Review on Formability of Tailor-Welded Blanks

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Abstract – In this paper, an overall review of the different parameter affecting on formability of tailor-welded blanks process is presented so that other researchers can concentrate on same to further critical investigations in this area. Tailor-welded blanks has been widely used in automobile and aerospace application now-a-days. It is the combination of more than or equal to two sheets having different material, thickness and coatings. Efforts have been put for determining the formability of TWB by various authors. Authors have been compared various test data for formability tests of TWB analytically with the help of various software. They have compared analytical data with practical data which were carried out in early 90's for formability test when various software were not available. The testing of data and analyzing them by generating Forming Limit Diagram (FLD) for various tests parameters carried out by Limit Dome Height (LDH) test has been being much simpler analytically rather than conducting them practically. The efforts have also been put to conduct data and to verifying them analytically for deep drawing process of formability for TWB sheets with the help of various available software codes. Future scope may include to conduct data practically and to analyzed them by varying various test parameters for deep drawing process of a cylindrical cups on a new software HYPERWORKS which is now-a-days immerging as a powerful tool for software applications due to its some key features of being more efficient and accurate than other available software codes. The analyzing process is very fast, reliable and accurate compare to other finite element code available in the market.

Index Terms—Tailor-welded blanks, Formability, Deep drawing process.

I. INTRODUCTION

A tailor welded blank consist of two or more sheet metals which are welded together prior to forming. The sheets which are welded together may be different in size, shape and even in thickness also. The blanks may be also differing in sense of coating and material grade also [1]. This different blanks are welded together to form in to one continuous blank.

In industries since last long years the materials which are used for preparing TWB's in general are combinations of mild steel to stainless steel with different grades. Also the common materials which are used for making TWB's are generally aluminum alloys with different grades or it may be combination of aluminum and steel alloy sheets. Since, the melting temperatures of aluminum and steel are quite different, conventional fusion welding processes does not yield a sound joint in this case of dissimilar metals joining. In addition, fusion welding produces high concentration of inter-metallic compounds that are detrimental to the joint. Also Joining material combinations such as aluminum and steel pose a number of problems viz., formation of brittle inter-metallic compounds, poor wetting behavior of aluminum, difference in physical and chemical properties of the base metals, etc.

The brittle inter-metallic compounds layer leads to fast rupture of the joint under stress [2].so because of their less familiar weldability requirements associated with conventional welding methods such as laser welding, Literature has description of different techniques for joining aluminum and steel such as friction welding, impact welding, friction stir welding and techniques derived from friction stir welding, cladding (by rolling or explosive),mash seam welding, electron beam welding, laser beam welding, ultrasonic welding, electric discharge joining, etc. generally To create a Tailored Blank two or more sheets are welded together by mash seam welding or laser welding. The width of a mash seam weld including the Heat Affected Zone is 10-15 mm while the width of a laser weld including the Heat Affected Zone is 1-2 mm. The volume fraction of martensite in the laser weld is large due to the high temperature rates during the cooling of the laser weld. Due to the lower temperature rates in mash seam welding, less martensite is formed, and consequently a less hard weld is formed. A disadvantage of the mash seam weld is its visibility in contrast to the almost invisible laser weld. Therefore mash seam welded Tailored Blanks will not be used in visible parts of a car. An advantage of laser welding is the narrow weld which hardly effects the cathodic protection in galvanised Tailored Blanks [18].

Now a days efforts are being put forth to apply friction stir welding (FSW) technology for the development of TWB in recent years which was initiated primarily for aluminum alloys in 1991 by welding institute(TWI) in Cambridge,U.K. [3,4].Radlymayr and Szinyur [7] measured the mechanical properties of the weld bead after wire eroding away the base material.

The choice of the welding technique depends on the production of a sound, heterogeneous, mixture of aluminum and steel at the interface. The most suitable method used for welding is the friction stir welding (FSW) method in which work pieces are butted together and firmly clamped and then joining is achieved by heat and material flow generated by the FSW tool which rotates as it moves along the butt line. The FSW technique has an edge over other techniques, since; it has low energy input, short welding time, low distortion, and relatively low welding temperature, which are essential criteria for Al–steel welding [5].

The benefits of TWB technologies are cost reduction by requiring less forming dies, weight reduction by welding sheet material with different thickness or strength for performance requirement, part dimensional consistency improvement by removing inaccurate spot welding processes, corrosion resistance enhancement by eliminating lap joints, strength improvement by substituting traditional spot weld with laser and mash seam welds, Improvement of tolerances, since the different parts of a product are welded together before the forming operation using a continuous welding process.

Other advantages may include Improvement of crash durability, Reduction of the amount of scrap due to the irregular shapes of the product, Smaller pieces of materials which form an irregular blank shape can be nested easily for better material utilization, Reduction of the number of parts to be assembled, which results in a simplification of the logistics and obviously, Lower personnel and production costs.

TWBs began appearing in Europe and Japan in the mid 1980s, and their use has continued to increase. It is estimated that 40 to 60 million TWBs will be produced in 2000 [6].

II. Application

In an effort to reduce the raw material cost and the weight of automobiles, demand for light-weight and/or high-strength steels TWB's has steadily increased in the automotive industry recently.

The application of TWB's in automobile components include pillars situated at both sides of the doors, Inner door panels , Longitudinal Cross rail bumpers, Floor panels, Wheel houses ,Inner panel tail gates.

III. Formability of Tailor Welded Blanks

The formability of sheet metal is dependent on many factor such as its properties, microstructure, thickness and external factors. To understand formability of sheet metal is essential to define formability. Formability is loosely defined as a sheet metals ability to be mechanically shaped by plastic deformation without machining. Sheet metal forming occurs when a sheet is clamped around the edge of a die and a punch forces the sheet (form) through a cavity where the sheet is stretched to conform to the shape of the tools [11]. To measure the formability of a metal, standardized sheet forming processes are used. There are many types of sheet metal forming processes used to measure formability, two well used forming operations are (1) stretch forming e.g. hemispherical punch test, and (2) deep-drawing.

The hemispherical punch test is a type of limiting dome height (LDH) stretch testing equipment that has a high degree of reproducibility when compared to other stretch forming tests. In this test, draw-beads are used to hold the steel sheet firmly in place to prevent drawing in during forming process. The resulting form of the sheet metal is a rounded dome shape. There are also many studies [12, 13, 14, 15] done using this test to determine the formability of metal.

On the other hand, deep drawing is an operation that forms the metal by forcing the punch against the sheet metal over a die edge and into the cavity. The resulting part looks like a cup and this test is used typically for forming cups, shells, short tubes, automobile bodies, and gas tanks [16] with a flat plane on the bottom.

IV. Modelling Simulation of Deep Drawing Test for Tailor-Welded Blanks

For the simulation of deep drawing a square cup deep drawing simulation set up constructed as per the NUMISHEET '93 benchmark specifications is used [23]. R. Ganesh Narayanan *et al.* [24] generated CAD models of the tools (like die, punch, blank holder) in deep drawing in Pro-E® and imported into PAM-STAMP 2G® for pre-processing, performing simulations and post processing. Two shims are used to compensate the thickness difference in TWB, and these shims are exactly positioned above and below the thinner sheet. The shims are compressible with properties same as the stronger base metal. The friction coefficient between contact surfaces is taken as 0.12 as this approximates all forming conditions. The blank holding force is optimized during simulation to avoid wrinkling and extra thinning. Downward stroke is given to the punch with a velocity of 0.5 mm/min. The solution is mapped in such a way that the punch force is monitored for each unit of progression of the punch.

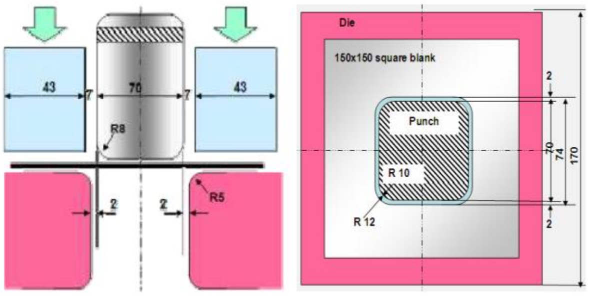

FIG.1: SQAURE CUP DEEP DRAWING SET-UP USED FOR SIMULATION [23].

V. LITRATURE REVIEW

A systematic study of the macro-performance of friction stir welded automotive sheets were carried out by kwansoochung *et al.* [4].to evaluate macroscopic performance the hardening behavior, anisotropic yielding properties and forming limit diagrams were characterized both for base materials and weld zones. They have considered four automotive sheets namely, aluminum alloy 6111-T4, 5083-H18, 5083-0 and dual phase steel DP590 sheets each having one or two thickness. They have modified the chaboche type combined isotropic-kinematic hardening law to describe transient hardening behavior. For anisotropic yielding properties, the non quadratic anisotropic yield function was utilized for base material zone while isotropy was assumed for weld material zone. And forming limit diagrams were measured for base materials and calculated for weld zones. Based on this mechanical properties containing similar gauges (SG) and dissimilar gauges (DG), formability of this four sheets were experimentally and numerically investigated [8].Particularly formability including the simple tension test with various weld line directions, hemisphere dome stretching and cylindrical cup drawing tests were evaluated. They have conclude based on Numerical study of weld line direction that formability performance of welded samples was dependant on weld zone line arrangement as well as its ductility and strength. Weld zone ductility was more important when major principal loading direction was aligned with weld zone line, while the thickness and flow stress of flow zone were more important if the major principal loading direction is vertical to the weld zone line.

Formability of tailor welded strips and progressive forming test were carried out by Z.Q.Sheng [9].dome test is the standard test for determining the sheet metal formability. Dome test has been carried out for four material combinations of steels namely DP800 (1 mm thick) – CRDQ, DP800 (0.7 mm thick)-CRDQ, annealed stainless steel 301(0.76 mm thick)-CRDQ, and annealed stainless steel 301(1 mm thick)-CRDQ having thickness of 1 mm of the CRDQ steel. He has investigated the FLD (Forming limit diagram) curves depend on weak base material. He has also modeled the deformation of LDH (limit dome height).he has conformed critical yielding ratio (CYR) and strength ratio (SR) by both numerical simulation and dome tests.

When traditional forming process is used to form the tailor welded blanks tearing in the weld seam and wrinkling in the die addendum often occurs.Cao and Kinsey [10] proposed a modification to the deep drawing process where segmented dies with local adaptive controllers clamp adjacent to the weld line during the forming operation thereby reducing the strain in the material near the weld seam, limiting the weld line movement, and reducing the concern of tearing failure.

Brad Kinsey *et al.* [11] presented forming limit diagram (FLD) produced from limit dome height (LDH) test data. They had implemented the test data presented by cao and Kinsey [10]. They had investigated that this innovative manufacturing process increased the drawdepth of a test panel by 22% by reducing the strain transverse to the weld line in the thinner material by over40% and the weld line movement by 44%.

M. Abbasi *et al.* [17] analyzed the wrinkling behavior of tailor welded blanks during deep drawing process. They had investigated wall wrinkling tendency of a TWB consisted of interstitial free steel with different thickness analytically, numerically and experimentally. ”Autogrid” software was applied to measure the geometrical data and strain during the experiments. The predicted results about punch stroke value and critical strain at onset of wrinkling were in good agreement with experimental results. They have also investigated that wrinkle waves just formed in thin segment of TWB, and wrinkling initiated by development of three wrinkle waves. There are no wrinkle waves formed in thick segment. He has also found that non homogeneous distribution of strain in TWB’s with TR (thickness ratio) >1 results in deviation of weld line from its initial position and deflection of it due to geometrical discontinuity.

T. Meinders *et al.* [18] has investigated the behavior of Tailored Blanks during deep drawing using the finite element code DiekA.he has simulated two different type of material blanks having different weld location. He has simulated round products with flat bottoms and also round products with spherical product having weld locations to the middle of the product, to the 130 mm left side of the product, and to the right side 130 mm of the product from middle. He has found that weld line motion in each case satisfies the simulated and experimented results. The weld line motion moves towards stronger material deforming the weaker material plastically.

R. Padmanabhan *et al.*[19] had also investigated deep drawing formability characteristic of aluminum-steel TWB using finite element code DD3IMP.In all combinations of Al–steel TWBs, aluminum being weaker is subjected to greater plastic deformation and hence the weld line shifts towards steel side. In this study, the weld line by itself does not have significant impact on the formability of Al–steel tailor-welded blanks, due to its small size and the large gradient in mechanical properties between the sheet blanks.

G. Venkateswarlu *et al.*[20] has determine the effect of blank temperature on forming behaviour of sheets and damage factor of such aluminium sheet alloys of 6061 and 7075 at elevated temperatures. A series of simulations were carried out on the formability behaviour of cylindrical deep drawing of aluminium alloys in the temperature range 50-500°C using DEFORM-2D.The results show that forming at elevated temperature can yield significant increase in product height, especially for aluminium 7075. The deep drawing of aluminium 6061 alloys show very good formability in a temperature range between 150-250°C and 400-500°C for aluminium 7075. Both the metals gave identical cup heights when drawn at 475°C.

RICHARD W. DAVIES *et al.*[21] has determined mechanical properties of aluminium TWB at superplastic temperatures. The sheet materials used are aluminium alloys AA5356 and AA5083. The experimental results show that in the temperature range of 500-550 C and at strain rate ranging from 10^{-4} to 10^{-2} the weld material has higher flow stress and lower ductility than monolithic sheet material. He has also noticed that the weld material exhibited elongation of 40% to 60% under these conditions whereas the monolithic sheet achieved 220-360% elongation. At the same temperature and strain rate the weld material exhibits flow rates 1.3-4 times greater than flow stress in the monolithic sheet.

TWB contains a heat-affected zone (HAZ) which has quite different mechanical properties from base materials. Base materials are tied together along the weld lines so that the HAZ is neglected. K.M. Zhao *et al.* [22] have found various finite element models for TWB including HAZ are presented. They have suggested an appropriate model based on the considerations of accuracy and computing efficiency. They have performed Free-bend test (three-point bend test), stretch-bend test (OSU formability test) and limit dome height (LDH) test to verify the proposed numerical modeling technique for TWBs.

VI. Results and Disccusion

From last two decades due to increased demand of light weight and high strength automobile vehicles and aerospace applications TWB has gain tremendous attentions due to its special characteristics of fulfilling the demands of the customer. Hence investigators from different universities and from different MNC's has done work on checking the formability of TWB's for appropriate applications analytically by performing various test and comparing their test data with analytical data. But due to limitation of testing hardware equipment and absence of necessary software applications the work need to be further investigated. As the increase of demands and availabilities of different software the work has been done on checking various forming parameters through analytically with the help of different graphs comparing it by conventional data. The investigators has performed various forming tests like FLD, DLH, and wrinkling behavior and verified the data analytically with the help of software like ABAQUES, AUTOGRID, and finite element code DICKA and to the some extend PRO-E.

The more attention has been given to the simulation of deep drawing process of TWB by various performers using finite element code DiekA and code DD3IMP.investigators has determined formability behavior of cylindrical cup deep drawing process using software finite element code DD3IMP.forming behavior of cylindrical cup deep drawing process at elevated and superplastic temperature has also been analyzed using software finite element code DEFORM-2D.

Recently Marco schwarze *et al.*[25] has performed deep drawing of a square cup, draw bending test, and deep drawing of cylindrical cup with anisotropy using commercial code ABAQUS and had successfully compared numerical data with experimental measurements.

VI. Limitation of Using TWB'S

The welding of the flat sheets is an extra step in the production process with added costs which is the main drawback of this process. Subsequently it includes other disadvantages also. The weld and the Heat Affected Zone can negatively influence the formability of the blank due to the development of martensitic structures. So the critical property of tailored blanks is the reduction of the formability due to the Welding process, compared to the formability of the base materials.

VII. FAILURE BEHAVIOUR OF TWB

The failure can occur at two stages in the TWB's. i.e. either crack initiated at the weld region by straining parallel to the weld line or crack may be initiated in the weaker material by straining perpendicular to the weld line [18].

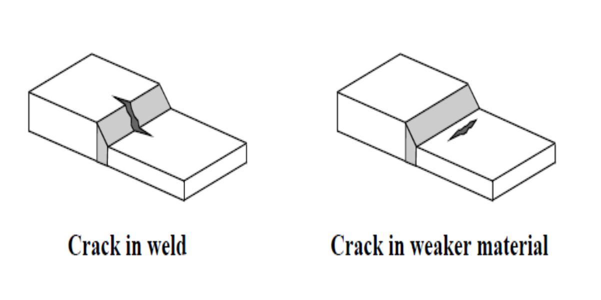

FIG.2: Failure Behaviour Of Teilored Blank [18].

VIII. CONCLUSION

From above literature we can reviewed that the formability of TWB has been checked by performing various tests and also recently from past decade analytically also on various software codes. The one of the process of forming i.e. the deep drawing process has been also performed by various investigators practically and they had verified their test data numerically also. The deep drawing of square cup and round cup has been performed and data has been verified by code ABAQUS.

HYPERWORKS is the new immerging code for analyzing various forming test data analytically having capabilities of changing various parameters like different material properties, die geometry, punch geometry and punch velocity, frictional resistance etc. for considerable test. It is more efficient and can give better results than other available commercial codes.

IX. FUTURE SCOPE

The deep drawing process for cylindrical cup can be performed analytically by varying various parameters like different material properties; different die geometry and punch velocity etc. using code HYPERWORKS. The test data can be verified also.

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