International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Review Article

Experimental Investigations, Modeling and Simulation of Tailor Welded Blanks : A Review

Satya Suresh V.V.N[Ȧ*], Srinivasa Prakash Regalla[Ȧ], Uday kumar R[Ḃ]

[Ȧ]Mechanical Department, Birla Institute of Technology and Science-Pilani, Hyderabad Campus, Shameerpet, Hyderabad, India
[Ḃ]Mechanical Department, MGIT, Gandipet, Hyderabad, India

Accepted 10 January 2014, Available online 01 February 2014, **Special Issue-2, (February 2014)**

Abstract

The present paper summarizes the state of the art developments in numerical modeling and simulation of sheet metal welds commonly known as Tailor welded blanks (TWB). This metal forming process gained lot of importance in recent times due to its vast applications in automotive and aircraft industries. The blanks which consist of different thickness, material and shapes are welded together and forming is carried out. Mechanical and metallurgical properties of weld zone, effect of thickness ratio, material combination and weld line movement were studied in detail. It is noted that very few studies were made towards the experimentation and simulation of TWBs at elevated temperatures.

Keywords: *Tailor welded blanks, Finite element simulation, Formability, Welding*

1. Introduction

Sheet Metal welds commonly known as tailor welded blanks or laser welded blanks consists of two or more sheet metals which are welded together with different size, shape and even in thickness also. The blanks may also differ in sense of coating and material properties. The major advantages of employing TWB's in mass production are weight reduction without loss of rigidity, cost reduction by cutting down the number of dies and punches and structural improvement. The advantages of using TWBs are numerous. They ensure that the components are light, stronger, 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. However, the disadvantages of TWB are related to the heterogeneous nature of the blank (due to weld and dissimilar materials used), where the thinner / weaker material may deform preferentially and tear prematurely in Stamping, which also results in weld line movement (Saunders and Wagoner, 1994).

1.1 Process parameters of interest

Factors that affect formability of TWB can be divided into three categories 1) Material 2) Process and 3) Testing equipment design as shown in table 1

The material properties that affect formability include the strain hardening coefficient, and anisotropy. Also, ductility contributes to formability, as it is an indicator of formability.

Table 1 Parameters affecting formability

Material	Process	Testing equipment design
Sheet thickness Material properties a) Strain hardening coefficient(n) b) Anisotropy (r) Grain size Inclusions Welding	Mode of Stretching a) In-plane b) Out-of-plane Strain path a) Bi axial b) Plain strain c) Uni axial Deformation speed Blank holding force Lubrication	Draw bead Die corner radius Punch corner radius Punch-die clearance

These material properties are obtained through intrinsic tests *i.e.* uni-axial tensile test. The two material properties that are related to the formability of a material 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. For example, the initial rolling of the sheet metal will affect further deformation of

*Corresponding author: **Satya Suresh V.V.N**

the material (Padmanabhan et al.,2007). Therefore, the study of these two properties on the formability of material provides TWB manufacturers a point of reference in choosing materials based on the application.

Yang and Hsu, 2001 studied the effects of the *n*-value and the r-value on the forming limit in the hemispherical-punch stretching test numerically. They found that the *n*-value was proportion to the LDH while the r-value was inversely proportional to the LDH. The numerical models showed that as the *n*-value increased and the r-value decreased, the strain distribution became more uniform with lower peak strains . Thus, the strain-hardening and anisotropy affect the results of the standard LDH tests for formability. On the other hand, Padmanabhan et.al, 2007 were interested in the effect of anisotropy under complex stress-strain state of the square cup deep-drawing process of mild steel welded to DP steel, numerically .

2. Mechanical and Metallurgical aspects of Weld zone

Rojek et.al, 2012 determined the mechanical properties of weld zone in forming of TWB. They presented different methods which can be used to determine mechanical properties of the weld zone in TWB. Methods based on experimental tests as well as those combining experimental procedures with numerical studies are described. The presented methods include uniaxial tension tests, micro hardness tests, and indentation tests combined with inverse numerical analysis. The stress strain relationships for the weld zone in a steel laser welded blank obtained using different methods have been compared with one another. Mohammad Riahi and Ahmed Amini, 2013 investigated the effect of location change of weld zone and differences in thickness combination of TWB sheets on their tensile characteristics and forming capabilities. Quality evaluations of weld zone metallographic and tensile as well as ball punch tests have been conducted. Tension characteristics of welded samples have been determined by conducting a uni-axial tensile test perpendicular on the weld line in those samples. Forming capability of TWB samples were also studied by using sphere head chisel test. By moving weld line toward thick sheets direction and increasing thin sheets share of the weld in TWB, an increase in relative elongation in tensile test and in chisel test increase in cups height was observed. This indicates that forming capability of TWB samples by moving weld line toward thick sheet increases and weld zone does not have much effect on forming capability of TWB. By using the derived recommended relation induced from this study, it is conceivable to obtain the amount of increase in relative length of TWB from its base sheets. Results of this relation are confirmed with obtained results from tensile test. Also by reduction in thickness difference of TWB sheets, their formability increased. Bayraktar et**.**al, 2008 made a comparative study for micro structural and mechanical-toughness characterization of the steel assemblies, base metal or welded by LASER. For that a procedure of test specifically adapted was used for welded joints (t < 4mm). The first part of this study consider different steel grades such as a grade of the FE360BFN steel (t = 4 mm) and a grade of the interstitial free steel (IF-Ti, t = 0.8 mm) and HR60 (t = 2.5 mm) welded by LASER that largely used in the automotive industry. Richard W Davies et.al, 2002 investigated the mechanical properties of weld material in aluminium tailor welded blanks (TWBs) at super plastic temperatures and discussed the potential application of TWBs in super plastic forming operations. Aluminium TWBs consist of multiple sheet materials of different thicknesses or alloys that are butt-welded together into a single, variable thickness blank. To evaluate the performance of the weld material in TWBs, a series of tensile tests were conducted at super plastic temperatures with specimens that contained weld material in the gage area. The sheet material used in the study was SKY 5083 aluminium alloy, which was joined to produce the TWBs by gas tungsten arc welding using an AA5356 filler wire. The experimental results showed that, in the temperature range of 500–550 °C and at strain rates ranging from 10^{-4} to 10^{-2} s^{-1}, the weld material has a higher flow stress and lower ductility than the monolithic sheet material. The weld material exhibited elongations of 40–60% under these conditions, whereas the monolithic sheet achieved 220–360% elongation. At the same temperatures and strain rates, the weld material exhibited flow stresses 1.3–4 times greater than the flow stress in the monolithic sheet. However, the weld material did show a substantial increase in the strain rate sensitivity when compared to the same material formed at room temperature.

3. Numerical Simulation modeling of TWB forming at room temperature and at elevated temperatures

Swadesh kumar singh et. al, 2010 studied about the warm deep drawing process of circular blanks and investigated using a 20 T hydraulic press and a finite element model coupled with thermal analysis. The work was aimed to investigate the limiting draw ratio (LDR) and the coefficient of friction of extra-deep drawing (EDD) steels at room temperature and at 200 °C. Simulation and experimental results showed an increase in the LDR as the temperature increases and the coefficient of friction was estimated by comparing the simulation and experimental load–displacement curve. Finite element simulation results were in good agreement with the experimental results. G. Venkateswarlu et. al, 2010 determined the effect of blank temperature on forming behavior of sheets and damage factor of such aluminium sheet alloys of 6061 and 7075 at elevated temperatures. An insight into such a study will throw light on the different temperatures required by the above materials when they are made into TWBs. In this investigation, a series of simulations were carried out on the formability behavior of cylindrical deep drawing of aluminium alloys in the temperature range 50-500^0 C using DEFORM-2D. The damage factor based on Cockcroft Latham algorithm was taken as the constraint for defect free product. 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^{0}c and 400-500^0 C for aluminium 7075. Both the metals gave identical cup heights when drawn at 475^0 C. Zhao et. al, 2001 presented various finite element models for TWB including HAZ. An appropriate model based on the considerations of accuracy and computing efficiency was suggested. Free-bend test (three-point bend test), stretch-bend test (OSU formability test) and limit dome height (LDH) test were performed to verify the proposed numerical modeling technique for TWBs. Scott Raymond et. al, 2004 studied Finite element analyses of standard tailor-welded blank (TWB) forming tests to determine the effects of weld modeling techniques on simulation results. Finite element models of TWBs were created that either included a simple representation of the weld properties and geometry or excluded both weld geometry and material properties. In all models, shell elements were used to represent parent materials of the TWB. The models excluding weld properties and geometry used nodal rigid bodies to join the thin and thick parent materials. The models including weld properties and geometry used solid elements for the weld materials, and a novel method for joining shells to solids. Simulations of three standard metal forming tests were performed: ASTM tensile test, in-plane plane strain test, and limiting dome height tests representing various biaxial strain states including: uniaxial tension, plane strain and biaxial tension. Results indicate that there are a number of relatively subtle effects associated with the manner in which the weld line is modeled. Most of these effects relate to the constraining effect of the weld line with respect to strain along the axis of the weld line. Sadok Gaied et.al, 2009 examined a numerical model to predict the forming height dome and a specific forming curve of TWBs is presented. Finite element analyses of standard TWB forming tests (Nakazima) were performed in Arcelor Mittal Auto Application Research Center to determine the interaction between the weaker and the stronger materials. One of the most important aspects in the instability analysis is the problem of the measurement of the critical strain at necking. A new method is presented based on the analysis of the major strain rate using the discrete Gaussian convolution. A comparison of numerical and experimental results highlights a good agreement. The numerical approach offers a considerable gain to obtain specific FLC for all configurations. Lai et al, 2007 developed a tooling system with a heating control function which can be used to heat the specimens up to 600 ^{0}C. The results reveal that the formability of Ti-TWB can be optimized with a well controlled tooling temperature system, thus resulting in a more efficient and effective forming of titanium alloys TWBs.

4. Investigations of weld line movement

The formability of TWBs may change according to weld line position in critical areas (Scriven et.al, 1996). Studies have suggested that the best formability will occur when the weld line is placed away from areas of high strain *i.e.* place the weld far from the major strain direction (Shi et.al,1993) .Placing the weld closer to the thinner material in a dissimilar thickness TWB (*i.e.* decreasing the amount of thinner material in the TWB) increases the formability by allowing the thicker material to deform more. Narayanan and Narasimhan, 2008 found that weld line location does significantly reduce the forming-limit strains when compared to the unwelded blank as where increasing the weld line offset increases the forming limit reduction when the decrease in limit strain is in the stretching region. The paper presented by Young Moo Heo et.al, 2001 dealt with square blanks which have been used having three different weld line locations. The differences of the weld line movements and the tendencies of the thickness strain distributions were investigated by experimental and analytical methods. With consideration for the amount of movement and for the thickness strain in the central and diagonal direction, the larger are the values, the longer are the distances from the center line to the initial weld lines. The drawbead adds additional restraining forces to the blank, so that the movement of the weld line is reduced and the thickness strain distribution is changed. Young Moo Heo et.al, 2001, investigated quantitatively the effects of the drawbead dimensions on the weld-line movements in the deep drawing of the tailor-welded blanks. Square blanks have been used and five different circular drawbeads of 0.0, 1.5, 2.0, 3.0, 4.0, 5.0 mm radius and also no drawbead were installed in the blank holder in the experimental apparatus. The differences in the weld-line movements and the tendencies of the thickness strain distributions were investigated by experimental and numerical methods. The results of the weld-line movement showed that the smaller the radius of the drawbead installed, the larger are the values of the movements. Also it is shown that for thickness strain along the central and diagonal direction that the larger is the dimension of the drawbead, the larger are the values of maximum thickness strain. The drawbead adds additional restraining forces to the blank, hence the movement of the weld line could be controlled by adequate drawbead installation. Clubotariu and Brabie, 2011 presented a paper which investigates the behavior and mechanical properties of the weld line in a tailor welded blank during and after its tensile testing by applying the following testing methods: parallel tensile test, micro-hardness testing, thermography, EDX and microscopy. Cheng et.al, 2007 presented a novel experimental method of analysis to determine the tensile properties of weldment of the heterogeneous tailor-welded blank (TWB) and its base metal. A real-time microscopic recording system was developed to acquire the true stress–strain data of the weldment during tensile testing. Specially designed tensile specimens of the weldment were cut from the prepared stainless steel (AISI 304) TWBs with a thickness combination of 1 mm/1.2 mm. With the aid of a newly developed measurement system, the real-time deformation of laser-marked circular grids on the surface of the tensile specimens was captured. The deformation recorded made possible the determination of the stress and strain values of the weldment based on the assumption of plastic incompressibility. The accurately measured tensile data of the weldment is used to determine the localized necking based on the vertex theory. The localized necking criterion is implemented into a computer program, LS-DYNA, which is critical in the numerical simulation of the TWB forming. The simulation makes it possible accurate determination of the strain distributions in TWBs along the centerline perpendicular to the weldment. The predicted strain distributions were compared with those measured and found to be satisfactory, thus demonstrating the validity of the proposed experimental method to accurately determine the true stress–strain values of the weldment and the parent metals. Li. et.al,2013 studied the formability of laser welded blanks (LWBs) and it was measured in the biaxial stretch forming mode using the limiting dome height (LDH) test. High strength low alloy steel and two dual-phase (DP600 and DP980) steels were used for fabricating LWBs. The failure location and the LDH values of the formed blanks were correlated to the hardness across the welds. The effects of weld line position and geometry on the formality was evaluated by investigating LWBs with three different weld line positions (0, 15 and 30 mm offsets from the blank center) for both linear and curvilinear geometry. The formability was found to be dependent on the weld line position and increased when the weld was located farther from the blank center due to more uniform strain developed during LDH tests. Interestingly, weld line geometry was observed to have a stronger influence on the formability of DP600 steel. In addition to weld line position and geometry, heat affected zone softening was observed to be the dominant factor in controlling the formability of all the DP980 LWBs and the curvilinear welds of DP600 with failure consistently occurring in the region with more severe softening. Brad Kinsey and Jian Cao proposed an analytical model to predict the weld line movement and forming height for a uniform binder force. This model provides designers a valuable tool to determine the location of steps on the die surface to accommodate the weld line movement and the potential forming height for a TWB forming with a uniform binder force.

5.Formability improvement with material combinations

The use of new manufacturing concepts and advanced materials is of interest to the major automotive manufacturers who are constantly seeking means to reduce weight and cost. Amit Bhagwan et.al, 2004 studied about different material combinations affecting formability of TWB. One of the problems encountered with stamping TWBs is the difference in load-bearing capacities of the dissimilar sheets that make up the TWB. This can result in a reduction in the formability of the TWB and possibly a movement of the weld from its design-intended location. They produced the results of investigating the use of different material combinations to manipulate this type of preferential straining in the TWB in an effort to minimize the movement of the weld line. Padmanabhan et.al, 2008 investigated finite element simulations which were carried out using home code DD3IMP to determine the formability characteristics of aluminium–steel tailor-welded blanks. Aluminium (AA6016-T4) blank sheet was combined with a range of steel blank sheets namely, mild-steel (DC06) and high strength steels (AISI-1018, HSLA-340, and DP600) to form four different Al–steel tailor-welded models. Aluminium, being relatively weaker, has the tendency to flow more than steel. In particular, dual-phase steel offers the maximum resistance to flow and mild-steel offers lowest resistance. A segmented blank holder allows the application of different forces on aluminium and steel sheet segments in the tailor-welded blank. Different blank holder forces enhance the formability of tailor-welded blank as well as control the draw-in. The simulation results indicate that even with large dissimilarities in material properties, Al–steel tailor-welded blanks can produce superior deep drawn parts. Tušek et.al, 2001 created welding of tailored blanks made of different materials. In general, fusion welding and welding with pressure, practically without fusion, are described. Fusion welding may be carried out with or without the addition of filler material. After welding, hardness of the welded joints was measured. The welded joints were subjected to deep drawing. Investigations have shown that tailored blanks of high-alloy stainless steel cannot be laser or TIG welded to those of low-alloyed ferrite steel without the addition of filler material. A suitable process and filler material should be selected. The purpose of the filler material is to compensate for the differences in chemical and physical properties of both materials. Zuki et. al, 2008 investigated the weld properties of high strength steel laser weld for joining the automotive panel. Laser weld and different types of steel are considered in their study. Experiment was carried out to determine the properties of materials after welding, forming and drawing process of TWB. It is observed from their results that their choice of TWB gives the best material combination. It can be seen that cross sectional area and steel grade are the most significant factors under tensile loading conditions.

6. Thickness ratio effects on tailor welded blanks

TWBs made with dissimilar thickness and strength ratios are very common in vehicles especially where weight reduction and structural integrity are required, such as in a door inner panel. A number of studies showed that increasing the thickness and/or strength ratios decreases the formability of the TWBs (Chan et.al, 2005 and 2003). A large thickness ratio forces more deformation into the weaker material and the strain is concentrated there, which results in premature failure. During deformation, the thinner material undergoes plastic deformation, whereas, the thicker material undergoes primarily elastic deformation. An increase in strength ratios has a similar effect on failure mode as the thickness ratio, whereby the weaker material deforms more and fails first. Chan et.al., 2003 used tailor-welded blanks (TWBs) of the same material but with different thickness combinations and were welded together to form a single part before the formability tests. Thus, SPCC steel sheets of thickness 0.5, 0.6, 0.8 and 1.0 mm were studied and combined to form TWBs of different thickness ratios of 2 (0.5/1.0 mm), 1.67 (0.6/1.0 mm) and 1.25 (0.8/1.0 mm). An Nd:YAG laser was used to weld the tailor-made blanks before the formability tests of the uniaxial tensile test and the Swift test. The experimental findings show that TWBs of different dimensions and radii of cut-off yield different major strain and minor strain values of the FLD. The uniaxial tensile tests show that there are no significant differences between the tensile strengths of TWBs and their relative base metals. In addition, the FLDs of the TWBs indicate that both the level of the forming limit curves and the minimum major strain value decreases as the thickness ratio increases. This implies that the higher is the thickness ratio, the lower is the formability of the TWBs. The influence of thickness ratio (TR) on the formability and forming limit diagram (FLD) of tailor welded blanks (TWB) obtained by pulsed Nd:YAG laser welding of St12 steel sheets are studied by Safdarian Korouyeh et. al, 2013. Steel sheets with thicknesses of 0.5, 0.8 and 1.0 mm were combined to form TWBs of different thickness ratios of 2 (1.0/0.5 mm), 1.6 (0.8/0.5 mm) and 1.25 (1.0/0.8 mm). Limit thickness ratio (LTR) is introduced as a new useful factor for prediction of forming limit of TWB. Results of this research show that by increasing the difference of thickness ratio of TWB and LTR, formability and the level of FLD will decrease. In addition, effects of thickness ratio of TWB on the punch's load–displacement, limit dome height (LDH) and weld line movement are studied. By increasing the thickness ratio, the LDH decreases and some defects such as weld line movement and wrinkling increase. The experimental findings of this study show that the thickness ratio of TWB can effect on the position of fracture in TWB products. Mahmoud Abbasi et.al, 2012 studied TWBs consisted of IF-steels with different thicknesses (0.8 and 1.2 mm), and limiting dome height as well as forming limit diagram were used for formability assessment. Experiments in regard with limiting dome height test showed that the decisive factor in decreasing the dome height is geometric discontinuity and the effect of weld zone is about 6%.

Conclusions

The conclusions from the review are that very few studies were made towards the experimentation and simulation of TWBs at elevated temperatures. The analytical model presented in the literature for the TWB forming can be extended to analyze a non-uniform binder force. Most of the work focused on finding the thickness distribution and force prediction thus there is a need to model location of fracture and wrinkling problems in TWBs. Using appropriate combination of rolling direction orientation, and hence controlling anisotropy, significant improvement in the formability of TWB can be achieved. Probably the weld itself has to be modeled when the weld is subjected to strain states which are not predominantly perpendicular to the weld line. Further investigations must be done to verify this. A more accurate description of the blank holder force in which friction is an important parameter is needed to accurately simulate TWBs. Development of relations to cope with realistic conditions is strongly advocated.

References

Amit V. Bhagwan, Ghassan T. Kridli, Peter A. Friedman(2004), Formability Improvement in Aluminium Tailor Welded Blanks via Material Combinations *Journal of Manufacturing Processes*,Vol.6,Issue2,pp134-140

Bayraktar E, Kaplan D, Yilbas B.S (2008),Comparative study: Mechanical and metallurgical aspects of tailored welded blanks (TWBs), *Journal of Materials Processing Technology"*, vol 204, Issues 1–3, pp 440-450

Brad L. Kinsey and Jian Cao(2003) An Analytical Model for Tailor Welded Blank Forming, *J. Manuf. Sci. Eng.* 125(2), pp 344-351

Chan L C, Chan S M, Cheng, C H, Lee T C, and chow C L(2005), Formability and weld zone Analysis of Tailor-Welded Blanks for various Thickness Ratio, *Journal of Engineering Materials and Technology* vol. 127, pp. 179-182.

Chan L C, Cheng C H, Chan S M, Lee T C and Chow C L(2005), Formability Analysis of Tailor- Welded Blanks of Different Thickness Ratio, *Journal of Manufacturing Science and Engineering*, vol. 127, pp 743-751.

Chan S M, Chan L C, and Lee T C(2003), Tailor welded Blanks of Different Thickness Ratios Effects on Forming Limit Diagrams, *Journal of Materials Processing Technology*, pp 83-89.

Cheng C H, Jie M, Chan L C, Chow C L(2007), True stress–strain analysis on weldment of heterogeneous tailor-welded blanks—a novel approach for forming simulation, *International Journal of Mechanical Sciences*, vol. 49, Issue 2, pp 217-229

Clubotariu V, Brabie G (2011), Weld line behaviour during uniaxial tensile testing of tailor welded blanks, A*rchives of Civil and Mechanical Engineering*, vol 11, Issue 4, pp 811-824

Lai C P, Chan L C, Chow C L(2007), Effects of tooling temperatures on formability of Titanium Tailor welded blanks at elevated temperatures, *Journal of Materials Processing Technology*, vol 119, pp 157-160.

Li J, Nayak S S, Biro E, Panda S K, Goodwin F, Zhou Y(2013), Effects of weld line position and geometry on the formability of laser welded high strength low alloy and dual-phase steel blanks, *Materials and Design*, vol 52, pp 757-766

Mahmoud Abbasi, Ketabchi, Ramazani M A, Mohammad Abbasi, Prahl U(2012), Investigation into the effects of weld zone and geometric discontinuity on the formability reduction of tailor welded blanks, *Computational Materials Science*, vol 59, pp 158-164

Mohammad Riahi, Ahmad Amini(2013), Effect of different combinations of tailor-welded blank coupled with change in weld location on mechanical properties by laser welding, *The International Journal of Advanced Manufacturing Technology*, vol 67, Issue 5-8, pp 1937-1945

Narayana R.G and Narasimhan K (2008), Influence of the weld conditions on the forming limit strains of Tailor welded blanks, *Journal of Strain Analysis for Engg. Design*, 43(4) pp 217-227

Padmanabhan R, Oliveira M C, Menezes L F(2008) Deep drawing of aluminium–steel tailor-welded blanks *Materials and Design*, vol 29, Issue 1, pp 154-160

Padmanabham R, Baptista A J, Oliveira M C and Menezes L F (2007), Effect of Anisotropy on the Deep- Drawing of mild steel and Dual-Phase steel Tailor welded blank, *Journal of Materials processing Technology*, vol 184, pp 288-293

Richard W Davies, John S Vetrano, Mark T Smith, Stan G Pitman (2002), Mechanical properties of aluminium tailor welded blanks at superplastic temperatures, *Journal of Materials Processing Technology*, vol 128, Issues 1–3, pp 38-47

Rojek J, Hyrcza-Michalska M, Bokota A, PiekarskaW(2012), Determination of mechanical properties of the weld zone in Tailor welded blanks, *Archives of Civil and Mechanical Engineering*, vol 12, Issue 2, pp 156-162

Sadok Gaied, Jean-Marc Roelandt, Fabrice Pinard, Francis Schmit, Mikhael Balabane(2009), Experimental and numerical assessment of Tailor-Welded Blanks formability, *Journal of Materials Processing Technology*, vol 209, Issue 1, pp 387-395

Safdarian Korouyeh, Moslemi Naeini H, Torkamany M J, Liaghat Gh(2013), Experimental and theoretical investigation of thickness ratio effect on the formability of tailor welded blank, *Optics and Laser Technology*, vol 51, pp 24-31

Saunders F I and Wagoner R H(1996), "Forming of Tailor-Welded Blanks," *Metallurgical and Materials Transactions A*, vol. 27, Issue 9, pp 2605-2616.

Scott D Raymond, Peter M Wild, Christopher J Bayley(2004), On modeling of the weld line in finite element analyses of tailor-welded blank forming operations, *Journal of Materials Processing Technology*, vol.147,Issue,pp28-37

Scriven P J, Brandon J A, and William N T(1996), Influence of Weld Orientation on Forming Limit Diagrams of Similar/Dissimilar Thickness Laser Welded Joints, *Ironmaking Steelmaking*, vol. 23, Issue 2, pp 177-182.

Shi M F, Pickett K M, and Bhatt K K(1993), Formability issues in the application of TWB sheets, *SAE Technical paper*, pp 27-35

Swadesh Kumar Singh, Mahesh K, Apurv Kumar, Swathi M(2010), Understanding formability of extra-deep drawing steel at elevated temperature using finite element simulation, *Materials and Design*, vol 31, Issue 9, pp 4478-4484

Tusek J, Kampus Z, Suban M(2001), Welding of tailored blanks of different materials, *Journal of Materials Processing Technology*, vol 119, Issue1,pp.180-184

Venkateswarlu G, Davidson M J and Tagore G R N(2010) Finite element simulation of deep drawing of aluminium alloy sheets at elevated temperatures, *ARPN Journal of Engineering and Applied Sciences*, vol. 5 No. 7 pp 93-98

Yang T S and Hsu T C(2001), Forming limit analysis of Hemispherical – Punch stretch forming, *Journal of Materials processing Technology*, vol 117, pp 32-36

Young Moo Heo, Sung Ho Wang, Heon Young Kim, Dae Gyo Seo(2001), The effect of the drawbead dimensions on the weld-line movements in the deep drawing of tailor-welded blanks, *Journal of Materials Processing Technology*, vol. 113, Issue 1–3, pp 686-691

Young Moo Heo, Youho Choi, Heon Young Kim, Daegyo Seo(2001), *Journal of Materials Processing Technology*, vol. 111, Issue 1–3, pp164-169

Zhao K M, Chun B K, Lee J K(2001), Finite element analysis of tailor-welded blanks, *Finite Elements in Analysis and Design*, vol. 37, Issue 2, pp 117-130

Zuki N M , Rahman, M M, Noor M M, Kadirgama K and Reja M R M(2008), An investigation into the effect of materials on joining for automotive panel using tailor welded blanks, *Regional Conference on Vehicle Engineering and Technology, RIVET08*, 15-17, pp 22-26