III - Stamping of tailor welded blanks

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1. Introduction

Our experience with the stamping of welded blanks is illustrated in two complementary sections.

The first concerns tests on tensile specimens and simple stretch and cup drawing tests.

It concludes with a number of elementary rules concerning the behavior of the weld (displacement, etc.) and its characterization (resistance to stamping stresses and strains, development of the concept of Forming Limit Curves specific to welded blanks).

The second section concerns tests performed on industrial components, both in ArcelorMittal’s laboratories and in customers’ workshops.

This section confirms a number of blank behavior rules and provides additional information.

2. Forming Limit Curves for tailor welded blanks

Classical stamping simulation analysis uses the forming limit diagram concept. However, in many cases the use of the base material forming limit curve is not sufficient (see Fig. 67).

When failure of a welded blank occurs in a sub blank (generally the thinnest), it is logical to consider that necking sets in when the maximum strain reaches the strain limit for the softer metal. However, the analyses show that when the position of the weld line induces an interaction between the two steels, the drawing limit of the welded blank is lower than that of the base metal (Fig. 65).

![FIG. 65 - Forming Limit Curves of different zones, base material and laser welded areas](image)

In order to understand this phenomenon, a detailed study has been carried out on the interaction between the two materials during drawing of a welded blank. The result of these analyses has led to the development of a Forming Limit Curves (FLC) model specific to welded blanks.

This model is based on a virtual behavior law for the welded blank, which is then used in the model presented above. The law involves the characteristics of the two materials concerned, but is not a simple average of their respective individual FLC. The model allows to determine some points of the FLC of the welded area by giving main data of each sub-blank (Fig. 66).

![FIG. 66 - Principles of the laser welded zone FLC model calculation](image)

To analyse a tailor welded blank from a forming point of view, three main aspects have to be considered:

> The ductile material using ductile material FLC.
> The hard material using the hard material FLC.
> Zone of interaction on one side of the weld with use of the specific welded zone FLC.

These curves are easily positioned in the major strains diagram from the simple knowledge of the thicknesses and the mechanical characteristics of the base material. They can be easily integrated into a numerical stamping simulation software. Therefore, by using laser welded zone FLC and the results coming from experimental stamping trials or the numerical stamping simulation, ArcelorMittal can offer its customers technical assistance in design and stamping.
We have developed reliable FLC for predicting the formability of tailor welded blanks. They are based on a numerical model to assess the formability of homogeneous blanks. Coupling this model with a “homogenization” method of tailor welded blanks we have managed to precisely account for the possible interaction between base materials. This “specific” FLC model has proved to reliably predict:

- The critical zones on welded blanks.
- The severity of the drawing conditions.
- The feasibility of a given welded blank.

The materials selection and numerical simulation assistance tools using FLC model are available through your usual ArcelorMittal contact. They have been developed in response to the requirements expressed by our customers, in order to provide the most pragmatic solution possible to some of their concerns. It should be emphasized that the ArcelorMittal's technical teams are available for the development of more appropriate tests and for the collection of data needed to make the processing of the steels as easy as possible. Do not hesitate to request our help, since this will help us to match our services even more closely to your requirements.
3. Stamping behavior of welded blanks

3.1. Stamping parameters of welded blanks

3.1.1. Identification of the parameters

In conventional stamping, i.e. with monolithic blanks (composed of a single steel grade and without weld) the behavior of the sheet is determined by a large number of parameters, which can be divided into two categories:

- “External” parameters not associated with the sheet (geometry, surface condition, loads and displacements of the various tooling components), which determine the boundary conditions imposed on the blank (friction forces beneath the blank holder, instantaneous position of the sheet between the punch and the die, etc.)
- “Internal” parameters (initial mechanical properties of the sheet and their variation during deformation, surface condition, coatings, dimensions, etc.), which, depending on the conditions imposed by the tooling, determine the state of the blank at each point (position, displacements, strains and internal stresses) so as to balance the forces involved.

The complexity of stamping and the number of parameters involved explain the difficulties encountered in simulating the process.

In order to take maximum advantage of the possibility offered by welded blanks to “put the right material (thickness, grade, coating) where it is needed”, sheets of quite dissimilar characteristics can be combined.

In the following description of welded blanks composed of two significantly different sheets, the term “ductile” material will be used to define the one with both a thinner thickness and lower strength, while the “stronger” material is that which is both thicker and has a higher yield strength.

This is theoretically the most unfavorable configuration for balancing the forces and therefore for stamping, due to the introduction of a highly non-uniform property distribution in different regions of the blank.

Available solutions

There are three types of parameters which can theoretically be changed in order to improve stamping behavior:

- Geometry of the component
- Material properties
- Position of the weld lines

Unfortunately, the latitude for adjustment is often small, the parameters either being determined by the mechanical property specifications or by previous experience with similar parts and validated by design calculations or test results.

- Part geometry
  - In the case of monolithic blanks, part geometry has a decisive influence on the feasibility, but the freedom left to change the geometry in favor of more robust stamping is often small.
- Steel grades and thicknesses
  - In addition to their effect within each single material (as in conventional stamping), the differences in grades and thicknesses play an important role in the behavior of welded blanks. However, here again, the choice of materials to facilitate stamping is fairly limited.

> Weld line position

The varying stress concentrations and displacements to which the weld is subjected depend strongly on its position. However, this parameter can only be adjusted within the limits imposed by the specifications. As will be seen below, to change the position of the weld or welds the most effective way is to solve stamping problems (and this is often the only one available, once the design of the component is fixed).

Although these three parameters are determined before studying the stamping operation, the choices will strongly influence the available forming possibilities. It is therefore important to consider the problem of forming right from the design stage, since the early feasibility study can allow modifications of the component geometry and its constituent materials.

Once the part design has been determined, the stampability can be only improved by acting on the following parameters:

- Design or alteration of the die skirt
- Design or alteration of the shapes and sizes of the blanks beyond the regions incorporated in the part itself
- Adaptation of the clamping forces and retaining systems such as drawbeads
- Design of tooling to optimize the distribution of forces (pressure slides, etc.)

3.2. Stamping behavior of welded blanks

In highly simplified terms, the successful stamping of a component involves an equilibrium between the displacement of material and the internal stresses. The two principal problems encountered specific to welded blanks are resistance to stamping of the weld and its displacement in the regions subjected to stretching or drawing strains.

Other factors then add to these, such as the flow of the weld over the small tool radii and the interaction between the sheet and the tooling, depending on the die gap.

3.2.1. Elongation stresses

The behavior of the weld and the sheet immediately adjacent to it depends on the orientation of the principal stress with respect to the weld line (perpendicular or parallel). No fundamental difference has been observed between the behavior under the blank holder or over the punch in the case of elongation.

> Stamping resistance of the weld in mid-sheet

Behavior

In mid-sheet, two types of fracture are encountered, depending on the orientation of the imposed stresses (see Fig. 67).

- Fracture parallel to the weld (type 1 fracture), situated in its immediate proximity (1 to 3 mm). On the side with the lowest thickness–strength combination, the crack sometimes propagates over large areas.

This type of failure is also observed in unsymmetrical blanks subjected to stretch tests and in plane strain tension tests performed perpendicular to the weld. In real components, this type of fracture, induced by a maximum stress
perpendicular to the weld, is observed for example at the punch nose, in a zone traditionally subjected to a loading mode situated between bi-axial expansion and plane strain tension (e.g. the weld running over the edge of an inverse drawing zone, or parallel to an edge of the punch nose, such as in door frames, etc.).

> Fracture perpendicular to the weld (type 2 fractures), in which the crack is initiated, with only slight propagation into the two adjacent sheets, except sometimes when it changes direction by 90° to run parallel to the weld, so that it is then similar to Type 1 fractures.

This type of fracture has been also observed in both symmetrical and unsymmetrical blanks but this time in cup drawing (Swift) tests.

In real components, it occurs in regions where the weld is heavily loaded in the longitudinal direction (for example, when the weld is perpendicular to a radius of the punch nose, or in an inverse drawing zone).

This behavior is explained by observations of the weld after deformation to large longitudinal strains, when numerous microcracks are found perpendicular to the weld axis all along its length, ending where they meet the more ductile base materials.

Beyond the internal elongation capacity of the thermally hardened weld metal, additional longitudinal strain can be taken up by the microcracks without causing macroscopic fracture.

This phenomenon has been confirmed by the study of real components. Thus, when the weld is situated in a region where the metal flow or extension is parallel to the joint, the behavior is generally satisfactory (e.g. in the zone that is vertical during stamping at the bottom of a door frame or “bending” type regions in beams, etc.).

**Available solutions**

The best solution presently available is to change the position of the weld by moving it out of the high risk regions wherever possible.

The regions of the component where the displacements and loads leading to Type 1 fracture occur can be fairly accurately predicted with the help of a simulation software, such as ISOPUNCH, AUTOFORM or PAMSTAMP, backed up by considerations based on practical experience. However, even when the potentially problematic zones have been identified in this way, this is not sufficient to reliably predict the result of drawing.

A better prediction of the resistance of the weld can be obtained by using the concept of FLC specific to welded blanks.

It is also preferable during the design stage to avoid the use of two sheets whose characteristics are too dissimilar.

An indication of the difficulty of balancing the forces between two sheets joined together can be obtained by multiplying the thickness (t) and the yield strength (Ys) of each of them and determining the ratio, i.e.: \( t_2 \times Y_{s2} / t_1 \times Y_{s1} \) where \( t_2 \times Y_{s2} \) represents the so-called “stronger” sheet and \( t_1 \times Y_{s1} \) represents the more “ductile” material.

> Schematically, if this ratio is less than 2, the difference between the two sheets is not excessive.

> Between 2 and 4, increasing difficulties can add to those inherent to the part itself, as the strength ratio rises.

> Beyond a ratio of 4, it will be difficult to balance the transverse load in the highly stressed regions. In this case, stamping will be only possible for parts in which the perpendicular load applied to the weld is small (beams, etc.).

If it is no longer possible to modify the component design, with regard either to the weld position or the choice of materials, the only ways of preventing cracking are those used in conventional drawing practice (change of the process sequence or blank holder force, the use of drawbeads in order to modify the metal flow, modification of the shape of the die skirt surfaces to improve the stress distribution, the use of pressure slides to counteract stresses locally, etc.).

Our teams of engineers are available to customers to determine the best fabrication method.

However, Type 1 cracking is more frequent. In order to draw maximum advantage from the possibilities offered by welded blanks, the parts concerned usually comprise significant differences in both thickness and mechanical properties of the constituent sheets.

Furthermore, the formability of the weld and its heat affected zone is slightly poorer than that of the ductile base metal, while the difference between the two materials leads to a displacement of the weld, together with a concentration and reorientation of the stresses, promoting Type 1 fractures.

Type 2 fractures only occur when the principal stress axis is parallel to the weld, whereas the weld has generally good resistance to this type of loading.

Indeed, the weld acts as a stiffener, promoting displacement of the blank rather than an elongation. Moreover, as observed in stretching tests and in tensile specimens taken parallel to the joint, the weld is capable of withstanding maximum longitudinal strains only slightly lower than those for the base materials.

**FIG. 67 - Type 1 fractures**

Type 1 fractures can be caused by local stress concentrations, by the modification of the metal properties in the weld and the heat affected zone, and by a change in loading path.

**FIG. 67 - Type 2 fractures**

Type 2 fractures are promoted by high longitudinal elongations, when ductility is significantly reduced by hardening in the weld.

**Type 1 fractures**

- Caused by local stress concentrations.
- Modified metal properties in weld and heat affected zone.
- Change in loading path.

**Type 2 fractures**

- Promoted by high longitudinal elongations.
- Ductility reduced by hardening in weld.

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> Stamping resistance of emergent welds

**Behavior**
In the presence of high elongations, at the edge of the blank or at a hole, the direction of the maximum stress is often perpendicular to the weld, and Type 1 fractures are sometimes encountered. These fractures initiated at edges occur in zones that are stretched beneath the blank holder (such as the part contour delimited by the concave shaped die entry line). They are also observed when the components include holes, either to facilitate metal flow from the inside (e.g. in the window region at the front of a door frame, in a body side frame, to either side of the B-pillar, stamped from thicker sheet and serving as a strengthener) or to join two different weld seams in a region subsequently cut away (e.g. a loudspeaker emplacement). The stress concentrations at edges are such that cracking is relatively frequent.

**Available solutions**
One method is to locally modify the blank or hole contour to move the stresses away from the edges which are more sensitive to crack initiation. This can be envisaged during part and welded blank design, but is also possible during press trials, by manual cut-out modifications. In series production, this approach implies either the welding of “shaped” sheets, requiring a number of cutting tools equal to the quantity of non-rectangular or trapezoidal segments in the welded blank, or including a complete blank routing operation during the first stamping step.

> Weld displacement in stretched zones

**Behavior**
Automobile component designers generally choose straight welds in the finished parts. Process engineers also prefer blanks in which the weld is straight. Tests performed on laser welded blanks show that these two situations are often incompatible, since deformation of the weld during drawing induces displacements that are not always parallel to the initial direction of the joint. If the position of the weld is crucial for the product and forming results in substantial displacement of the weld, it is possible to predict such displacements. Our dedicated teams of engineers are available to customers to prevent these problems. The displacement of the weld is due to many different factors.

One of the most important ones is the presence side by side of two sheets with highly different properties in a region of stretching. When the principal stress is parallel to the weld, the forces are in equilibrium within each sheet, so that the difference in material has little effect. Any resulting displacement would be parallel to the weld and therefore of no great consequence. However, in the case where the major stress is perpendicular to the weld, the force equilibrium occurs across the joint, causing it to be displaced towards the stronger material, which has the greater and elongation resistance.

**FIG. 68 - Cracking at the end of a weld in a region of elongation**

This type of fracture was observed in tensile tests perpendicular to the weld in unsymmetrical blanks, where cracks appear very rapidly at the edges of certain specimens.

**FIG. 68 - Protection at the end of a weld in a region of elongation**

The displacement is enhanced by:
> A large difference in thickness and mechanical strength between the two materials.
> A drawing process in which the entrainment of the stronger sheet is less than that of the ductile material (for example, a region where the metal is deformed in the drawing mode beneath the blank holder next to the stretching zone, so that thickness becomes a highly limiting parameter).
> Low friction, either due to the process (low friction coefficient, local absence of contact with the tool, etc.) or to the region considered (large flat zones, such as at the punch nose for a door frame, before the die forms the details), since friction stresses attenuate the differences between the two constituent materials.
Various problems can occur due to weld displacements:
> Lack of support beneath the blank holder.
> Increased loading perpendicular to the joint.
> Local shape and appearance defects.
> Shifting of the weld or a sheet of the wrong thickness into a critical region (i.e. a hole, as fastening zone, a geometrical detail, etc.).

**Different types of displacements during stamping**

**Behavior**

The ideal situation is to anticipate the weld displacement and to choose its initial position so that the required final position is obtained after stamping. This is possible if the final position is the only constraint and if the weld displacement during drawing is acceptable.

**FIG. 69 – Relative displacement of the sheets**

If the weld displacement cannot be tolerated, or if it must be limited, two types of solutions are available:

1 - The first of these involves modifying the component design, for example by placing the weld in a less heavily stressed zone, by reducing the differences between the two materials, or by introducing shape obstacles in the stronger sheet, to hinder its flow or increase the friction, etc.

Beyond the simulation mentioned above, the following rules can be followed:
> The major component of the displacement in the proximity of the blank holder is generally the principal stamping direction, or more precisely, the displacement in a monolithic sheet, which is only a function of the geometry of the drawn part and the process parameters (greasing, clamping force, blank shape, etc.).
> In the absence of further information concerning the behavior of the welded blank, the weld lines beneath the blank holder are therefore positioned parallel to the predicted displacements during conventional drawing (for example, perpendicular to the die entry line, or parallel to the sheet displacement observed in a similar component already produced).

2 - The second type of solution is to take into account potential problems during tooling design (for example, by the use of a local pressure slide on the stronger sheet, or a blank holder surface that promotes entrainment of the stronger material next to the high risk zone, etc.).

In many cases, the principle remains the same. Indeed, since the displacement of the weld and the stresses to which it is subjected are strongly related, most methods for overcoming this problem have the common objective of «fixing» the region of the stronger sheet in the neighbourhood of the weld by modifying its contacts with the tooling (local contact stresses are increased relative to those acting on the remainder of the stronger material).

3.2.2. Compression stresses

In the case of elongation or tension, the behavior of the weld and its immediate vicinity depends on the orientation of the principal stress with respect to the weld line (perpendicular or parallel).

**FIG. 70 – Use of a local pressure slide to limit weld displacement**

No difficulties in stamping behavior specific to welded blanks have been observed when the maximum compression stress is parallel to the weld. In contrast, as in the case of stretching, when the maximum compression stress is perpendicular to the weld, problems may appear, depending on the situation of the drawing zone.

The general tendency in compression is a transfer from the stronger to the ductile material, since because of the difference in thickness and stiffness, the stronger sheet is only slightly drawn, so that the weld is displaced towards the ductile sheet, which must absorb the excess ductile material by thickening or even wrinkling.

Due to this phenomenon, great care must be taken in the design of the contact surface between the blank holder and the ductile sheet in order to minimize the detrimental consequences.

The analysis of the components obtained shows that this displacement of the stronger sheet towards the ductile one is a relative effect. Indeed, it is possible that the weld is effectively displaced towards the stronger material.

The stronger sheet appears to approach the ductile one, whereas it is in fact the latter which runs into the former, with the creation of folds or wrinkles.
In both cases, the result is the same (marked wrinkling of the ductile sheet in the immediate vicinity of the weld) but the methods used to overcome the problem are different:

> In the case where there is a real displacement of the stronger sheet towards the ductile one, it is necessary to locally prevent this movement (by adding draw beads or by modifying he blank holder contact surface or the die entry skirt zone etc.).

> When there is only a relative displacement of the stronger sheet towards the ductile one, it is the movement of the latter material which must be controlled locally, because of the relative displacement of the stronger sheet is the real overall displacement of the ductile one.

> **Compression in the punch region**

**Behavior**

In the punch region, the sheet is generally in contact with the tooling only on one side (on the punch side in the pulling zones and on the die side in inverse drawing zones, but without any contact between these two regions, i.e. in free segments). For this reason, it is difficult to counteract the tendency for wrinkling. The phenomenon is well known in the case of monolithic blanks, as wrinkling is of second order and is amplified by the presence of two different materials. When the compression stresses are perpendicular to the weld, the stronger sheet, whose greater thickness decreases its tendency for wrinkling, repulses the ductile one.

The latter is thus subjected to its own excess material and to the decrease in space imposed by the stronger material. Due to its small thickness, its resistance to wrinkling is poor.

When the weld runs across a region of compression at the surface of the punch, the consequences are therefore:

> A low degree of compression in the stronger sheet, generally accompanied by undulations.

> A relative displacement of the weld from the stronger sheet towards the ductile one.

> Enhanced wrinkling in the ductile sheet.

**Available solutions**

Here again, certain solutions are available at the design stage:

> Positioning of the weld outside of potential compression zones, which can be predicted from the part geometry. The degree of difficulty can be estimated with the aid of drawing simulation software such as ISOPUNCH or AUTOFORM one step at the design office state or by means of any other simulation software in the process engineering office.

> Orientation of the weld in the same direction as the principal compression stress, so that the stronger sheet does not accentuate wrinkling in the ductile one.

> Local modification of the part geometry (ribs, undulations, etc.) in order to consume the excess material in either the stronger or ductile sheet, depending on the real displacement direction.

Other solutions applicable at the tooling design stage are those that limit the displacement by the use of local pressure slides for instance whose aim is to prevent the movement of the stronger sheet from amplifying wrinkling in the ductile one.

Once the development stage is reached, the only methods available are the classical solutions involving adjustment of the stresses and displacements by modifying the restraints beneath the blank holder.

Their effect is extremely limited when the problem zone is situated inside the component, far from the die entry line.

> **Compression in the region beneath the blank holder**

**Behavior**

This case is extremely frequent in stamping, for example when the contour of the part delimited by the die entry line is locally concave in shape, like at a corner (e.g. bottom of a door frame, etc.) or a straight edge, but with a large metal flow in the center.

When drawing occurs beneath the blank holder, the weld is generally relatively parallel to the metal flow lines, so that the weld undergoes a relative displacement towards the ductile sheet, with two possible consequences, depending on the gap provided beneath the blank holder:

1. When the flow gap is adjusted to the thinner material on its side and in the immediate vicinity of the weld and if the thicker sheet is displaced in this direction, it is squeezed into a space too small for it, creating a violent hard point (restricting flow, causing rapid tool wear and promoting instability, etc.) However, this only occurs when the stronger sheet is effectively displaced towards the ductile one.

2. When the flow gap on the thin sheet side is adjusted to the thickness of the stronger sheet up to a certain distance from the weld, the ductile material is locally not supported on either side, and the compression zone will have a strong tendency to wrinkle as soon as the stronger sheet begins to move in its direction. This phenomenon also occurs when the metal flow gap is adjusted as in case 1, but the displacement is relative - the thinner sheet then wrinkles as it runs into the thicker one.

**Available solutions**

As for the previous cases, the solutions to this problem are relatively restricted if it is not taken into account right from the design stage. The best solution is to avoid regions of compression at the blank holder surface in the vicinity of the joint.

In multi-material blanks where the thickness is uniform, the problem is not crucial, due to the identical flow gap. Only the possible extra thickness at the weld itself is liable to cause tool wear.

If the positioning of the weld in a region of compression cannot be avoided, there remains the possibility during tooling design and development to reduce weld displacement perpendicular to the joint line by using conventional methods to modify the behavior of the stronger sheet, for example by adjusting the bearing surface or introducing a draw bead parallel to the weld.
This can be envisaged provided that it is possible to limit the overall movement of the weld towards the stronger sheet, leaving only the local compression displacement towards the ductile component, which can be controlled by suitably adapting the bearing surface.

Example: In a door frame, where it is wished to place the weld in the lower front corner at an angle of 45°, the overall forward displacement of the weld can be decreased by using a pressure slide, or by balancing the part so that the weld exits at the upper rear corner, i.e. with the weld running diagonally across the whole part.

In general, when a precise blank holder bearing surface is necessary, a satisfactory result can often be obtained during the workshop development stage. However, it must be remembered that this surface is sensitive to differences in sheet thickness. While it is possible for a monolithic blank to compensate batch-to-batch thickness variations by adjusting the height of the blank holder slide, this cannot be applied to welded blanks if the thickness variations of the constituent sheets are not the same or, worse, if they are of opposite sign (i.e. an increase for one component and a decrease for the other).

This problem can be solved by designing the blank holder in several parts, each of which clamps a blank component of given thickness. However this makes the tooling expensive and demands timeconsuming adjustments for each change in material batch.

3.2.3. Blank positionning

We just have seen that tailor welded blanks forming tools have gap variations for the material flows taking into account the blank thickness variation. The limits of these zones are determined in grades of thickness on blank and tool. In most cases, it is interesting to have a good blank positioning on the tool to obtain good matching of the thickness grades. This guarantees a drawing process corresponding to the set up mode by simulations, and furthermore an unchanging production.

3.2.4. Fracture at bends

**Behavior**

Several cases have been observed in which cracking is initiated in the weld and perpendicular to it when the latter flows perpendicularly over a small radius bend:

- In a body side frame with an overall thickness of 0.7 mm, incorporating a B-pillar strengthening element of 1.5 mm local thickness, cracking was observed at the small radius of the punch nose separating the visible part of the bottom member from the door hole.
> In a rear door frame, the same type of cracking occurred at the small punch nose radius forming the upper part of the window contour. This fracture was situated at the junction between the 0.8 mm thick sheet representing the majority of the part and the front element incorporating the hinge reinforcement function (1.8 mm thick). In both cases, the cracking was due to several factors:

> The punch radii were identical to those used for producing the same parts from thin monolithic blanks (0.7 - 0.8 mm sheet) and had not been adapted to the extra thickness of the strengthening element.

> Because of the difficult part configuration, the modifications made to the metal distribution during tooling development were poorly balanced, leading to a much larger flow from the outside of the component (upper part), causing slipping over the small punch radius.

Since the weld is less ductile than the base metals, it is more sensitive to the flow conditions over the small radius. Moreover, the difference in thickness between the two sheets leads to a discontinuity in the position of the neutral fiber on crossing the joint and can create stress concentrations when the weld is bent over a sharp radius.

Available solutions
As is the case for the majority of problems, the most effective solution is to allow these difficulties at the design stage:

> By decreasing the larger thickness.

> By increasing the radius to adapt it to the deformation capacity of the thicker sheet.

> By changing the position of the weld so that it flows over the radius with an angle of incidence sufficient to increase the relative radius. However, this is often contrary to the rule whereby the weld line should be oriented parallel to the direction of metal flow.

At the development stage, the only solution is to minimize slipping at the radius by balancing metal flow on either side of the weld.

3.2.5. Conclusion
The characteristic feature of the forming behavior of laser welded blanks is an imbalance between the forces acting on the constituent sheets. This imbalance leads to metal displacements and stress localizations different to those observed during the drawing of a monolithic blank and which must be accommodated.

It is therefore extremely important to anticipate the possible problems and to allow them during both component and tooling design. Such prediction requires appropriate simulation software and the establishment of specific design rules.

Over 500 million welded blanks used in the manufacturing of recent vehicles argue in favor of finding an appropriate solution to stamping problems involving sheets of standard tolerances (geometric and mechanical). ArcelorMittal and Tailored Blanks teams master the full range of processes involved in forming and can contribute to the success of their customers’ projects.

3.3. Examples of parts

3.3.1. Door frame
A widely used blank configuration involves a front part composed of relatively thick sheet (of the order of 1.8 mm), sometimes with a high yield strength, welded to a thinner rear part (0.7 to 0.8 mm) in deep drawing quality, as shown by the weld in Figure 76.

This solution enables a hinge and wing mirror reinforcement function to be incorporated in the frame.

The differences between the various blank designs mainly concern the forms and positions of the welds, each having its advantages and drawbacks. The factors which have to be considered are (see Fig. 76 and 77):

> Due to the proximity of the front edge of the frame, to which it is parallel, the weld tends to be displaced frontwards during drawing, placing it in an unfavorable zone and leading to an increase in the stresses on the ductile sheet in the central part, etc.

> In the lower part of the frame, the position of the weld close to the front corner, corresponding to a drawing zone beneath the blank holder, can cause wrinkles in the thinner sheet, accentuated by the overall frontward displacement of the weld in the center of the part.

> Near the window location, the weld is fairly close to the front corner, which is heavily stressed during drawing.

> The position of the weld virtually rules out the use of holes or slots to facilitate forming.

> In the upper part of the frame, the metal flow beneath the blank holder occurs at a significant angle to the weld. Along the direction of metal flow, a thick region beneath the blank holder is then pulled by a thin region over the punch, leading to a risk of fracture if the bearing surface is not adapted to restrain the thicker sheet sufficiently at this point.

Besides the standard design, other weld positions are also possible. Weld 2 in Figure 77 reduces the quantity of metal on the thicker side, whereas with the "diagonal weld" configuration (weld 3, Fig. 77), the joint traverses the whole frame and balances the drawn component.

> The punch radii were identical to those used for producing the same parts from thin monolithic blanks (0.7 - 0.8 mm sheet) and had not been adapted to the extra thickness of the strengthening element.

> Because of the difficult part configuration, the modifications made to the metal distribution during tooling development were poorly balanced, leading to a much larger flow from the outside of the component (upper part), causing slipping over the small punch radius.

Since the weld is less ductile than the base metals, it is more sensitive to the flow conditions over the small radius. Moreover, the difference in thickness between the two sheets leads to a discontinuity in the position of the neutral fiber on crossing the joint and can create stress concentrations when the weld is bent over a sharp radius.

Available solutions
As is the case for the majority of problems, the most effective solution is to allow these difficulties at the design stage:

> By decreasing the larger thickness.

> By increasing the radius to adapt it to the deformation capacity of the thicker sheet.

> By changing the position of the weld so that it flows over the radius with an angle of incidence sufficient to increase the relative radius. However, this is often contrary to the rule whereby the weld line should be oriented parallel to the direction of metal flow.

At the development stage, the only solution is to minimize slipping at the radius by balancing metal flow on either side of the weld.

3.2.5. Conclusion
The characteristic feature of the forming behavior of laser welded blanks is an imbalance between the forces acting on the constituent sheets. This imbalance leads to metal displacements and stress localizations different to those observed during the drawing of a monolithic blank and which must be accommodated.

It is therefore extremely important to anticipate the possible problems and to allow them during both component and tooling design. Such prediction requires appropriate simulation software and the establishment of specific design rules.

Over 500 million welded blanks used in the manufacturing of recent vehicles argue in favor of finding an appropriate solution to stamping problems involving sheets of standard tolerances (geometric and mechanical). ArcelorMittal and Tailored Blanks teams master the full range of processes involved in forming and can contribute to the success of their customers’ projects.
The most common design (weld 1, Fig. 77) has the advantage of using a blank with a straight weld, which costs less and is easy to perform during the stamping shop development phase.

Compared to the standard design, the “minimum weight” design (weld 2, Fig. 77) has several advantages:

- By limiting the thick part to the contour of the hinge reinforcement, the final component weight is reduced.
- For the same reason, less metal is needed to produce the blank.
- By avoiding the window zone, the weld does not cross any region of excessive stretching, facilitating optimization of the critical zone situated behind the wing mirror support.

However, the following factors should be taken into account:

- When the thicker sheet is only on one side of the part, it tends to create a marked imbalance, drawing the whole blank towards it.
- The displacement of the weld towards the thicker sheet, which already occurs with a “standard” weld configuration, is accentuated in this case.

The diagonal weld design (weld 3, Fig 77) has the following features:

- The weld is straight, decreasing the cost and simplifying blank manufacturing.
- The critical wing mirror region is avoided, even if the weld crosses the top rear corner of the window frame, which is somewhat less heavily stressed.
- In the “minimum weight” configuration, the stronger sheet pulls the weld in a single direction (forwards), while in the “standard” design, the behavior beneath the blank holder of the thick parts situated on the lower edge of the frame and above the wing mirror enables this displacement to be controlled to a certain extent. In the diagonal configuration, because the thicker sheet surrounds half the component, it is easier to balance the force.

The extra weight is however a significant handicap. Similarly, the quantity of metal employed is very large, due to the area of thick sheet used to produce the blank.

3.3.2. Body side inner

There are two advantages of using welded blanks to produce this component. Firstly, it is possible to incorporate reinforcements (B-pillar, A-pillar, etc.) and thereby to reduce the number of parts.

Secondly, because of the large spaces occupied by the two doors, the metal yield with monolithic blanks is very poor, and can easily be improved by an assembly of small blanks to form the ring frame (contour of the door). However, this component is already fairly difficult to stamp and can, with welded blanks, become problematic if a certain number of precautions are not taken.

In particular, the proximity of the inside corners of the door frame leads to significant stress concentrations on the welds, particularly on their extremities.

In the body side the most critical zones are situated to either side of the B-pillar at the junctions with the top and bottom members. There are several reasons for this:

- The part often has very sharp corners (corresponding to a very small die entry radius) and because of the inclination of the B-pillar, two of the corners (front door top and rear door bottom) form closed angles. Furthermore, the drawing depth is large in these zones compared to the punch width, so that this configuration creates heavily stretched zones, which are difficult to control even with monolithic blanks.

> In order to obtain the minimum component weight compatible with the mechanical property specifications, the weld is often situated close to the corners, which are heavily stressed during drawing.

The weld extremities should thus be protected by means of:

- Metal tabs or notches that deform and protect the weld extremities.
- Draw beads that limit metal flow perpendicular to the weld.

Figures 78 to 81 illustrate the critical locations and the solutions proposed.

Our engineering teams are available to work together with the customers to determine the best solution.
But even more important is the problem caused by the residual shear stresses to which the spot-weld is subjected as a result of differences in flow over the radius of the punch nose in the neutral layer of the two welded sheets. The problem increases with increasing blank thickness, with the difference in flow equal to the gap existing between the neutral layer, i.e. half the sum of the thicknesses whatever the punch nose radius. This difference in flow affects the spot-welds in the metal flow zone, i.e. the entire surface with the exception of the punch nose. Care should be taken in determining the location of spot-welds, except for those under the punch nose.

ArcelorMittal has developed a digital spotweld model for use in forming software and can work with the customer to determine the zones where spot-welds can be placed without risk. It is of course possible to add finishing spot-welds once the part has been stamped, and this can be done without a specific compliance investment. The patch cutting burr should be placed opposite to the substrate blank to avoid damaging the blank.

5. Forming of Usibor® 1500P and Ductibor® 500P welded blanks

Tests were successfully carried out to determine the formability and functional properties of Usibor® 1500P and Ductibor® 500P welded blanks. The material is hot formed and quenching takes place within the tool, generating very high yield strengths. Another advantage of this material forming process is that there is no springback. Hot forming (at 900°C) goes a long way towards solving forming problems. At this temperature, the base metal and the weld are superplastic, and the forming process is made in stretch more than usual. These blanks are used primarily for B-pillars and rails. The weld appears to be subjected to metal flow and deformation parallel to the weld; these conditions are very favorable. Conclusive tests were carried out in which Usibor® 1500P was laser welded to Ductibor® 500P less quenchable but with very stable mechanical characteristics obtained after hot forming. This application makes it possible to delimit a zone that can be deformed and absorb energy next to a stiff Usibor® 1500P zone.

ArcelorMittal has developed a Usibor® 1500P forming simulation model which considers all thermomechanical aspects and identifies the ones where careful attention must be paid to the contact with the tool. Development teams are available to assist you.