



# Forming Limit Diagrams of Tailor Welded Blanks

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**ABSTRACT:** The possibility of having dissimilar sheets of different thickness, strength, and material properties enable the designer to distribute the material optimally. Tailor welded Blank best suited for both automotive and aerospace applications. In producing of Tailor welded Blanks, a structural part or product is made by joining two or more metal sheets of possibly different thicknesses, materials, and surface coatings. The Demand for lightweight vehicles along with attractive and complicated geometric shapes is growing day to day in a rapid way. By reducing the weight of the vehicles, the fuel consumption and emissions are considerably reduced as well. For weight, cost reduction and for better utilization of scrap remained after some sheet metal operations, the Tailor Welded Blanks (TWBs) is a promising technology. This paper deals with forming characteristics of Tailor welded Blanks.

**KEYWORDS:** Mechanical properties, Tailor welded blank , Formability, FLD

## I. INTRODUCTION

The main advantages of using Tailor Welded Blanks [TWB] in mass production are weight reduction without loss of rigidity, cost reduction by cutting down the number of dies and punches and structural improvement[1].The advantages of using TWBs are vast. They ensure that the components are light in weight, stronger in strength, and provide required functionality at lower costs than parts made from monolithic pressed sheets, as well as improving structural integrity, safety and corrosion resistance in specific areas and they allow greater flexibility in materials selection.The part integration possible with TWB reduces the number of parts and assembly time required per vehicle.TWBs are formed by joining two or more metal sheets together, of possibly different thicknesses of different materials, and are of coated with different surface coatings. The point to be noted is that the welding is done prior to the forming it into the desired shape [2-3].Optimal distribution of the material means creating lighter structures, higher strengths, and joining before forming results in lower production costs. Among welding methods, laser beam welding (LBW) and mash seam Welding (MSW) have received much more attention. Due to some reports, either CO<sub>2</sub> or Nd: YAG laser welding is used in approximately 99% of all TWB application. However, other types of welding such as friction stir welding (FSW), electron beam welding, and induction welding can also be used for this purpose. Friction stir welding (FSW) is also become an important joining technology for the automotive industry [4-5]. In fact, FSW process is probably the solution to overcome some of the usual problems which are associated with the fusion welding of aluminium alloys, but is also an important step in now a days environmental concern by the possibility of reducing the wasting of material and avoiding radiation, fumes and harmful gas emissions usually come out with the fusion welding processes [6]. These material properties are obtained through some experimental tests such as uni-axial tensile test. The two material properties which are related to the formability of TWBs are the  $n$  value and the  $r$  value, where the  $n$  value is the ability of the material to redistribute strain before necking and  $r$  value is the ability of the material to resist thinning during deformation. It should be noted that anisotropy may be introduced by the large deformation inherent in the steel sheet manufacturing process[7-8].For example, the initial rolling of the sheet metal will affect further deformation of the material.

One important point which is to be noted is factors which affect formability of TWBs can be divided into three categories 1) Material 2) Process and 3) Test equipment design. The factors such as strain hardening coefficient ( $n$ ), anisotropy ( $r$ ), grain size, inclusions and welding, affects the formability of tailor welded blanks when the material is considered. When Process is considered the factors such as Mode of stretching (i.e in-plane welding or out-of-plane welding), strain path (i.e bi-axial or plain strain or Uni axial), deformation speed, blank holding force and lubrication affects the formability [9-11].In case of testing equipment design the factors such as draw bead, die corner radius, punch corner radius and punch die clearance affects the forming characteristics of tailor welded blanks [TWB].

## II. FORMING CHARACTERISTICS OF TWBs

In the Uniaxial tensile test case, the size of the specimen selected would be as large as the size of the standard ASTM E8 specimen. If the weld metal is being tested, only the weld metal should be present in the gauge length. It showed that only sub-sized specimens (smaller than ASTM E8 specimens) can give mutually consistent tensile test results. The results are not consistent with the results obtained by the standard sized specimens. It is because of the fact that the contribution of the weld to the tensile load reduces as the size of the specimen increases. Although tensile testing of tailor welded blanks [TWB] is similar to other materials, some special considerations are to be considered in case of TWBs. The most important factor to be considered in testing of tailor welded blanks [TWB] is the size of the specimen [12]. The size of the specimen to be prepared depends on whether the joint or the weld metal is to be tested. If the joint is being tested, the specimen should include both the weld and the base metals. Now a days many are using the rule of mixtures method. This method only can be used for the longitudinal test specimens. The standard test specimens can be used in this method. In this test it is assumed that the total tensile load is divided between parent metal 1, parent metal 2, and the weld metal. If the strength coefficient and the strain hardening coefficient of the parent metals are known, then it is easy to calculate the average weld metal stress. The rule of mixtures is used for determination of the stress-strain curve of the tailor welded blanks [TWB]. The most important difficulty associated with the rule of mixtures method is determination of the weld metal cross section. Microhardness measurements can be used for this purpose. In fact, the standard specimens overestimate the ductility of the weld metal. When the relative size of the weld metal in the cross section increases, the stress-strain curve of the specimen approaches to one of the weld metals [13]. Therefore, many researchers have chosen to use small or miniature test specimens. The miniature test specimens are small enough to ensure that only the weld metal is being present in the gauge area. It is shown that reliable weld properties can be obtained by using miniature test specimens. The uni-axial tensile test is conducted to study the yield strength, tensile strength and ductility of TWBs. The strength of the material is affected by the type of joining process (welding), type of materials and welding parameters [14]. It is shown that post-weld strength of some steels, e.g. SPCC, remain at the strength of the base metal regardless the welding method. The same holds for annealed aluminum alloys. However, hardened aluminum alloys lose their properties during welding, and tend to have less strength comparing to the base metals. Due to local heating and re-melting, the size of the grains in the weld zone can be affected and changed from those of the base metal. The disparity between grain sizes results in different yield stresses and, thus, reduced strength (Hall-Petch relationship). Yield strength and tensile strength of TWBs is known to be dependent on orientation of the weld line. Also yield strength and tensile strength of longitudinally welded specimens are 10-12% stronger than transversely welded specimens. Some experiments are showing that tensile tests are used for the evaluation of work hardening and strength indexes of weld metal. Some are concluded that normalized workhardening indexes of the welded metals are lower than the mean value of those of the parent materials. However, the strength indexes of the welded metals are higher than the mean value of those of the base metals alone [15]. Experimental results are showing that ductile nature of TWBs decreases after welding Process. The level of decrease is highly depends on the welding method, weld line orientation, percentage of the weld material in the cross section of the specimens, and the thickness Ratio (TR). Experiments are showing that increase in porosity of weld metal and the percentage of the weld material in the cross section of the specimen would decrease the ductility. Smaller TRs will also result in improved ductility. It concludes that the formability of welded blanks is not as good as the base metals. Formability of TWBs are mostly analysed by three tests, namely Swift cup Test, Limiting dome height, and Ohio State University OSU tests. Based on the selected formability test, one can develop FLD curve (FLDs). For drawing FLDs two approaches are followed. The first approach combines properties of the base metals and the weld material and provides only a FLC representing the whole blank [16]. The second approach, instead, provides different FLCs for the base metals and the weld material. Most investigators are using the first approach. The second approach to improve accuracy of the forming limits diagrams. In this method, three different FLCs are plotted in the major strain planes. Two of the curves represent the FLDs of the base metals and another represents the FLD of the weld metal. Figure 1 gives a typical FLDs obtained by the first approaches. Since there is a considerable difference between the FLDs of the base metals and the weld material, the FLDs obtained by the second approach are generally more accurate [17]. It is known fact that formability of TWBs reduces after the welding Process. Experimental methods are needed for formability analysis of TWBs.

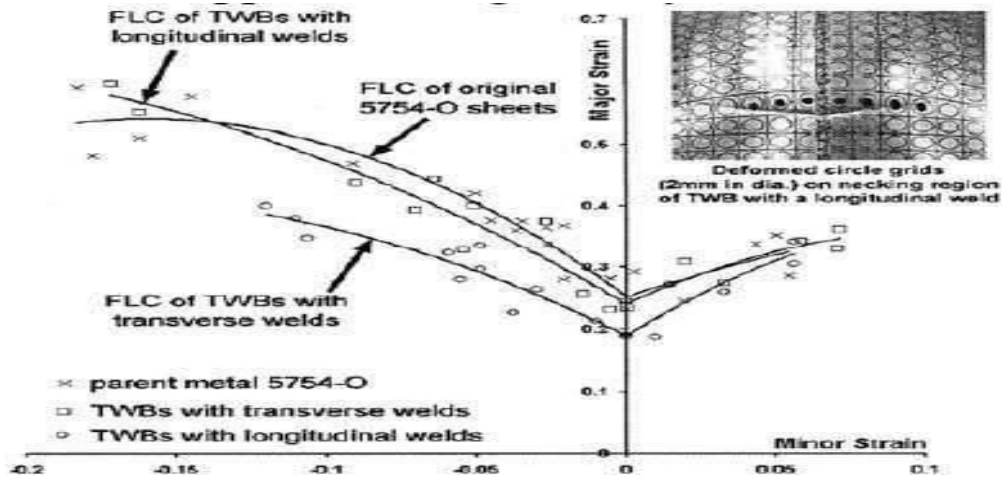


Fig.1 Forming limit diagram

Formability of TWBs is also influenced more by the microstructure of the weld and the HAZ in particular. Generally, Al alloys become more brittle with increase in grain size. This is because of the fact that inter granular fracture takes place more easily. However, it is not the case for Al-Mg alloys, in which increase in the grain size results in larger elongations under uniaxial tensile loading. The thickness ratio (TR) can also affect the formability of TWBs[18]. Simulation based formability tests have been widely used for the formability analysis of TWBs. These tests show that stress concentrations caused by the inhomogeneous strength distribution across the weld or imperfect fusion zone geometry decreases the formability for all alloys. Similar results are available for other welding methods such as FSW. Welding method chosen and welding parameters can also influence the formability. The FSW TWBs are more formable than GTAW ones. Imperfections at the weld region decrease the ductility of TWBs. A higher tensile strength is associated with a higher amount of magnesium in the weld region.

It is believed that MSW specimens have good formability in ball-stretching test, while laser welded specimens have good formability in ball hole-expansion test. The higher percentage of Mg is lost at lower welding speed or a higher laser power is used. The formability of the blanks is not the same for all types of forming processes[19]. It is observed that minimum major strain of TWBs with longitudinal welds is almost the same as of the base metal. The formability is also dependent on loading conditions such as orientation of loading with respect to the weld line.

Dissimilar properties of two pieces of sheet metal in a tailor-welded blank can cause forming problems such as decreased formability and/or metal flow. Tearing and wrinkling are two modes of failure in the forming of TWBs, generally in all deep drawing applications. As the different pieces of sheet metal, used in a typical TWB will have different strengths. It means that they might deform differently. If material on the punch side was stretched perpendicular to the weld line, deformation of the weaker material would be larger than the stronger material, and it may cause tearing failure. Reversely, compressive stresses in the sidewall and the flange area may lead to wrinkling in some forming applications [20]. Inability of the weaker material in withstanding such a high compressive stress and the reduced buckling strength in case of thinner sheet results in movement of the weld line towards the thinner material and buckling of the thinner material in the side wall or the flange area. The material flow adversely affects the formability of the TWBs. In order to find strategies for control of the material flow during forming of TWBs. Placing of some draw beads can be helpful in the control of the material flow so that they add local constraints to the TWB to have better formability.

Through the experiments observed that stress concentrations are in the weld region. The concentrations are more pronounced as the thickness ratio [TR] increased. The observation explains why the level of experimental FLDs reduces as the thickness ratio [TR] increases, it is because of the fact that the failure is mainly caused by the thickness difference between the materials. For e.g., the heat affected zone (HAZ) has its own material properties which are completely different from those of the base metals. Other one is the temperatures raised by the welding process may eliminate the heat treatment of tempered aluminum alloys, and this result in an area of less strength. In addition, from

fracture point of view, it is better to have the weld line always placed in the low strain regions because of the fact that the blank can deform more before its failure, and knowledge of stress and strain distribution within the TWB is important for all of the above mentioned purposes.

It is reported that stress concentrations in the weld during deep drawing of GTAW TWBs. In the experiments, localization occurred in the thinner sheet several millimeters away from the weld line for some gauge combinations. Measurement of residual stresses in TWBs is possible by using a neutron diffraction method. The results of the study indicate that residual stress distributions in the weld region of TWBs can be complex, but the magnitudes of stresses tend to be small as comparing to conventionally welded thicker materials.

### **III. FAILURE MODES OF TWBs**

Depends on loading conditions, different failure modes may occur in TWBs. Two types of failure can occur during forming of TWBs. The first type of failure initiates in the weld and propagates to other sections. This failure mode takes place when straining is parallel to the weld line. Due to lower ductility of the weld metal compared with the parent material, the weld fails. The second type of failure is that the thinner weaker base metal fails. This failure occurs when the straining is perpendicular to the weld line. Owing to a higher flow stress of the weld material, the strain is localized in the weaker thinner parent material, and this leads to failure in the thinner base metal.

### **IV. CONCLUSION**

The forming characteristics of tailor welded blanks has been studied. The formability of tailor welded blanks is mainly depends on the orientation of the major strains with respect to the transition zone which includes both the weld and heat affected zones. Depending upon the welding method chosen for making tailor welded blanks, the size and properties of the transition zone varies. The thickness difference and presence of the weld metal plays important role in causing local stress and strain distribution patterns at the transition zone. Always high stress concentration factors are observed at the transition zone. For Fe-based alloys, the weld strength is higher or some times equal to the base metals strength. But in case of Al alloys the weld strength is always less than its parent metal strength. This is due to the fact that the relatively high welding temperature removes the original heat treatment. Two types of complexities are observed during the formability analysis of tailor welded blanks. In other words, the in-homogeneous mechanical properties influence the forming behavior of tailor welded blanks. The spring back behavior of sheet metals is affected by the welding process and also material flow phenomenon. In case of Al alloys higher the magnesium content, higher will be the hardness and tensile strength. Decrease in ductility and tensile strength in laser welded aluminum is originated by the depletion of the magnesium content during the welding process. The region of hardness increase can be from tenths of millimeter to few millimeters depending on the material and welding method. Formability of tailor welded blanks is also influenced more by the microstructure of the weld and the heat affected zones. The more emphasis is to be given on the two material properties, which are related to the formability of tailor welded blanks are the  $n$  value and the  $r$  value, where the  $n$  value is the ability of the material to redistribute strain before necking and  $r$  value is the ability of the material to resist thinning during deformation. The normalized work hardening indexes of the welded metals are lower than the mean value of those of the parent materials. These material properties are obtained by conducting uniaxial tensile test. The strength indexes of the welded metals are higher than the mean value of those of the base metals alone. The type of heat input is also an important factor which is to be considered as it affects the hardness. When the more concentrated heat input is given, like in laser welding, results in narrower regions of hardness increases compared to other less concentrated methods, like metal inert gas welding.

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