3.9 SPECIAL DESIGN CONSIDERATIONS

Advances in materials and manufacturing technology are creating new opportunities for design alternatives that improve performance and reduce cost and mass. This section addresses areas of body design where advances in design, materials and manufacturing technology can be utilized to increase performance and improve cost effectiveness.

3.9.1 TAILOR WELDED BLANKS

Tailor welded blanks are used for two purposes:

- Combine several steel options into a welded blank prior to stamping. By combining varying thicknesses, coatings and material grades, the product and manufacturing engineers can tailor the blank to take advantage of the different properties of the steels within the part.
- Integrate and eliminate parts, resulting in savings for tooling, operational costs, and lead time.

Tailor welded blanks are currently used for:

- Door inner panels
- Body side frames
- Underbody frame rails
- Engine compartment rails
- Center pillar inner panels

They may be considered for any application to realize one or more of the following benefits:

- Fewer parts
- Fewer dies
- Fewer spot welds
- Reduced design and development time
- Lower manufacturing costs
- Less purchased material due to better utilization
- Mass reduction
- Improved dimensional accuracy
- Improved structural integrity
- Improved safety

3.9.1.1 Types of Welds

Four types of welds are used or have been considered for tailor welded blanks:

- Laser beam, with and without filler wire
- Resistance mash seam
- High frequency induction
- Electron beam (non-vacuum)

Currently, laser beam and resistance mash seam welds are employed in vehicles built in North America. These processes are illustrated in Figure 3.9.1.1-1 and Figure 3.9.1.1-2.

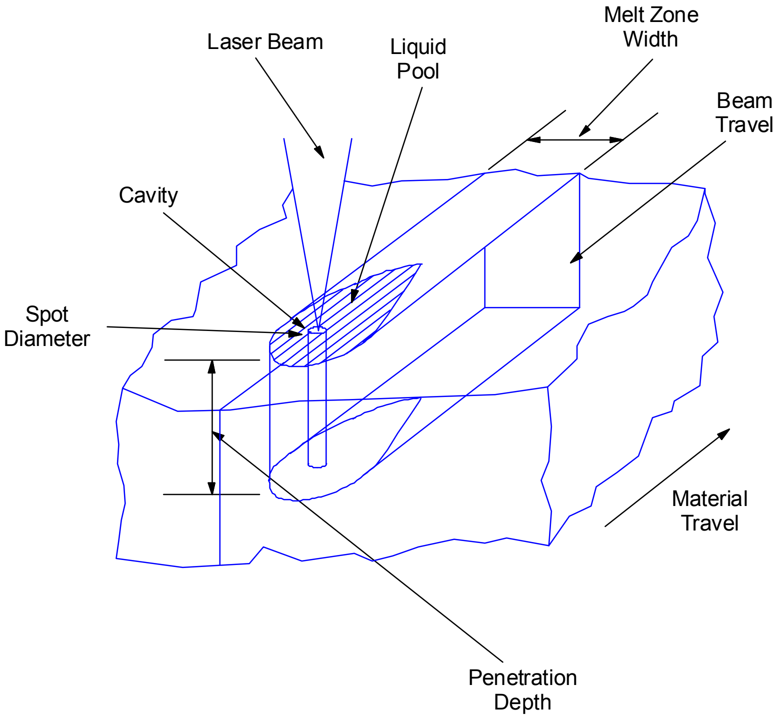


Figure 3.9.1.1-1 The laser beam butt seam welding process

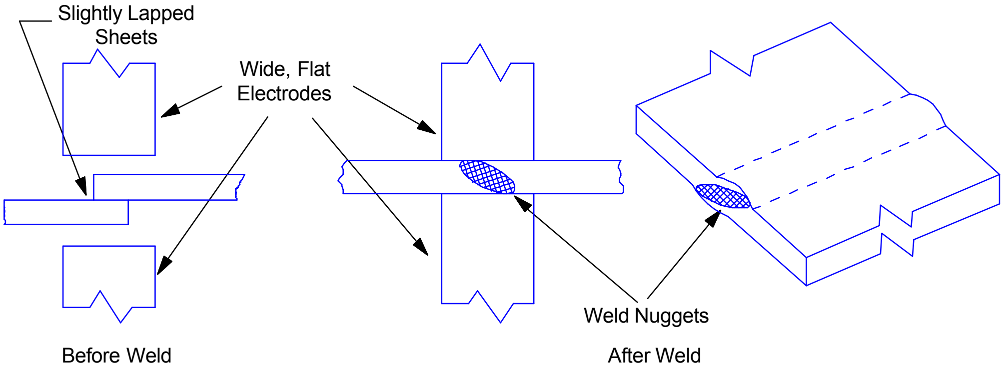


Figure 3.9.1.1-2 The resistance roller mash lap seam welding process

3.9.1.2 Welding Process Selection Criteria

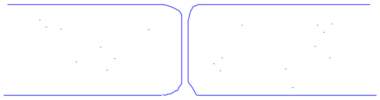
The welding process selection is driven by factors such as:

- Cost
- Structural requirements
- Stamping process requirements
- Blank welding capability
- Availability of material
- Aesthetic requirements

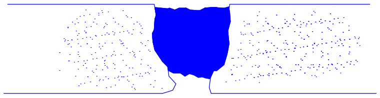
Resistance mash seam welding requires an overlap and produces a seam that is 10% to 50% thicker than the thicker of the materials. The latitude to reduce the thickness is limited by process requirements. Thicknesses toward the low (10%) limit are usually achieved by a post-weld planishing operation, which compresses the weld joint between steel rollers. The heat affected zone is approximately twice the width of the weld. Currently available tailor welded blank mash seam welding processes are able to produce welds in lengths from 50 mm (2.0 in.) to 2500 mm (100 in.) in a straight line only. Edge preparation is unnecessary unless welding multiple piece blanks, such as for a bodyside ring. Gauge limitations are:

- Minimum thickness 0.7 mm (0.030 in.)
- Maximum thickness 3.0 mm (0.120 in.)
- Total thickness 5.0 mm (0.200 in.)
- Maximum material thickness ratio 3:1

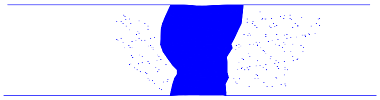
Laser beam tailor welding produce a narrower heat affected zone than mash seam, but requires precision shearing of the blank edges to assure a good fit up prior to welding. The joint is concave when no filler wire is used, as shown in Figure 3.9.1.2-1.



Shear cut shapes



Non-filler welded bead



Filler welded bead
after grinding

Figure 3.9.1.2-1 The effect of filler wire use and grinding on a laser beam butt seam weld

The use of a filler and post-weld grinding produces a weld that is flush with the parent metal when the two pieces of stock being joined are of equal thickness. Maximum weld length is currently about 3800 mm (150 in.), and the process can weld non-parallel lines. However, maintaining edge alignment becomes more difficult with welds over 500 mm (20 in.) in length, and edge preparation becomes more critical. Gauge limitations are:

- Minimum thickness 0.7 mm (0.030 in.)
- Maximum thickness 3.0 mm (0.120 in.)
- Maximum material thickness ratio 3:1

Neither process is currently being used for a "Class A" exposed surface on an outer panel. However laser welded blanks are being used on secondary exposed surfaces, such as the bodyside frame and door inner panels. Other advantages of laser welding include:

- Where appearance is important and where weather seal surface or wind noise is important, the laser weld process may have advantages over resistance mash seam due to surface geometry.
- Hem flange requirements may favor laser beam welding.
- Laser welding has a narrower heat affected zone. For example, the heat affected zone of a mash seam weld joining two pieces of 1.0 mm (0.040 in.) stock is typically 4 to 8 mm (0.16 to 0.32 in.), while the width for a laser weld is 2 to 3 mm (0.080 to 0.12 in.).
- Laser welding is more suitable for joining coated steel because it is a non-contact process, and its narrower heat affected zone burns off less of the coating.

Where either process is acceptable, resistance mash seam welds generally cost less to produce.

3.9.1.3 Potential Applications for Tailor Welded Blanks

Potential product applications are best identified by recognizing the advantages, particularly in terms of economics, of tailor welded blanks, which include:

1. Part integration and tooling cost reduction
2. Improved material yield
3. Mass reduction and structural integrity
4. Reduced dimensional variation

Other product considerations are discussed in Section 3.9.1.4.

In assessing the economic effects of part integration, product engineers and designers should assess the following factors:

- Total reduction in parts count, including engineering, design and assembly costs.
- Total reduction in the number of tools, including the costs of designing, building and operating them.
- Cost reduction derived from the selective use of coated steels and different strengths and thicknesses of steel.

Material yield is affected by three factors:

- Part design
- Draw die development
- Blank nesting

Parts made in draw dies typically have material utilization ranging from 30% to 80%. In other terms, a material utilization rate of 80% means that 1.25 kg (lb) of material must be purchased to produce one kg (lb) of product; a utilization rate of 30% requires the purchase of 3.3 kg (lb) to produce one kg (lb) of product. Parts that are nearly rectangular in outline, made from blanks that nest efficiently, tend toward the upper end of the range. Those that are very irregular and cannot be nested efficiently tend toward the lower end.

In some cases it is possible to split the blank into pieces that can be nested efficiently, then weld them to produce the desired shaped blank. Figure 3.9.1.3-1 illustrates one way in which material that would otherwise have been engineered scrap is utilized to improve nesting and increase material utilization. Table 3.9.1.3-1 summarizes material utilization in typical body applications.

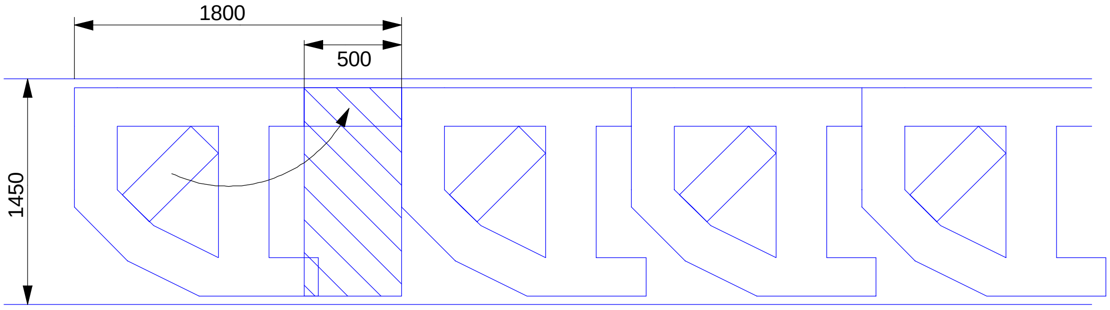


Figure 3.9.1.3-1 By utilizing stock that would otherwise be engineered scrap and making tailor welded blanks, blank nesting is improved and purchased stock reduced by 28%.

Table 3.9.1.3-1 Effect of Part Shape on Material Consumed

Part Shape	Typical Parts	Blank Mass (kg)	Panel Mass (kg)	Eng. Scrap	Stock Mass/ Panel Mass
Rectangular or Trapezoidal	Roof Outer	11.35	9.03	20%	1.25
	Hood Outer	12.45	9.98	20%	1.25
	Rocker Outer	2.70	2.15	20%	1.25
	Deck Lid Outer	9.60	6.01	37%	1.60
Irregular	Front Fender	5.94	3.04	49%	1.95
	Quarter Outer (coupe)	16.53	7.52	54%	2.20
	Quarter Inner (coupe)	9.92	5.85	41%	1.70
	Quarter Outer (sedan)	14.76	4.76	68%	3.10
	Quarter Inner (sedan)	4.32	1.19	72%	3.63
	Front Body Hinge Pillar	6.39	1.86	71%	3.44

The manufacturing engineers generally determine the economic feasibility of using tailor welded blanks, and the product engineers evaluate the effects of the composite structure on the product.

The factors that drive the potential for mass reduction from the use of tailor welded blanks also drive the potential for improved structure. The following illustrations may allow a reduction in mass, improvement in structure or a combination of both. Structure includes both NVH (noise, vibration and harshness) and crashworthiness considerations.

- Joining sheet stock of varying thicknesses allows material thickness to conform more nearly to structural requirements, and eliminates the tendency for one critical feature to drive the thickness of the entire part.
- The weld joints require little or no overlapping of metal, as is required with spot welded or bonded joints.
- The continuous welds generate a monolithic structure, which is inherently stronger and stiffer than spot welded or adhesive bonded reinforcements.

Dimensional variations can be reduced significantly by the use of tailor welded blanks. Variations are reduced by:

- Eliminating stack-up tolerances.
- Eliminating distortions, such as those caused by welding guns when parts do not meet exactly.

Reduction in dimensional variations have been reported by both domestic and foreign manufacturers. For example, door opening variations have been reduced by as much as 50%.

3.9.1.4 Other Product Considerations

In addition to the applications noted above, production experience with tailor welded blanks indicates satisfactory performance, and in some cases improved product performance, in the following areas.

3.9.1.4.1 Crashworthiness

The following have been concluded from tests of axial and bending modes on components made from tailor welded blanks.

- Rectangular thin wall section beams formed by laser and mash seam tailor welded blanks performed satisfactorily in crush tests at speeds up to 42 km/hr (26 mph) and 25 km/hr (15.5 mph).
- There was minimal difference between laser and mash seam welded blanks in terms of maximum energy absorption, peak load and maximum crush distance.
- The energy absorption of rails formed by tailor welded blanks increases significantly with steel sheet thickness and slightly with material yield strength.
- Galvanized sheet surfaces showed minimal effects on crashworthiness performance.
- High strength steels enhanced the local stability in the axial mode of collapse.

3.9.1.4.2 Sealing Compounds

Since the welds used in tailor welded blanks are continuous, compared with intermittent spot welds, no sealing compounds are required at the weld joints. Savings are realized from the elimination of investment, material and application costs. Environmental benefits and minor mass savings may also accrue.

3.9.1.4.3 Corrosion Resistance and Coating Adhesion of the Weld Seam

Corrosion resistance of coated stock is affected by the width of the heat affected zone, because the heat of welding destroys the coating. In general, the narrower the zone, the better the corrosion resistance. Paint adhesion is highly dependent on the formation of a good phosphate coating prior to painting. The formation of the phosphate coat is adversely affected in the heat affected zone. Where high levels of corrosion resistance are required, special attention to corrosion resistance of the seam will be required.

The information in this section was extracted from Tailor Welded Blank Design and Manufacturing Manual, Auto/Steel Partnership, 50 30-01 895 MPG, July 1995. Please consult this source for additional information and references.

3.9.2 VALUE ENGINEERING/VALUE ANALYSIS

3.9.2.1 Introduction

Value engineering/value analysis,[1] (VE/VA) was originally developed to identify and eliminate unnecessary manufacturing costs without reducing product functionality, reliability, durability or appearance. It has been successfully applied to a variety of steel products and processes simultaneously improving functionality and reducing cost.

VE/VA is a disciplined, clean sheet approach to problem solving. It focuses on specific product design and manufacturing process characteristics. VE/VA comprises two related disciplines: value engineering (VE) and value analysis (VA). VE is employed is employed up front, is design focused, and is done before production tooling is established. VA is employed to improve value after the start of production.

3.9.2.2 Advantages of VE/VA

Traditional approaches to cost reduction focus on eliminating obvious unnecessary cost. Today's competitive global marketplace demands a more comprehensive approach. The VE/VA provides that. It:

1. Asks "How can we maintain or improve reliable performance of this part for the least cost?"
2. Is function oriented.
3. Addresses unnecessary cost, both obvious and not obvious.
4. Maintains or improves performance for the customer.

VE/VA helps engineers get new ideas in steel materials and processes to market faster, at a price the customer is willing to pay. The power of the VE/VA technique is derived from five key ingredients:

1. The synergistic power of a multi-disciplinary team.
2. Positive atmosphere.
3. An easy to follow, disciplined approach to gathering the required information.
4. Active participation in the decision making process by those people who will implement the proposals that are generated.
5. Systematic, logical series of separate problem solving steps involving separate types of mental activity, including:
    - Exhaustive accumulation of facts and data.
    - Identification and improvement of assumptions.
    - Penetrating functional analysis.
    - Creative brainstorming.
    - Critical judgment and evaluation.
    - Systematic searching of the creative thoughts to maximize advantages and minimize disadvantages.

3.9.2.3 How the VE/VA Process Works

The VE/VA process is performed in six distinct steps:

1. Gather information

    Define the scope of the project and gather the most accurate, up-to-date information from appropriate sources.

2. Define functions

    During this stage, the questions "What does the product or process do?" and "How much does it cost to do that?" are answered in very specific terms. This process identifies functions with high value-improvement potential.

3. Generate creative alternatives

    Creative forces and abilities are called upon in a brainstorming session to generate a great number of alternate methods of providing the selected functions.

4. Evaluate and develop proposals

    The ideas generated in the creative stage are combined and developed into proposals for implementation.

5. Recommend proposals

    The most promising proposals are critically reviewed with the appropriate audience for "buy-in".

6. Implement proposals

   Effective follow-up ensures that the appropriate activity such as testing and validation of the proposal are carried out. Related cost savings and performance improvement are documented.

Timely execution of these six steps will avoid most product development problems in the design phase. It also helps to achieve a fundamental objective of most projects: to meet or exceed customer requirements at reduced cost.

3.9.2.4 Value Defined

Value is a relationship between product function and cost, and may be defined by the equation:

$$\text{Value} = \frac{\text{Function}}{\text{Cost}}$$

Equation 3.9.2.4-1

where function = those things that the product, process or procedure must do to satisfy the customer
cost = expenditures of resource including time, money, people, energy and material

The equation indicates that the greatest value improvement occurs when function is increased while simultaneously reducing cost.

Ultimately, value depends on the effectiveness with which every usable concept, material, process and approach to the problem has been identified, analyzed and implemented. Maximizing value is the goal of every VE/VA effort. VE/VA brings better combinations into focus with less expenditure of resources.

3.9.2.5 Details of a VE/VA Program

Detailed information on how to conduct a VE/VA program for steel automotive body components has been developed for AISI and is available on request[1].

3.9.3 DESIGN GUIDELINES FOR ULTRA-HIGH STRENGTH STEELS

High strength and ultra-high strength steels (UHSS) with moderate ductility have become increasingly important in automotive structural design. In particular, they enable body engineers to meet various safety requirements at minimum mass and cost. UHSS are produced by a continuous heat treatment, which includes a controlled high temperature heating followed by a water quench and a mild reheat cycle. UHSS are relatively isotropic in mechanical properties, have maximum through-coil uniformity, and are available in thicknesses from 0.5 to 2.0 mm (0.020 to 0.080 in.).

There are some design limitations due to manufacturing considerations. Ductility generally decreases as yield strength increases. Lower ductility of UHSS limits bendability, defined as the ratio of bending radius to stock thickness (r/t), to a minimum of about 4. In addition, springback, which increases with the yield strength of the material, is higher in UHSS than in mainstream sheet steels. Most UHSS can be formed in stamping dies, as long as provision is made for lower ductility and limitations in bending radii. Bend stretching, drawing and flanging are all possible.

Most of the UHSS can be formed by roll forming. Pre-piercing and post-roll forming operations, such as sweeping and limited stamping, are routinely practiced. Hence, components with essentially constant cross section are excellent candidates for UHSS. Because of the relatively low tooling costs and high production rates of roll forming, this technology is used extensively to exploit the mass reduction potential of the UHSS. Most of the applications for door intrusion beams, bumper reinforcing beams and structural tubing are roll formed.

As sweep curvature is increased, roll forming operations become more challenging because increasing curvature increases both tensile and compressive stresses. Two options are available to ensure ease of production:

1. Maintain maximum allowable beam depth (for minimum mass) and reduce yield strength to increase ductility. For example, several high sweep bumpers are produced in 965 MPa (140 ksi) yield strength steel rather than 1300 MPa (190 ksi).
2. Reduce depth and increase thickness, reducing the strains from sweeping, and permitting the use of 1300 MPa (190 ksi) steel, again to minimize mass.

Design guidelines for UHSS are discussed in several publications[2, 3, 4].

Deflection of UHSS components can involve large elastic deflections as well as localized plastic deformation, such as crippling. Successful application of FEA requires that both the overall load-deflection curve and the local deformation be accurately predicted. When full curve tensile properties are required, refer to individual steel suppliers.

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