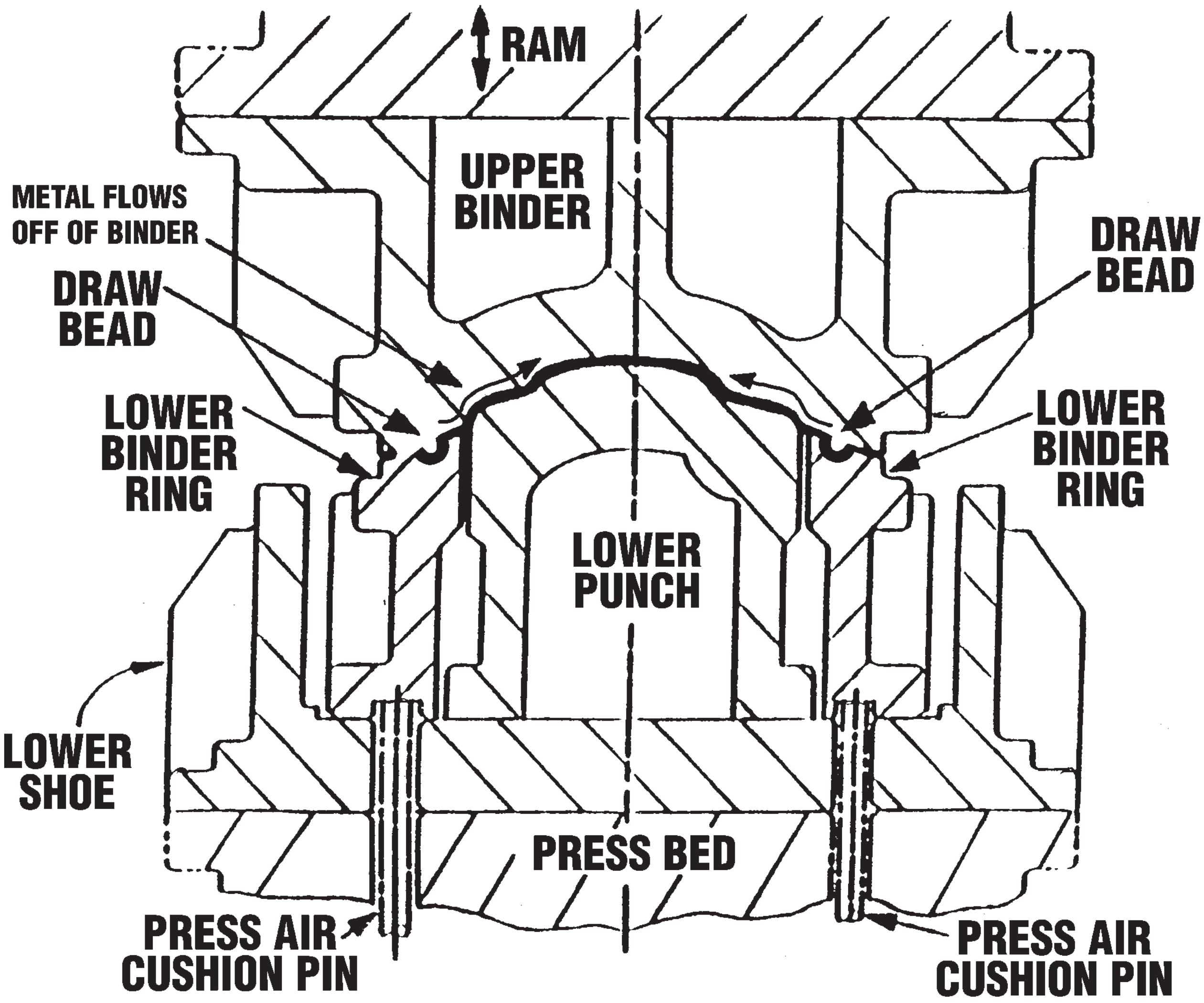


Sketch #7 – Draw-Die Single Action Press (Lower Binder)

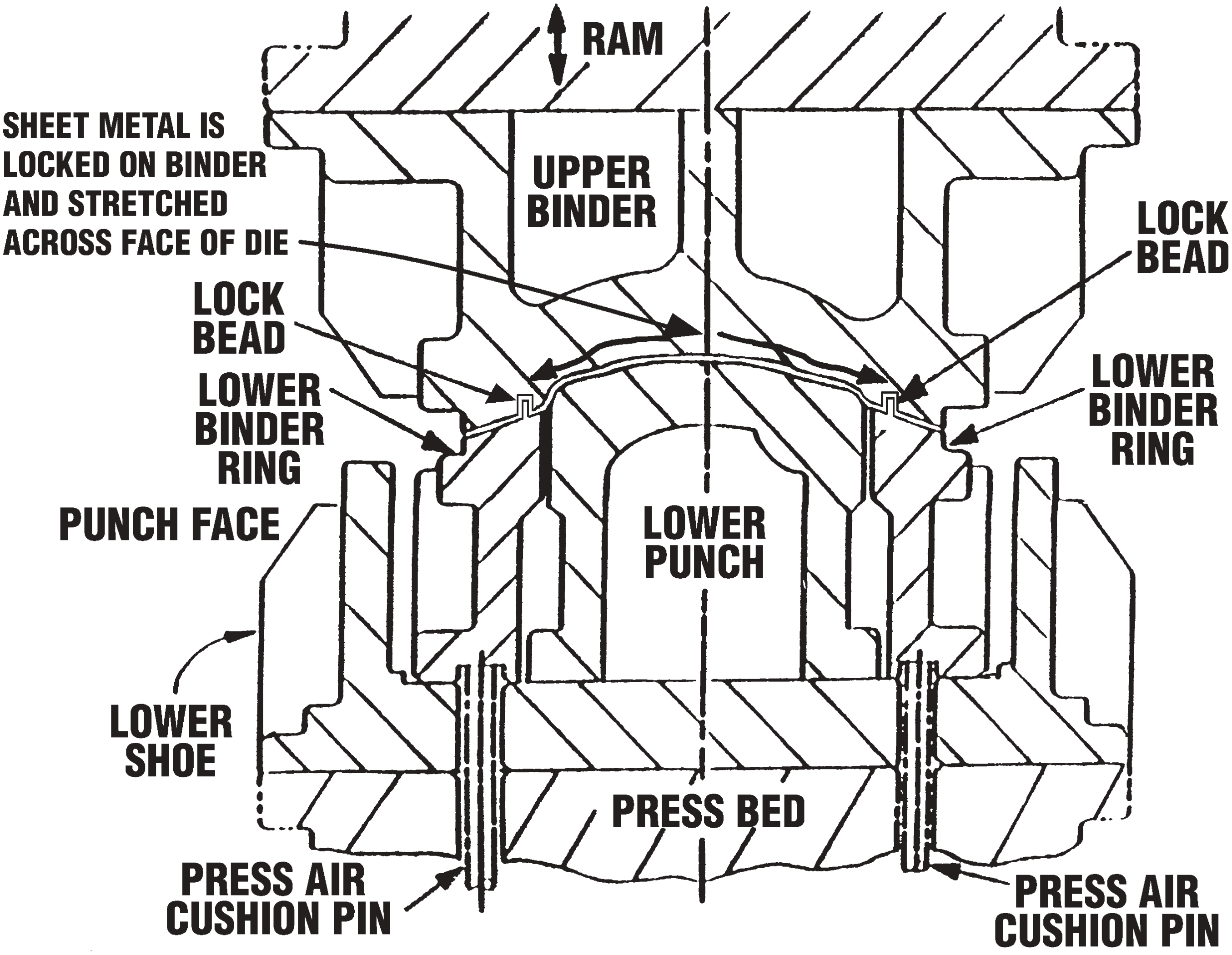
Some parts with more severe plan view and elevation contours, and/or unequal length sidewalls, will require draw die operations. The binder pressure can be provided by die-mounted cylinders or a press bed pressure system. This process uses a rough blank and requires a subsequent trim die to remove the binder scrap. For HSS parts of 270 MPa (40 KSI) and higher, an open-end draw die is recommended.



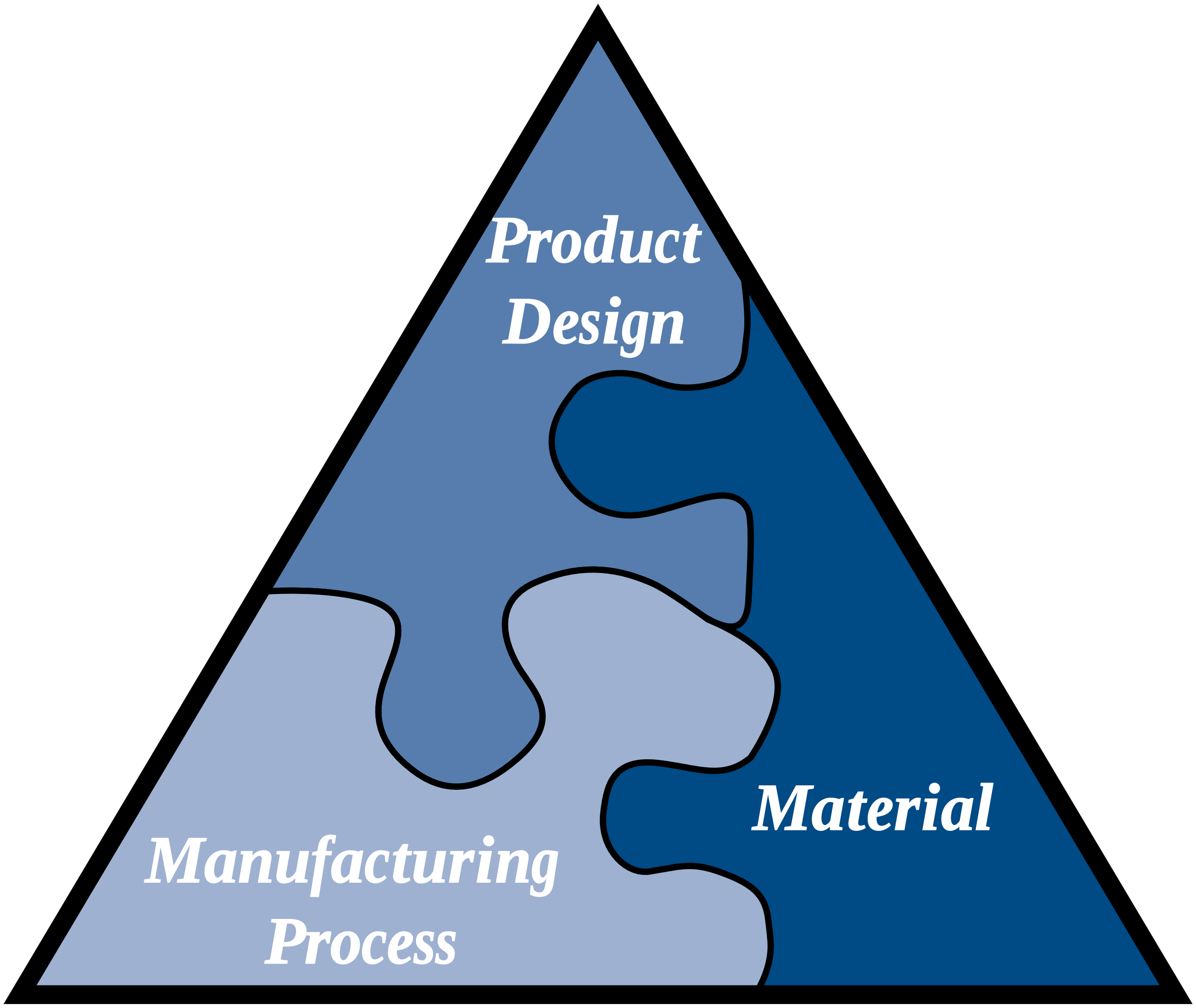
Sketch #8 – Double Action Draw-Die. This type of die requires a double action press. It is used primarily for drawn panels with large surface areas.



Sketch #9 – Air Cushion Draw-Die. This type of draw die runs in a single action press. Cycle time is reduced by approximately 25% from the double action press.



Sketch #10 – Stretch-Form Die. The stretch form die is used to induce bi-axial stretch and work hardening in outer panels. The result is a stiffer panel with better dent resistance. However, panel depth is limited.


Product Design
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General Guidelines for Die Design and Construction

Draw Dies

Higher than normal binder pressure and press tonnage is necessary with H.S.S. in order to maintain process control and to minimize buckles on the binder. Dies must be designed for proper press type and size. In some cases, a double action press or hydraulic press cushion may be required to achieve the necessary binder forces and control. Air cushions or nitrogen cylinders may not provide the required force for setting of draw beads or maintaining binder closure if H.S.S. is of higher strength or thickness.

Draw beads for H.S.S. should not extend around corners of the draw die. This will result in locking out the metal flow and cause splitting in corners of stamping. Draw beads should “run out” at the tangent of the corner radius to minimize metal compression in corners, as shown in figure 16 on page 47.

Better grades of die material may be necessary depending on the characteristics of the HSS, the severity of the part geometry, and the production volume. A draw die surface treatment, such as chrome plating, may be recommended for outer panel applications.

Form and Flange Dies

Part setup in form and flange dies must allow for proper overbend on all flanges for springback compensation. Springback allowance must be increased as material strength increases; 3 degrees for mild steels, but 6 degrees or more for HSS.

Punch radii must be fairly sharp. 1t for lower strength steels. Higher strength steels may require larger radii, but keeping them as small as practical will reduce springback in the sidewalls.

Flange steel die clearance must be held to no more than one metal thickness clearance to reduce springback and sidewall curl.

Form and flange steels should be keyed or pocketed in the casting to avoid flexing.

Flange steels should be designed to wrap over and coin the flange break in order to set the break and reduce springback. See figure 17 on page 48.

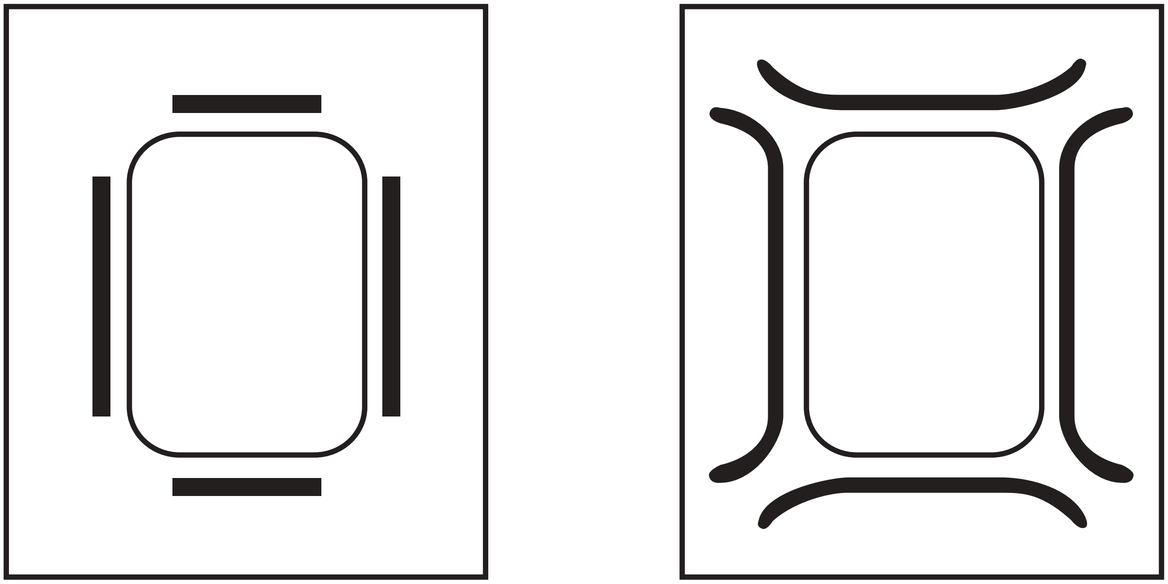
Die strength must not be compromised with light-weight die construction. High strength steel will require a stiffer die to resist flexing and the resultant part distortions, especially for channel or “hat-section” parts. This type of part can also cause serious die damage if double blanks occur.

Cutting Dies

To reduce press tonnage requirements and extend die life, a minimum shear of four to six times metal thickness in twelve inches of trim steel length is recommended.

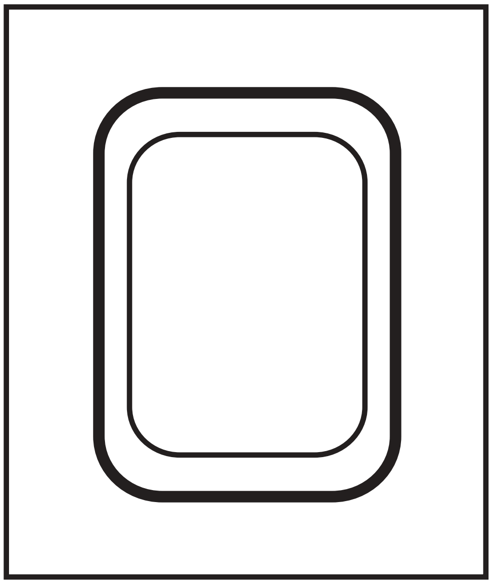
To reduce die maintenance, maximum trim angles should be about 5° to 10° less than those used for mild steel. Trim steels should be keyed or pocketed in casting to avoid flexing. Die clearance should be 7 to 10% of metal thickness.

Drawbead Types



Conventional Drawbeads

Run-out Drawbeads
For H.S.S.



Lock Beads
for Stretch-Form Die

Figure 16

SPRINGBACK SOLUTIONS

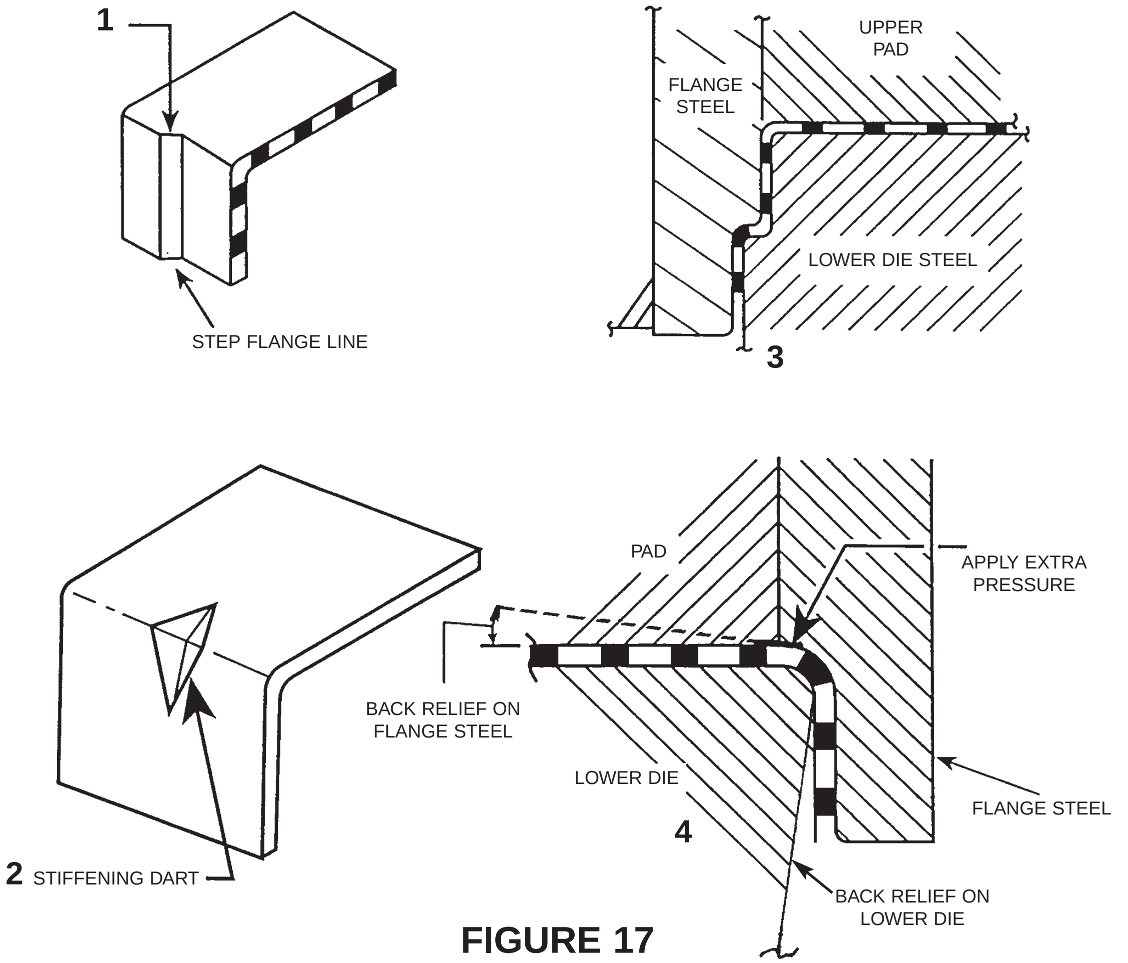
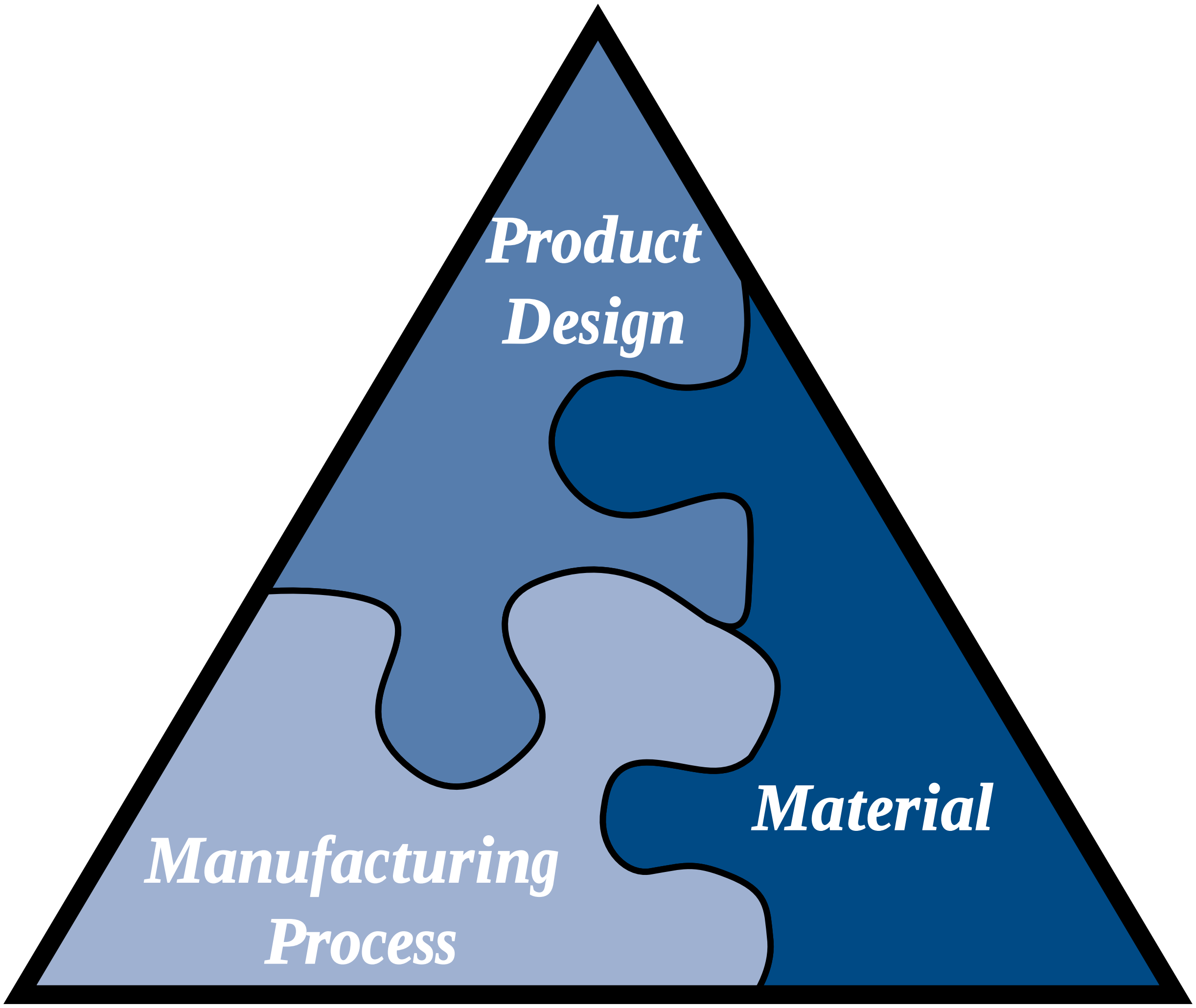


FIGURE 17

1. Providing a vertical step in the flange stiffens and straightens the flange, stopping sidewall curl as well as springback.
2. The addition of stiffening darts helps maintain a 90-degree flange.
3. By adding a horizontal step along the flange, the flange is stiffened, resulting in reduced springback.
4. Back relief on the upper flange steel allows for extra pressure to be applied futher out on the formed radius.


Product Design
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General Guidelines for Die Tryout

Draw Dies

Higher draw die binder pressure and press tonnage will be necessary in order to maintain process control and draw parts without buckles. A double action press or a press with hydraulic cushion may be required in some cases to achieve the required binder forces.

HSS draw die operations will require sheet steel lubricants that are formulated for extreme pressures. Mill oils will not provide sufficient lubricity for most applications. Pre-lubes or dry film lubricants may be necessary for process control.

Die plan view punchline corner radii should be larger than with mild steels to avoid buckling in the corners of the binder.

Stretch Form Dies

Lock beads may require modification to avoid cracking or tearing with higher strength grades of HSS. Opening side walls of beads and enlarging corner radii will avoid cracking of high strength sheet steel. Lock beads should be continuous around the punchline for stretch form dies.

For large panels from stretch-form dies, such as a roof panel or hood outer, elastic recovery may result in a shrunken panel that does not fit well on the male die member of the trim or flange dies. This problem is corrected by adding a “plus” factor to the overall part dimensions of the draw die or stretch form die punch. This “plus” is usually no more than 2.5 mm at the center of the sides and the front, tapering to 0.0mm at the corners of the part profile on the punch. Finish part profile is defined, and plus is removed, in the main flange die

Form and Flange Dies

The punch radius should be fairly sharp with 1 or 2t used for lower strength steel. HSS may require larger radii, but as small as practical to reduce springback of sidewalls.

The flange steel radius affects sidewall curl and springback on any offset flanges. This radius should also be small to reduce springback of side flanges.

Overbend for springback compensation must be increased as tensile strength increases: 3 degrees is standard for mild steels, but 6 degrees or more will be required for HSS.

Flange steel die clearance should be tight, maintaining no more than one metal thickness clearance to reduce springback and sidewall curl.

Cutting Dies

To reduce press tonnage requirements and extend die life, a minimum shear of four to six times metal thickness in twelve inches of trim steel length is required.

Die clearance should be 7 to 10% of metal thickness for HSS.

To reduce trim steel maintenance, reduce maximum trim angles by about 5° to 10° from those used for mild steel. Trim steels should be keyed or pocketed in the casting to avoid flexing.

Die Tryout When Using Bake Hardenable Steel

In order to obtain the maximum benefits of BHS, tryout of the dies should be performed as follows:

Circle grid analysis must be performed on a panel before any die rework is attempted. With the gridded panel as a reference, the die can be modified to provide a minimum biaxial stretch of 2.0%. Stretch-form or draw dies are best for this material.

For rough or functional tryout, it is possible to use mild steel with a 6% to 8% gauge increase to perform the normal process of die preparation. This alleviates complications when the BHS strengthens between each die being tried out. The reason for this is the time lag that normally occurs between a panel being formed and its use in the next operation.

When the entire line of dies is ready for approval, all dies must be set in line. Panels should be run through all the die operations consecutively. This will avoid some of the strengthening effects of time delays between stamping operations that can cause variation in panels. Dimensional approval of the panel will be most difficult if this procedure is not followed.

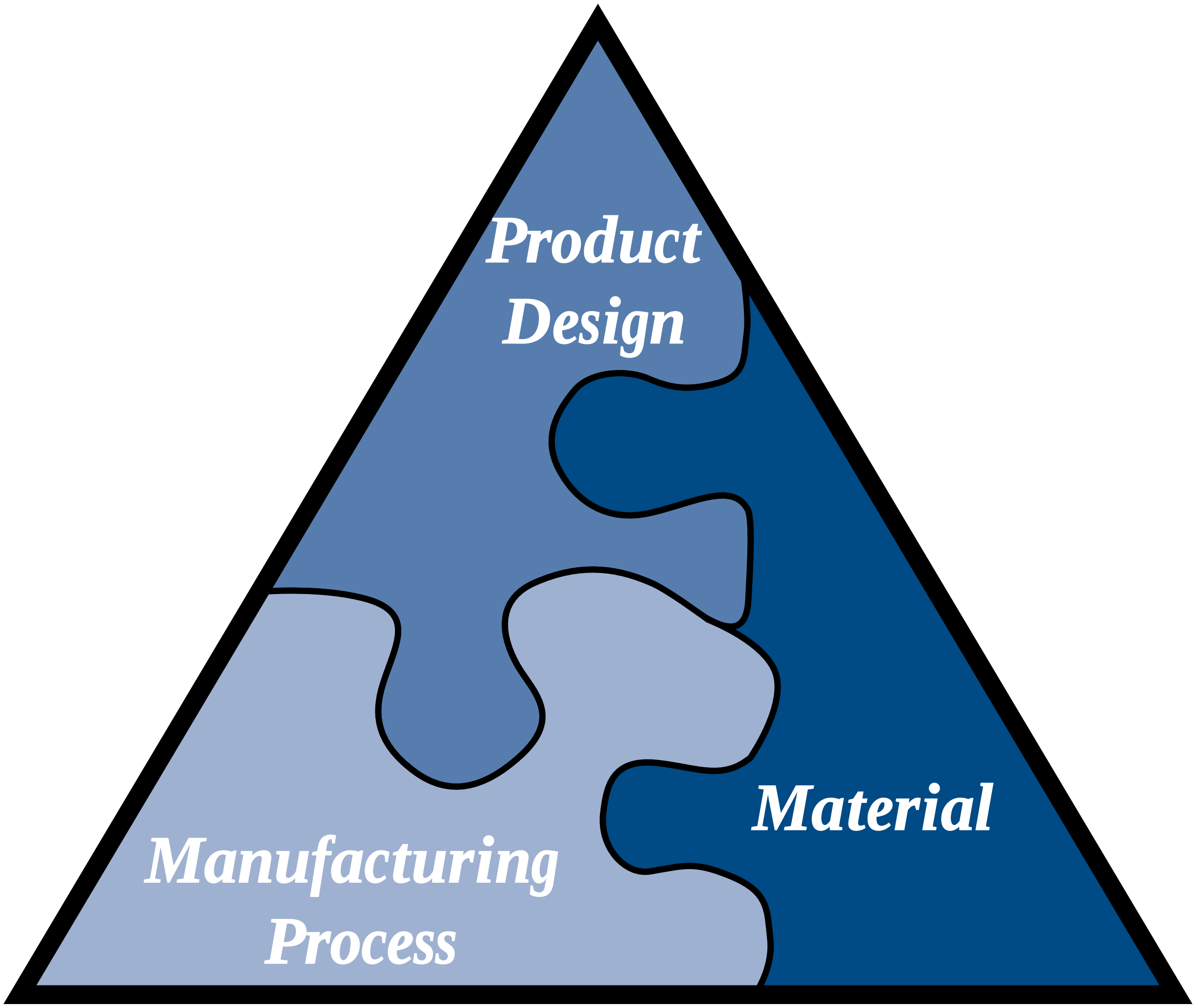
The strengthening reaction in the BHS can cause dimensional variation in flanges since springback will vary with time as the strength increases. This is why running the panel through all die operations consecutively is crucial to a successful buyoff.

Part Buyoff

To reduce the part buyoff time and eliminate many hours of tryout time, the benefits of functional build must be considered. This procedure has been proven to save time and money by concentrating on an acceptable sub-assembly rather than making each stamping to part specifications. Those parts that are easiest to change are revised to suit the sub-assembly dimensional targets. Those parts that do not affect the sub-assembly quality are not changed, but the detail part specifications are revised. The functional build process will eliminate excessive tryout hours if used for part buyoff on HSS stampings.

In addition to saving tryout time and die rework costs with functional build, lower part variation can also be realized. Two dimensional challenges faced by the die maker when first trying out dies are to reduce the dimensional variation from nominal specifications, and to reduce the short term variation from part to part. The typical priority is to first minimize part-to-part variation and later address nominal deviation. A strong argument for this strategy is that the deviation from nominal is not precisely known until a dimensionally consistent part can be evaluated. The results are a dimensionally consistent part even though a number of checkpoints may deviate from nominal, and perhaps even be out of tolerance. In many situations when dimensions on the die are reworked to shift them closer to nominal, they become less stable and result in higher part-to-part variation. The functional build philosophy evaluates the acceptability of the part after it becomes stable, and before minor dimensional shifts are made. Large deviant or critical dimensions may be identified for rework even with functional build. There are dimensions that can often be spared rework based on a functional build approach. In these cases, the part remains more stable and the die more robust because less rework occurs while attempting to shift dimensions.

For more information on functional build, refer to the Auto/Steel Partnership publication. “Event-Based Functional Build: An Integrated Approach to Body Development”.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Below is a glossary of terms used in this manual or likely to be encountered in die design and/or the stamping production process. They are grouped, not alphabetically, but by association.

Draw die – A die in which sheet metal is radially compressed on the binder and stretched as it is pulled off the binder and into the die cavity by the punch. Most automotive draw die stampings will have radial compression primarily in the corners of the stamping. Draw stampings for parts such as cups and cans will have radial compression around the entire punchline.

Open-end draw die – A die process similar to a draw die, but with little or no compression of the sheet metal due to the absence of closed corners at the ends of the stamping. A rough blank is used and a subsequent trim die operation is necessary, similar to that required for the draw die process. This is a recommended process for higher strength steel structural members such as rails and crossbars.

Draw-action form die – A form die in which an external pressure pad (similar to a binder) is used to control compression and buckles on flanges during the deformation process. This type of die normally utilizes a developed blank which eliminates the need for a following trim die operation. This is a recommended process for “hat section” parts with compression flanges.

Air draw – A draw operation performed in a single-action press with blankholder force supplied by air or nitrogen pressure cushion.

Draw development – The process of developing a die-setup for the workpiece, including the flange trim angles, addendum sheet metal and binder surfaces in order to design a draw die and subsequent trim die operation.

Blank – A precut sheet metal shape ready for subsequent press operation. Developed blanks are produced in blank cutting dies. Rough blanks are produced in shear lines or cutoff dies.

Developed blank - A flat sheet steel blank with a profile that can be used to produce a finished part with a minimum of trimming operations. This type of blank is used primarily in form dies.

Rough blank – A flat sheet steel blank with a rectangular, trapezoidal or chevron periphery. These blanks are used for draw die or stretch-form die applications.

Binder – The upper and lower holding surfaces that control sheet metal flow into the draw die cavity.

Blankholder – That part of the draw die binder which has pressure adjustment.

Programmable blankholder – A blankholder actuated by a press or die cushion that can be programmed to vary the pressure profile during the draw die process. HSS stampings can benefit from increased cushion pressure at the bottom of the press stroke.

Pulsed blankholder – A programmable blankholder that cycles the amplitude and frequency of the pressure profile to allow the sheet metal to alternately slip and stretch.

Flexible blankholder – A blankholder designed to apply specific pressures to target areas of the binder surface. Controllable pressure sources are required under each target area. The blankholder must be designed to allow minor flexing.

Active draw beads – Draw beads that can be actuated near the bottom of the press stroke to increase restraint of the sheet metal flow off the binder. This is intended to provided “shape set” for HSS stampings.

Punchline – The die plan view of the draw die punch periphery.

Stretch-form die – A die similar to a draw die in which the sheet metal is locked out at the binder surface. The sheet undergoes bi-axial stretch to form the part. In theory, sheet metal is not compressed during the deformation.

Post-stretch form die – A form die in which the sheet metal stamping is locked out and stretched over the die post or punch, shortly before the press reaches bottom dead center. This is done to reduce residual stresses that cause springback and other distortions in HSS stampings.

Shape set – The result of the die action on the part in a post-stretch form die. The term could also be applied to the results of a draw die process with a programmable blankholder or active draw beads.

Form and flange die – A form die that produces part surface contours, or part shape, as well as peripheral flanges. Usually, a developed blank is used which reduces the need for trim die operations.

Upstroke deformation – Damage to the stamping caused by the action of opposing pressure pads in some types of form dies. This occurs as the press is on the upstroke and the opposing pressure pads deform the part. To correct the problem, the lower pad must be locked down during the press upstroke.

Single action press – A press with a single slide to activate the die.

Double action press – A press with inner and outer slides to activate draw dies. Usually, the outer slide drives the blankholder and the inner slide drives the punch.

Residual stress – That stress remaining in the sheet metal as a result of the stamping operation.

Elastic recovery – The reaction of sheet metal to residual stress. The reaction is increased with higher strength steels.

Process capability – The ability of the die process to maintain variation within part tolerances.

Process variation – Variation has two components. One is the variation caused by differences in the run-to-run press and die setups. The second is the part-to-part variation within the same run caused by process variables such as lubrication, cushion pressure, die temperature, non-uniform material, etc.

Bake hardenable steel – A low carbon, cold formable sheet steel that achieves an increase in strength due to age hardening after forming, and accelerated by the paint baking process.

Dual phase steel – A low carbon, cold formable high strength sheet steel obtaining additional strengthening during forming and consisting of ferrite and martensite phases in the microstructure.

DQSK – Drawing Quality Special Killed Steel, a highly formable grade of mild steel usually aluminum deoxidized and sometimes referred to as DQAK, Drawing Quality Aluminum Killed.

HSLA – High Strength Low Alloy Steel. These steels generally contain microalloying elements such as titanium, vanadium or niobium which increase strength by precipitating hardness.

HSS – High Strength Steel. Steels of higher yield strengths as defined in SAE standard J 2340.

IF Steel – Interstitial Free Steel. Highly formable steel in which small amounts of elements such as titanium or niobium combine with interstitial elements such as carbon and nitrogen to enhance the formability properties without sacrificing strength.

TRIP steel – TRansformation Induced Plasticity steel. A low carbon, high strength sheet steel consisting of a complex microstructure of ferrite, austenite and bainite. TRIP steels increase in strength during rolling, forming and/or thermal treatment.

n-value – The work hardening exponent derived from the relationship between true stress and true strain. It is a measure of stretchability.

r-value – The plastic strain ratio. A measure of the normal plastic anisotropy as defined by the ratio of the true width strain to the true thickness strain in a tensile test. The average plastic strain ratio, or r bar, is determined from tensile samples taken in at least three directions from the sheet rolling direction, usually at 0, 45 and 90 degrees. The plastic strain ratio is a measure of deep drawability.

MPa – MegaPascal. A measure of force per unit of area. One Paschal = 1 Newton per square meter. One MegaPaschal =1,000,000 Newtons per square meter or 1 Newton per square millimeter. A measure of pressure in fluids and stress in materials.

KSI – Thousands of pounds per square inch. One KSI = 6.89 MPa. A measure of pressure in fluids and stress in materials.

Necking – Localized thinning that occurs during sheet metal forming prior to fracture. The onset of localized necking is dependent upon the stress state which is affected by geometric factors.

Major Strain – Greater direction of strain as measured from the major axis of the ellipse resulting from the deformation of a circular grid pattern on the blank.

Minor strain – The strain in the sheet surface in the direction perpendicular to the major strain.

Batch annealed – Steel which has been heated and slowly cooled as batches of coils to reduce brittleness and toughen the steel.

Continuous annealed – Steel which has been heated and slowly cooled as uncoiled sheet in a continuous thermal process.

CASE STUDY:

ACTION REPORT TRYOUT OF UNDERBODY RAIL

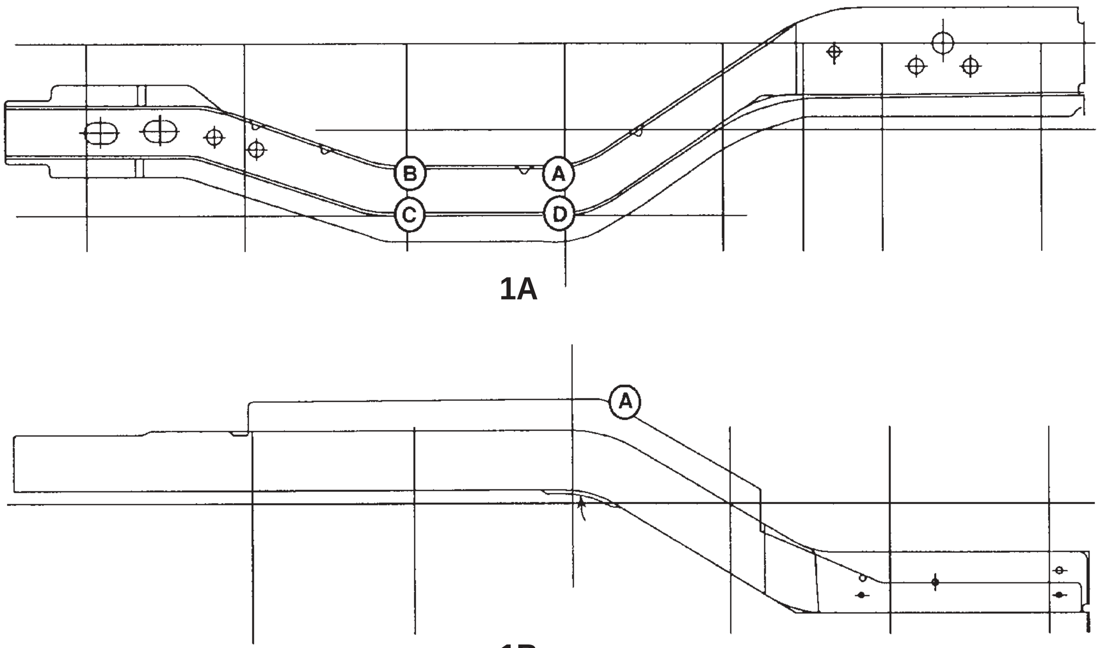
Background

The following report details the tryout of a set of Chrysler rear floor pan rails for the PL-Car (Neon) rear floorpan rail, Figure #1 below. The dies were built and tried out at Windsor Tool and Die using 1.88 mm 40 KSI High Strength Steel. It should be noted that the soft tool or prototype parts were not the responsibility of the construction source for the production dies. The line of dies consisted of five dies including a form die which gives the part its major shape configuration, the trim die which finishes all areas that cannot be controlled from the developed blank, a restrike die, a pierce die and another added restrike operation which brings the part into its final tolerance configuration.

Procedure

The process used for the PL rails was based on past processes used on similar parts. After performing the necessary grinding, gaging, spotting and nesting of the die, part forming was initiated. A step-by-step breakdown of the panel's forming process revealed that more balanced or equalized forming was required. To accomplish this, a major change to the binder was required to allow both sides of the hat-section shaped rail to begin forming at the same time. This resulted in a balanced forming operation. Binder pressure was also lowered, and equalizer blocks were added to allow the metal to run into the cavity of the die without wrinkling.

At the time the first form die was being tried out, tryout on the first re-strike die was also being performed. Using these dies, the initial formed parts were re-struck, resulting in splits in the areas that had been wiped to produce a vertical surface. This area also represented the highest stretch and deepest drawing portion of the forming operation. Due to these conditions, it was necessary to add metal to the blank and increase the radius from 1.5 mm to 3 mm at area A in Figure 1B below.



1A

1B

Figure 1
Chrysler PL-Car (Plymouth/Dodge Neon) Rear Floorpan Rail
Rail Shown in Side View (1A) and Plan View (1B).

The lower cavity walls of the forming die had to be opened from 0 to 3 mm, with additional radius increases of 5 mm to form a consistent part. A bead was also added to help control springback in the length of the part. Despite these efforts, the side walls remained out of tolerance. Consequently, it was determined that the first restrike operation could not bring the part into the desired shape as processed. To remedy this, an additional restrike die was incorporated into the process with stiffening darts used to help control springback. This allowed the part to be squeezed into a 90-degree condition in areas B-C and A-D in Figure 1A.

The trim and pierce dies were coordinated to accept the change incorporated into the forming operations. Trim lines were moved and holes adjusted to complete the rail.

Summary

The part was brought into tolerance by squeezing and re-striking the side walls to a 90-degree condition. It was discovered that once the hat-section shape was balanced, and the side wall flanges were true 90-degree corners, the part's twist was minimized. The addition of the final restrike die sharpened all of the radii.

Analysis

If soft prototype tooling had been used to prove production intent, much of the trail-and-error activities and many of the changes to the production dies could have been prevented. Also, the die process and design could have been improved to allow for the adjustments needed to bring the part into tolerance.

Recommendations

The following recommendations resulted from this case study:

- Design the part with short walls in the areas of inside corner configurations to minimize stretch.
- Attach mating parts so that the need to match in the corners is eliminated. This opens the tolerances in these areas and gives the construction source an opportunity to compensate for springback, distortion and metal thinning. The checking fixture will also reflect a more generous tolerance range in the corners.
- Use an adequate number of forming operations as a part of the process. This is easily determined when the build source also has the responsibility for prototype parts and the tools to make them. Having OEM engineering and manufacturing personnel work with the steel supplier early in the part development has shown to save time and money while producing a higher quality part.

CASE STUDY:

PL CAR FRONT SIDE RAIL (ENGINE COMPARTMENT) WEIGHT AND MAKEABILITY STUDY

Published by the A/SP High Strength Steel Design/Formability Task Force IRG (Industry Resource Group).

Figure 2
EXTENSION FRONT SIDE RAIL PART #4655084
Assigned production material .044 GAL.-50KSI

Rail is produced in two (2) die operations:

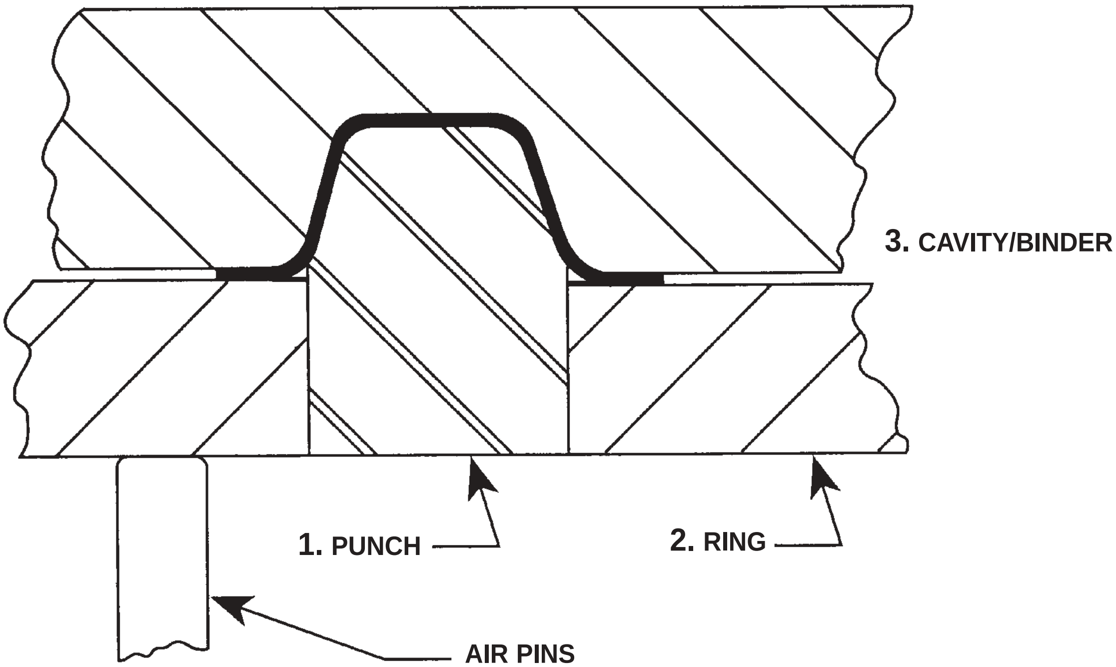
- 1st operation blank and pierce complete
- 2nd operation form complete

The original form die design consisted of a three-piece conventional air pin Draw Die, as shown in Figure 3. below.

1. Stationary lower punch
2. Lower draw ring on air cushion
3. One-piece upper cavity and binder

This design produced a part with extreme springback and curled side walls.

Figure 3



At the start of preliminary tryout, tight binder control, as would be used with conventional material, was used. Panels with few buckles were produced, but side wall springback and curl were severe. With additional tryout, it was found that by using higher binder/ring pressure the sidewall problems were reduced. At this point, parts were made with the lower ring in home position, the press cushion drained of air and additional improvements in eliminating sidewall springback and curl were realized.

Knowledge gained from a similar part made with HSS reversed the conventional forming practice of increasing draw radius size, and the entire edge of the upper cavity was welded to produce a smaller draw radius of .090" from the original .375". This eliminated springback on the lower surface shown in Figure 4 below.

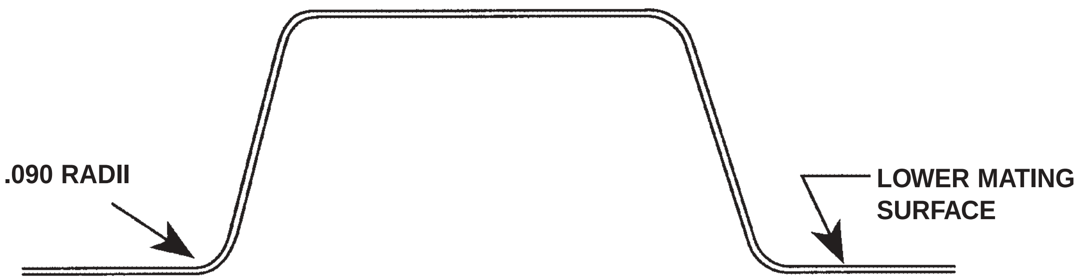


Figure 4

Parts that were very close to acceptable tolerance were produced and it was felt that the upper one-piece cavity should be changed to incorporate a separate pad with Nitrogen-activated cylinders. This die change would prevent the blank from bulging into the cavity on initial contact, as shown in Figure 5 below.

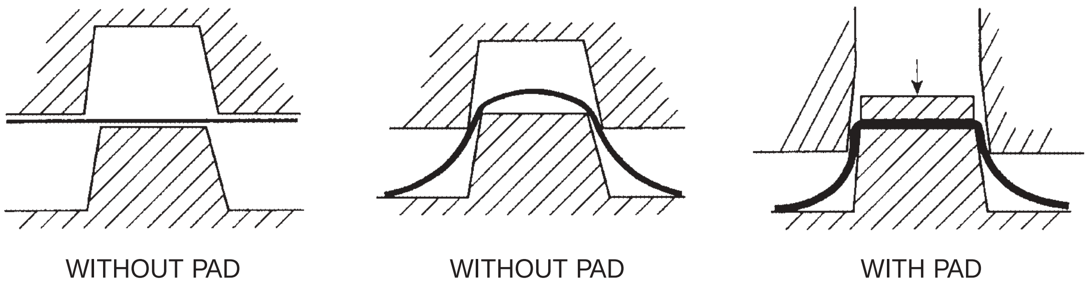


Figure 5

On making new parts with the upper pad on Nitrogen-activated cylinders, it was found that the quality of the stamping with respect to springback and curl showed no improvement and was somewhat worse. Two things were determined; first, the side walls of the upper die were breathing after cutting the pad out and leaving a doughnut-shaped ring; and second, by locking the pad in home position and allowing the blank to bulge into the cavity as shown in Figure 5, it was determined that as the die hit home, the excess metal or bulge on the top surface was flattened and the material was forced into the outside corners. The upper cavity was reinforced with heavy gussets to stop the breathing of sidewalls and hardened bottoming blocks were added to the pad, which was now allowed to float without Nitrogen pressure. This brought the tooling design back to a two-piece die.

Due to the fact that the depth of this channel-shaped part was not uniform and that design intent included open-angled walls, the die was changed away from the model from .000 to .030" inboard from point “A” to “B” respectively, shown in Figure 6 below, to compensate for springback.

Note: 0.0 to .030” from Point “A” to “B” will change Point “C” approximately .060".

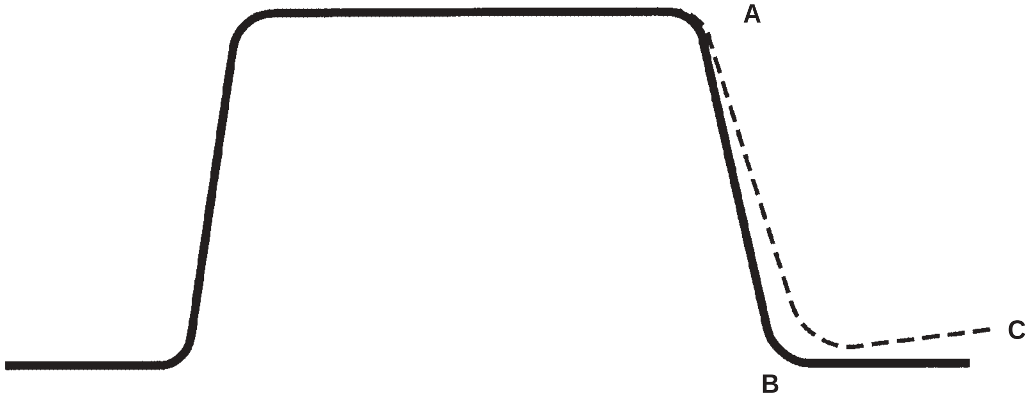


Figure 6

It was also possible to make parts using .039 GAL-60KSI. Additional springback compensation, however, would have been necessary in the dies.

What was learned from this example:
- Keep walls 90 degrees where possible.
- <u>NO</u> binder is required on straight channel-formed parts
- Start with less than metal thickness radii.
- Design tooling to be used for stamping HSS with added strength to avoid component breathing (flexing).
- Design the product with uniform depth, and length of line.
- Incorporate springback into tooling, based on strength of material to be used.

CASE STUDY: FRONT SIDERAIL

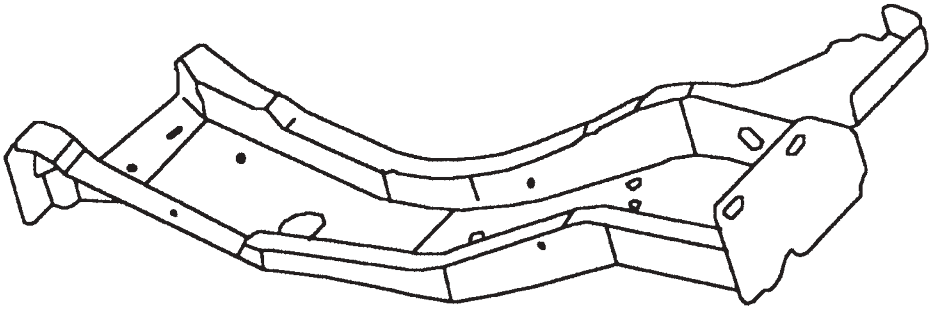


Figure 7

FRONT SIDE RAIL PART #4655064
Assigned production material .072 GAL. 40KSI

This part is produced in five die operations:

1-Rough partial finish blank and pierce gauge holes.
2-Form complete except end tabs.
3-Form end tabs and restrike complete
4-Finish trim

Design of second operation below (Figure 8).

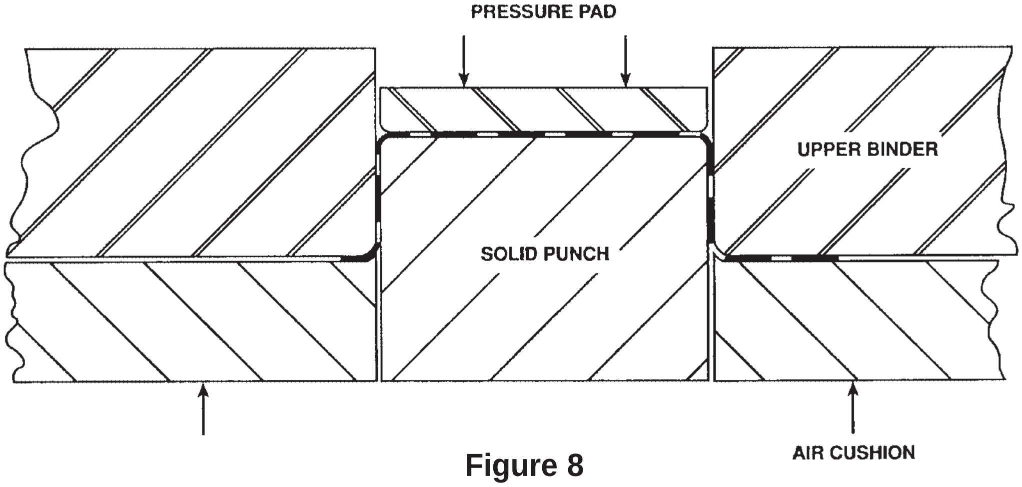


Figure 8

The parameters established in example #1 hold true for this part with following exceptions:

- Part shape (cross section) is a channel (see Figure 8) although depth and length of line vary through the entire length of part. The first form die was designed to keep depth of draw as uniform as possible, with finish form and flanged tabs in the second form die.
- Channel walls are not straight from end to end, creating a horn/elbow configuration.
- With the above mentioned part characteristics it is necessary to use a draw binder.

The use of a binder minimizes wrinkles in the horn/elbow area, which, if allowed to form, will cause restricted flow of material and result in fractured and/or lapped metal. The binder should be designed to allow absolute pressure control with the use of hardened steel balance blocks and a hardened steel binder surface to reduce galling and resist wear/surface distortion at metal compression points. Splits and wrinkles in the horn/elbow area were also reduced by blank changes. Material added in the wrinkled area added strength, which resisted lapping. The addition of a scallop in the split area increased the length of the line at trim edge and reduced splitting.

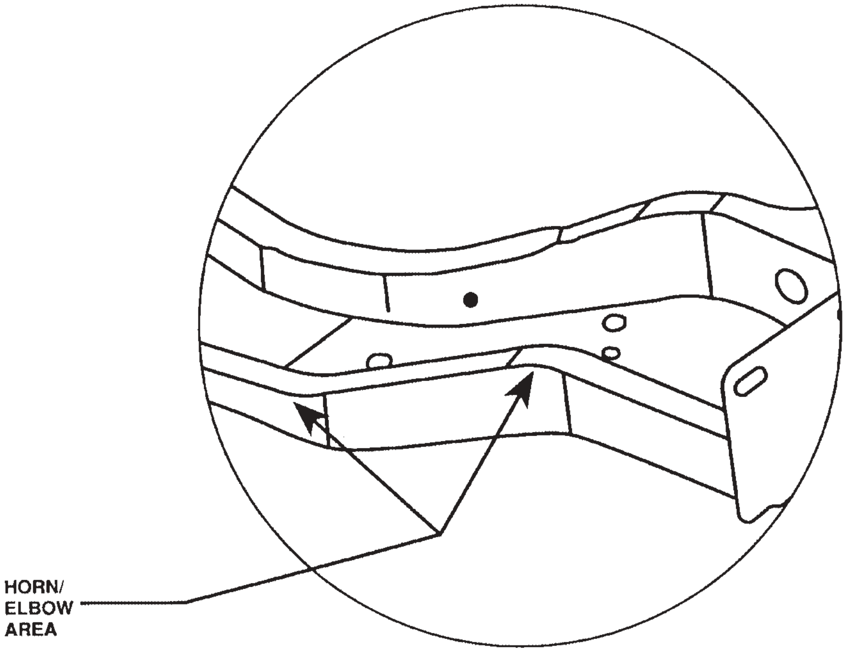


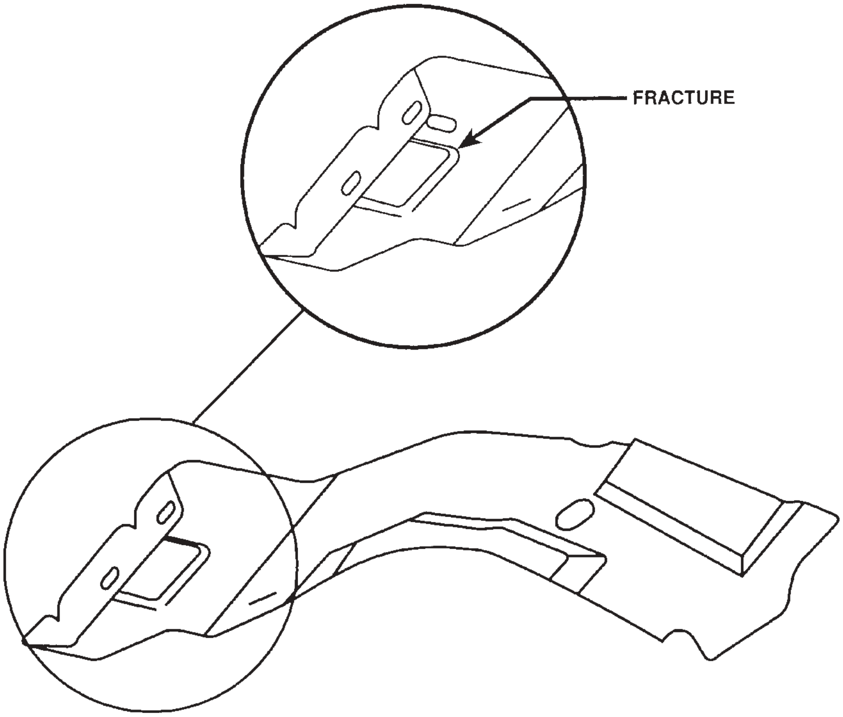
Figure 9

Since the process has two forming operations, the first form die design should be as uniform as possible for depth of draw and length of line off the binder. The second form operation should then be used to bring depth to design intent and overbend for springback where necessary.

Designing and processing hat section-type dies for the use of HSS such as that used with this part enabled production of quality parts with a weight reduction of 24%, the result of using thinner gauge, higher strength material.

Basic Guidelines
- Form channels as deep as possible with attention to uniform depth and length of line
- Avoid closed ends on channels.
- Utilize sharp die radii.
- High binder pressure.

CASE STUDY: REINFORCEMENT - FRONT SIDERAIL



REINFORCEMENT FRONT SIDE RAIL PART #4655062/3
Assigned production material .060 GAL. 50KSI

Figure 10

This part is produced in three die operations:

1-Blank and pierce (R & L)
2-Form complete (R & L)
3- Flange tabs and part (R & L)

The form die incorporates the use of gage pin holes for positive location and control. Trim lines and holes are developed on the blank. The form die consisted of a solid upper cavity with a floating lower pad, and solid lower pedestals to form the embosses.

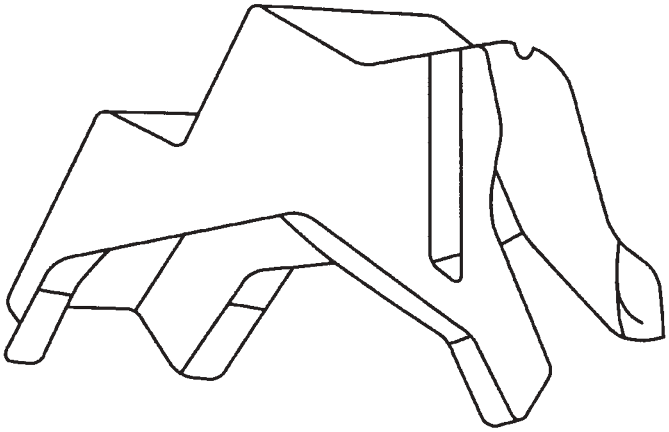
Parts produced during preliminary tryout were distorted from end to end and it was felt that this was caused by the amount of forming performed by the floating pad and by transition lines between the two surfaces having gradual slopes rather then sharp steep angles.

A pedestal was added to form the large embosses. Product design concessions were obtained to sharpen the slope on the three-sided emboss. These changes corrected the distortion and parts were produced with 50 KSI yield strength material.

The problem of a crowned surface at the outside edge on the length of the large emboss, which was to be flat, remained. This was caused by material stretch on three sides causing loose metal on the outside trim edge. This can be eliminated by adding formation or a stiffening flange. See Figure 10.

Quality parts were also produced with a weight reduction of 21% using lighter gauge, higher strength 60 KSI material. A small fracture was experienced in the two inside corners of the square opening. See Figure 10. Scalloping the corners in the blank prior to forming eliminated this problem.

CASE STUDY:RAIL - FRONTSIDE REAR



RAIL FRONT SIDE REAR PART #4655066/7
Assigned production material .072 GAL. 40KSI
Figure 11

This part is produced in three die operations:
1-Rough and partial finish blank
2-Draw, with a three-piece die on air pins
3-Restrike complete
4-Trim
5-Cam pierce

This is a 19"-long hat section-shaped part. This part was difficult to stamp because the length of line had large variation throughout. Sections ranged from a girth of 8" to 12" inches within distance of only 3 inches.

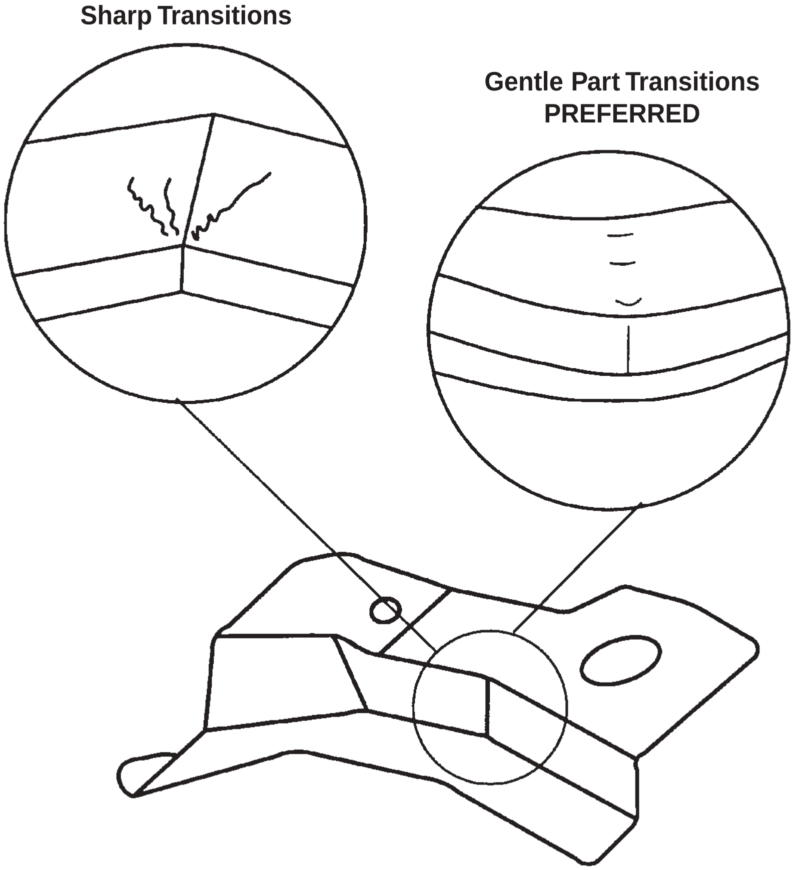
HSS has a reduced elongation from drawing quality material and will resist compression. If during the forming cycle, one area developed an excess metal condition, it would “overlap” at a given point or “fold over on itself,” then flatten out at the bottom of the press stroke, producing a double metal condition in the stamping.

It was critical in this type of stamping to use all of the “Guidelines.”

1. The first die should form as deep as possible.
2. Keep sharp binder draw radius.
3. Hardened steel, Ring surface
4. Use balance blocks, high ring pressure and tight die clearance. (Balance blocks are used to keep rings one metal thickness apart; high pressure is used to keep rings closed during the forming process.)
5. Die surface treatment such as chrome-plating or ion-nitriding is recommended prior to full production.

It appeared during initial tryout that even lower strength 40 KSI material would not produce an acceptable part. Using the guidelines above, acceptable parts were not only produced from the production material, .072" GAL 40 KSI, but also from .059 GAL 50 KSI for a weight reduction of 21%.

CASE STUDY: REINFORCEMENT - SIDERAIL INNER



REINFORCEMENT SIDE RAIL INNER PART #4655077/264
Assigned production material .055 GAL. 50KSI

Figure 12

This part is produced in three die operations:

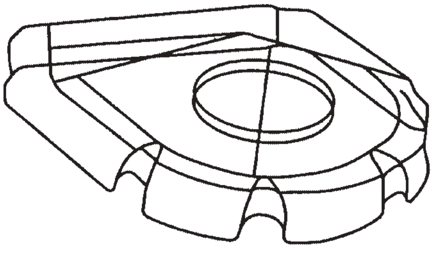
1-Form (from rectangular blank).
2-Trim
3- Flange
4- Pierce

The first die received a rectangular blank and formed the top surface plus flanges in the first bend. Both surfaces had sharp bends which at the point they intersected produced wrinkles due to metal compression. See Figure 12.

These wrinkles were minor with production material, but quite pronounced with the study material of .039" GAL 60 KSI. This condition would have been alleviated with product changes to produce larger and more gentle transitions.

Note: That the sidewall is not a mating surface.

CASE STUDY: REINFORCEMENT - FRONT STRUT MOUNTING TOWER



REINFORCEMENT FRONT STRUT MOUNTING TOWER PART #4655088/9
Assigned production material .092 GAL. 40KSI

Figure 13

This part is produced in three die operations:

1. Blank complete
2. First form
3. Second form

Parts produced with production material during initial tryout were unacceptable due to severe metal thinning at spherical corner. A concession was obtained to increase the size of the spherical radii and this reduced thinning to less than 10% with all study material.

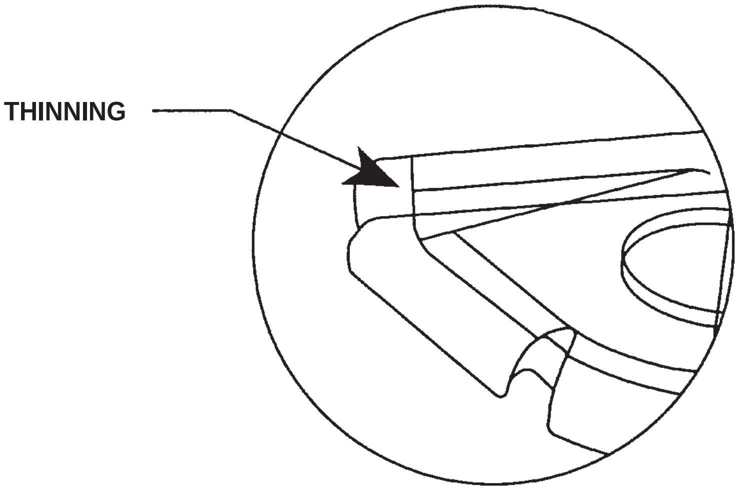


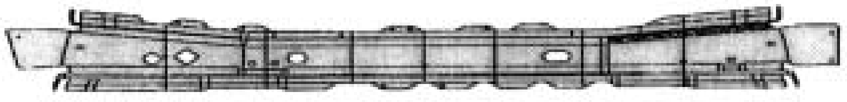
Figure 14

Some metal compression also was found in the top of the sidewall notches. Adding form in these areas would alleviate the condition.The .082" GAL 50 KSI study material produced acceptable parts with a weight reduction of 12%. Greater weight reduction could be realized successfully on this part with higher strength material.

CASE STUDY: BAR - COMPARTMENT PAN CROSS

Background

This report details the trial run of the Bar-Compartment Pan Cross @ Kickup (#5 Bar), part number 22592862, currently in production for a General Motors program at the Lansing Stamping Plant of the Metal Fabricating Division (MFD). The specified production material is 3.5 mm SAE 1008/1010 mild steel. Four trial runs were conducted by the Auto/Steel Partnership Team to evaluate a material change to 2.00 mm 50 ksi High Strength Steel (HSS). This material was selected to reduce mass without sacrificing the structural integrity of the underbody. The production version of this stamping is currently produced in a three-piece die utilizing an upper pressure pad and a fully developed, finish trimmed blank. The die used in this study was a duplicate of the production die with one exception; the addition of a lower pad with 6 mm travel to lockout the metal near the bottom of the press stroke. This process was intended to stretch the stamping and thereby reduce the sidewall curl and springback of the 50 ksi HSS. The main purpose of the project was to determine if the panel could be made from 40 or 50 KSI HSS, and also to examine the potential benefits of the "post-stretch" die process for HSS applications.



Bar-Compartment Pan Cross @ Kickup (#5 Bar)
Part # 22592862

Figure 14

Procedure

The following will describe the four trial runs and the analyses of the measured results from each phase. In all cases, two materials, 40 & 50 ksi, and three die processes, single pad-rough blank, single pad-developed blank and two pad-rough blank, were used. The stampings made from rough blanks were laser trimmed to finished size prior to being measured.

PHASE I: Conducted at the GM Major Tooling Lab-1997

The single pad method, with the lower pad deactivated, produced a panel that was approximately 1 mm short on the sidewalls. Elastic recovery of the HSS was the probable cause of this difference from the die measurements.

Measured results of the two-pad process indicated that upstroke deformation as great as 6-7 mm occurred as the die opened. Upstroke deformation is caused by the opposing forces of the upper and lower pressure pads on a stamping during the press upstroke, or die separation.

PHASE II: Conducted at Arrowsmith Tool & Die - January/February 1998

Weld flange surface changes were made in the die to have the part shape conform to the production condition of the mild steel stamping and the required assembly fit-up. Radius changes were made on the hat section from the specified 6 mm to 12 mm. In this two-pad die trial, an attempt was made to stop the mechanical press at bottom dead center and bleed the nitrogen system to simulate a delayed return of the lower pad. Upstroke deformation was still found to be approximately 1.5 mm. Deformation is believed to have occurred due to incomplete bleeding of the residual pressure retained within the cylinders and by not attaining true press position on bottom.

Phase III-Utilization of a Hydraulic Press at RJ Industries, Fraser, MI, conducted by Arrowsmith, October 1998

Arrangements were made to repeat the Phase II test in a hydraulic press as this type of press can be readily stopped on bottom. The measured results indicated some parts were within tolerance and others were not. This was interpreted as due to incomplete bleeding of the nitrogen from the lower pad.

After total bleeding of the nitrogen system at bottom dead center, acceptable parts were produced. Because it was determined this was not a feasible method for use under production conditions, this was necessary to investigate the use of a lower pad delay system. The DRAC (Delayed Return and Control) nitrogen system and other equivalent systems were considered for this purpose.

Phase IV- Pad Delay Device added - Arrowsmith Tool & Die International - August 1999

A cost effective mechanical pad delay device was incorporated into the tool at Arrowsmith. An air driven cam slide was mounted onto the lower pad and moved into position when the upper form steels made contact with the lower pad, approximately 6 mm before bottom. Upper pad extension rods make contact with the air driven slide block. The contact made between the slide block and the upper pad rods lifts the upper pad as the lower pad begins to travel, Figure 15 below. This device is timing-sensitive and is used only as a last resort in a production application.

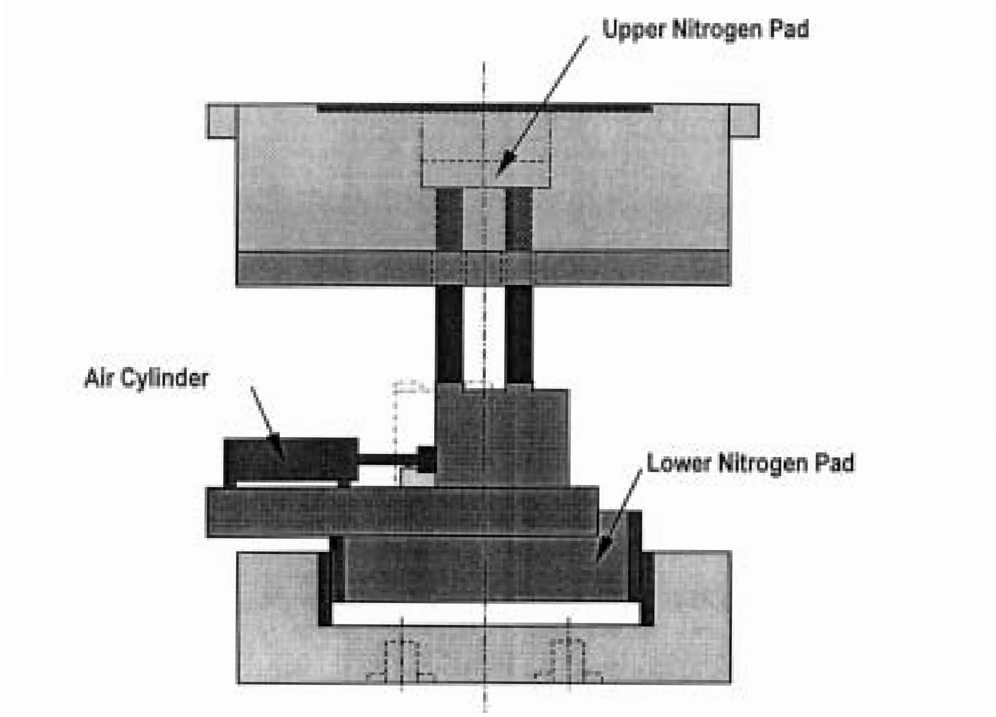


Figure 15

Test Methods @ 40-50ksi (fig. 16)

P1-N 2 pad die w/rough blank on lock step - lower pad active w/delay on return stroke.

P2-SB 2 pad die w/developed finish blank - lock step not engaged by blank.
- lower pad active w/delay on return stroke.

P3-PD 1 pad die w/rough blank on lock step - lower pad inactive.

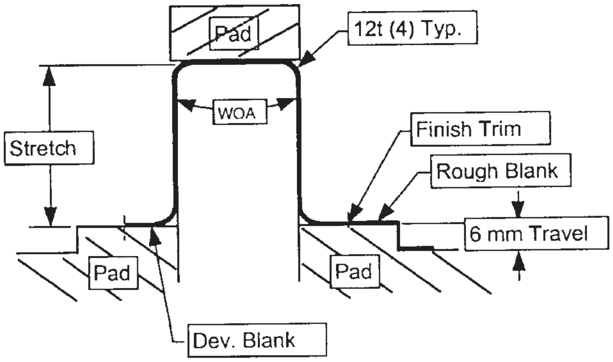


Figure 16

Summary

All conclusions are based on the Phase IV trial run at Arrowsmith Tool & Die and the subsequent GKS Inspection Services, Inc. measurement report of November, 1999 and supplement of December19, 1999.

Test method P2-SB 2 (lower pad active) which utilized a short blank that did not engage the lock step, resulted in a stamping with the most springback and the most dimensional variation.

Test methods P1-N (lower pad active) and P3-PD 1 (lower pad inactive) both utilized rough blanks that engaged the lock step of the lower die and were stretched by the closing die action. These two processes showed springback reduction and dimensional improvement in both the 40 and 50KSI material. The measured difference between these processes indicates no dimensional advantage by using the active lower pad to stretch the stamping. A solid lock step on the lower die steels appears to be equally effective. Both processes resulted in a wall opening angle due to springback of 3.30 degrees. Some amount of overbend for springback will still be required in dies with these processes. See National Steel report of July 1997 and GKS reports of November 1997, November 1998 and January 1999, available from the Auto/Steel Partnership.

One of the negative aspects of the post-stretch process is the extra cost of the larger blank and an added trim die operation.

Recommendations

To reduce springback and sidewall curl, the post-stretch die process should be considered when forming typical hat section HSS parts. The use of a solid lower die with a lock step provides the least complex approach.

More complicated hat sections, with transitional part geometry in profile, will require the two-pad process in order to control buckling of compression flanges as well as other part distortions.

When opposing pads are present in the die, a pad delay device is required on the lower pad in order to avoid upstroke deformation of the stamping.

This study has shown that the #5 Cross Bar is a viable candidate for 2.00 mm, 40/50 ksi material which will provide a significant mass reduction for this part.