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Experimental and Numerical Investigation of Tailor Welded Blanks [TWBs]

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Abstract:

Tailor Welded Blanks (TWBs) made of dissimilar, uniform or non uniform thickness materials have potential application in automobile and chemical industries in order to improve fuel efficiency and cost of carrier. Tailor Welded Blanks have been widely used in automobile and aerospace application now-a-days. Efforts have been put for determining the formability of TWBs by various authors. The focus of the study is to propose an analytical Model to predict various parameters like True and Engg. stress-strain, Total elongation and Maximum Force for TWBs of two dissimilar metals. The Proposed model is validated through simulation (UNIGRAPHICS NX) and experimentation, The comparison of results show good agreement and also confirms the validity of the proposed model. The specimens for experimentation are prepared with two dissimilar metals (SS. 304 and M. S.). NDT was performed to ensure the quality of joint before experimentation. The benefits of present study are in two folds. One cost reduction and second the reduction in weight. Second benefit is reduction in weight. Where strength requires at that place strong material can be used and at other place light/economic material can be used where it is require to just covering the machine parts.

Keywords: Tailor Welded Blanks (TWBs), Uni-axial Test, Dissimilar Materials, Tungsten Inert Gas Welding (TIG).

I. Introduction

In recent years, parts are being stamped from blanks made by welding two or more sheets of different base materials. The purpose is to save weight by using weaker gauge material where its strength is sufficient and using stronger material where necessary. The automotive industry has paid a great deal of attention to cost reduction and fuel economy. In the contents Tailor Welded Blanks (TWBs) made of dissimilar, uniform or non uniform thickness materials have potential application in automobile industries for light weight materials in order to improve fuel efficiency and cost of carrier. [1]

The main advantage of using a TWB is that it gives thicker or stronger materials at critical parts of the sheet metal blank. This can also reduce the weight of automotive panels [2]. However the critical properties of tailor-welded blanks introduce many challenges in to the manufacturing process, compared to those for homogeneous materials. The basic factor influencing the formability of tailor-welded blanks is the hardening of the weld joint and the heat-affected zone during the welding process [2], and uneven strain distribution in forming blank. So it is require to pay attention of stress and strain states of TWB during forming for success for forming process Brad L. Kinsey and Jain Cao [3] have developed analytical model for weldline movement and forming height for TWB with different thickness ratio for their study on forming limit diagram.

C. H. Cheng, L. C. Chan, S. M. Chan, T. C. Lee [4] Determination of True Stress-Strain analysis on weldment of heterogeneous tailor-welded blanks-a novel approach for forming simulation. This experimental method of analysis to determine properties of weldment of the heterogeneous tailor-welded blank (TWB) and its base metal. Specially designed tensile specimens of the weldment were cut from the prepared stainless steel (AISI 304) TWBs with a thickness combinations. The deformation recorded made possible the determination of the stress and strain values of the weldment based on the assumption of plastic incompressibility.

Frederick I. Saunders [5] in his Determination of Forming Welded Blanks noticed that based on experiments performed by Wang the laser welds much stronger than the base materials, while mash seam welding had the identical properties to high strength material also galvanized coating adversely affect the laser weld strength while it slightly enhanced the strength of the mash seam weld. It was also found that the welding two materials of different thickness together resulted in a weaker weld than a weld of similar material of same thickness. Fredrick concluded that failure in TWBs is highly dependent upon the amount the weld line moves and how this weld line movement influences the strain of the base material surrounding the weld line. If the weld movement causes stretching of the base material, the base material parallel to the weld line will tear. If the weld movement does not result in a stretching of the base material, the blank will either fail in the weld bead itself or at some other part of the blank depending on the loading condition. Most researchers have only studied the sheet-thickness effect on the base metal instead of performing a similar study on TWBs.

In this study, the focus was made to develop an analytical model to find elongation; stress and strain of TWB for uniaxial test and results of model was compared with experimentally evaluated results of TWB.

II. experimentation

Experiments related to TWBs, made by TIG, are carried out at the Institute, for same thickness combination of blank to observe failure pattern of Tailor Welded Blank. The results are used to relate the developed analytical model.

A. Test Piece Material

The materials used in present experiment are M. S. and SS304. M. S. is known as black iron sheet susceptible to rust and corrosion due to uncoating protected by painting and is mostly used for water tanks, fabrication works, and agricultural implements.

SS304 is widely used in fabrication of chemical process equipments, like condenser, nucleate filter, blender, dairies, food processing plants etc., due to its good corrosion resistance properties. Prior to fabrication of test pieces, material testing was carried out to find chemical composition. Material testing is carried out using X-Ray alloy analyser. The prime advantages of these alloy analysers are, it uses non destructive testing, results are falling in very narrow standard deviation and very user friendly devices.

The sheets of M. S. and SS304 used for TIG were cut in to different dimensions with thickness of 1. 0mm, 1. 5mm, and 2. 00mm. These different thickness combinations of TWBs are shown in Table I.

Table I: Different Thickness Combination of TWBs Used in Experiments

TWB No.	Blank: 1	Blank: 2	Thickness Ratio
1	1. 0 mm	1. 0 mm	1
2	1. 5 mm	1. 5 mm	1
3	2. 0 mm	2. 0 mm	1

B. Preparation of Specimens:

The dimensions are taken as per ASTM standards of “Standard Test Methods for Tension Testing of Metallic Materials”, Designation: E 8/E 8M-08 [6]. The basic material properties are derived by experiments and same properties are used in analytical calculation of different parameters of Tailor Welded Blanks. The dimensions used to find base material properties are shown in Figure 1.

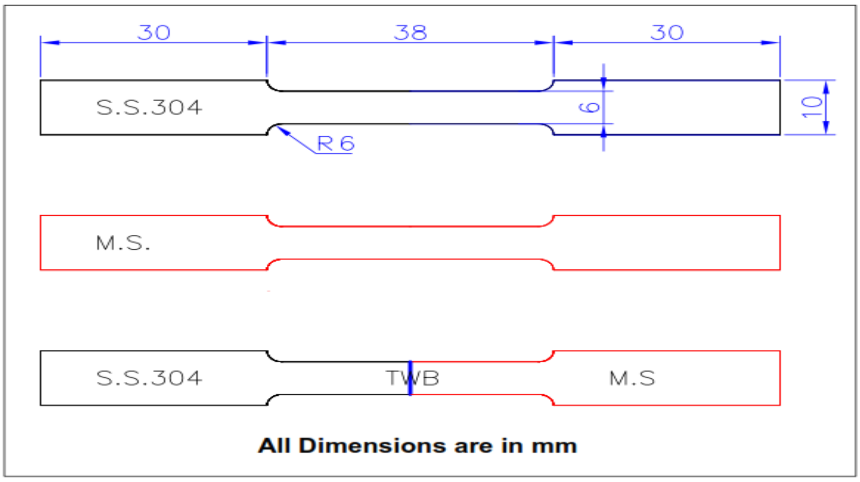

Fig. 1: Blank Dimensions

Fig. 2: Before & After failure

Fig. 3: Experimental Set up

C. Experimental Set Up:

Experimental were carried out in laboratory of the institute SVNIT Surat, Metal Forming Section on Tensometer (KIPL-PC 2000) of 2 tone Capacity. The tensile testing was performed at the moderate speed available with Tensometer (i. e. 1. 5 mm/min). The test was conducted until the occurrence of localized necking and extended up to fracture. Figure 3 shows the experimental setup used.

III. EXPERIMENTAL RESULTS:

Figure 2 shows deformed tailor-welded tensile specimens of both base metals, and transverse TWB. It also shows that the failure occurs on the weaker part of the tailor-welded tensile specimens. Figure 4 to 6 shows tensile strength comparison of both base metals, and transverse TWB in form of stress vs. strain relationship for different thickness ratio. Also value of K and n, derived from graph, of base metal are indicated in figure for the assumed material characteristics of $\sigma = K\varepsilon^n$

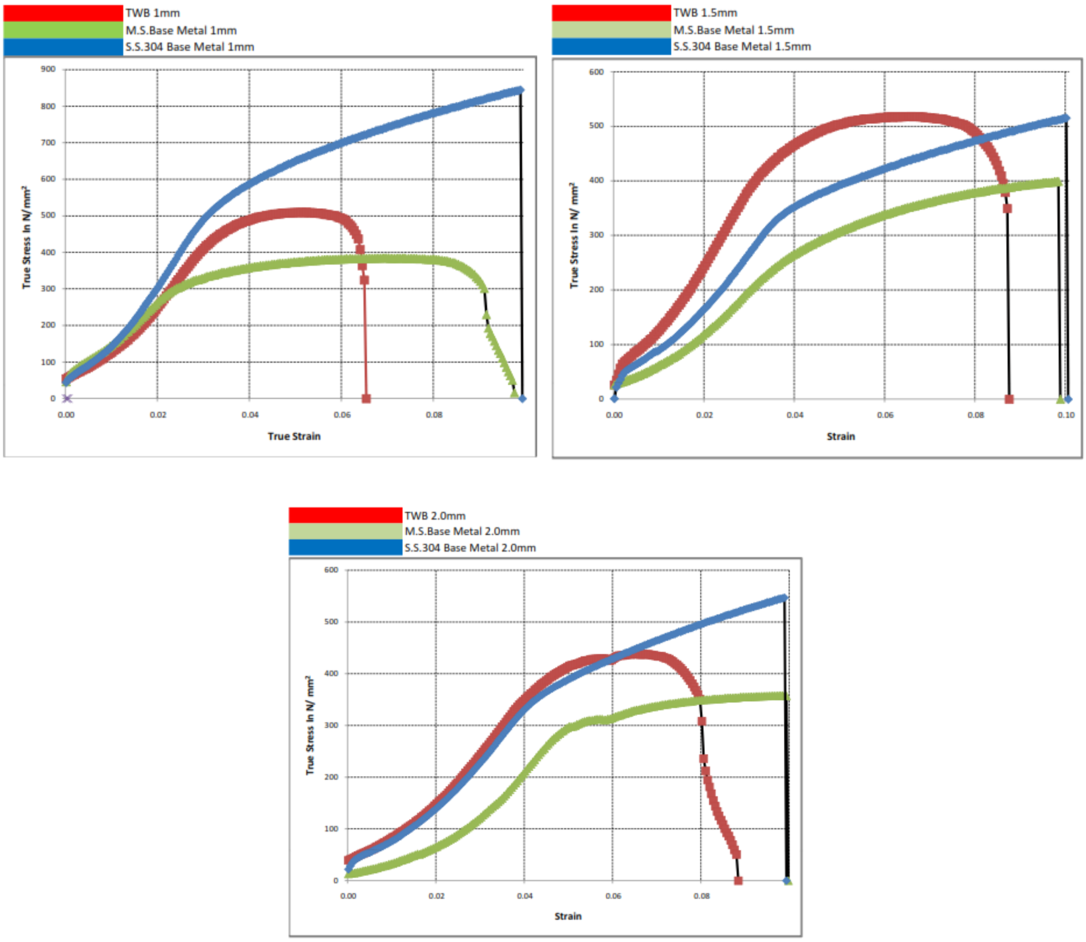

Fig. 4-5-6: True Stress Strain Curve for Base Metals, and Transverse Welded TWB with thickness combination of 1. 0mm, 1. 5mm, 2. 0mm.

The Value of K and n were found from these stress strain graphs as per the method suggested in ASTM standards of “Standard Test Method for Tensile Strain-Hardening Exponents (n-values) of Metallic sheet Materials” [6]. The values obtained for these test piece materials are listed in following table II.

Table II: The value obtained of K and n of Test Piece Materials.

Material Combination Thickness of Blanks	S. S. 304		M. S.	
	K N/mm^2	n	K N/mm^2	n
1. 0 mm	2718	0. 792	1222	0. 579
1. 5mm	1707	0. 808	1457	0. 877
2. 0mm	1831	0. 862	2152	1. 171

IV. AN ANALYTICAL MODEL TO FIND STRESS STATES OF TWB AND FE SIMULATIONS:

The aim of the proposed analytical model [1] is to calculate the total Elongation of Tailor Welded blank at the time of maximum force. The analytical model generate in MATLAB. The present model also calculates, maximum force can be taken by TWB, maximum Strain develop in thick blank, Instantaneous length of TWB at time of maximum force, etc. for complete stress state of TWB. For Simulation, three finite element models 1mm, 1. 5mm, 2. 0mm thickness are employed to simulate the forming by UNIGRAPHICS NX. The Proposed model is validated through simulation and experimentation.

Outcome Results of FEA Simulation for 1mm thickness specimen as shown in Fig. 8: a. Maximum Force withstand by TWBs, b. Engineering Stress, c. Engineering Strain, d. True Stress, e. True Strain.

A. Analytical Model Development:

Following figure 7 indicate TWB made by two blanks, which is loaded axially. Blank 1 is made of Weaker Material and Blank 2 of Stronger Material.

Blank 1 is the Weak portion of the TWB. So Hence, analysis is done when weak blank reaches the maximum force (Fmax).

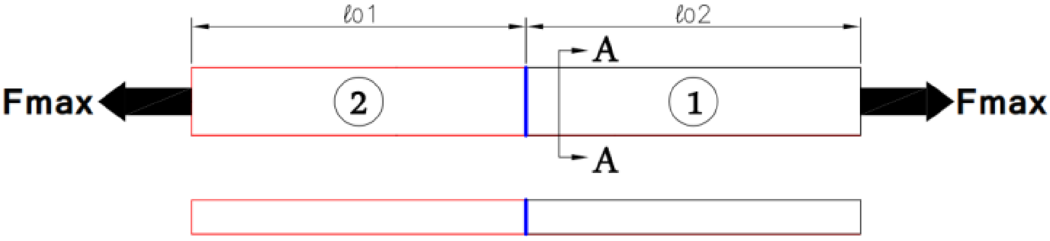

Fig. 7: Tailor Welded Blank

B. Input Parameters:

For M. S. Blank (Weaker Blank)
Strength co-efficient K_1
Strain Hardening Exponent n_1
Original Length l_{01}
Original Cross-Section Area A_{01}
Maximum True Stress σ_{1max}
For S. S. 304 Blank (Stronger Blank)
Strength co-efficient K_2
Strain Hardening Exponent n_2
Original Length l_{02}
Original Cross-Section Area A_{02}
Maximum True Stress σ_{2max}

The Strength Co-efficient K and Strain hardening exponent n of both the blanks are calculated from experiment assuming power law material behaviour [6]. Also maximum stress that can resist by M. S. Blanks and S. S. 304 Blanks are also obtained from experiment.

C. Maximum Force withstand by M. S. Blank:

As shown in Figure 7. Shown as force applied on blank is increased the stage will reach when the stress developed M. S. blank reaches at its maximum value. As resisting area for S. S. 304 blank is more hence Stress states may not reach up to its critical value.

Let's consider M. S. blank at force F_{max}, Stress induced in M. S. blanks reaches as its maximum value. From the fundamental equation, for M. S. blank, it can be written as,

$$\sigma_{1\,max} = \frac{F_{max}}{Ai} \qquad \text{Eq. (1)}$$

Where,
$\sigma_{1\,max}$ = Maximum Stress in Blank1 [Weaker Blank]
F_{max} = Maximum Force on TWB,
Ai = Instantaneous c/s area of thin blank side at F_{max}

$$\therefore F_{max} = \sigma_{1\,max} \times A_i$$

$$= \sigma_{1\,max} \times \frac{A_0 l_{01}}{l_{i1}} \quad \text{As, } A_0 l_0 = A_i l_i$$

$$= \sigma_{1\,max} \times \frac{A_0 l_{01}}{l_{01} \times e^{\varepsilon 1 max}} \quad \text{As, } \varepsilon = \ln\left(\frac{l_i}{l_0}\right)$$

$$\therefore F_{max} = \frac{K_1 \times \varepsilon_{1\,max}{}^{n1} \times A_0}{e^{\varepsilon\,max}} \quad \text{As, } \sigma_1 = K_1 \times \varepsilon_1{}^{n1}$$

Where,
A_0 = Original c/s area of Blank1 [Weaker Blank]

l_{01} = Original length of weaker blank portion,

$\varepsilon_{1\max}$ = Maximum true strain in Weaker blank

D. Maximum Force withstand by S. S. 304:

As discussed earlier, due to more resisting c/s area of thick portion, stress state may not reach at maximum value at Fmax.

To find total elongation of thick blank portion, it is required to find strain state of thick blank portion; it is required to find strain state of thick blank portion at this force. The, true stress induced in thick blank portion can be written as,

$$\sigma_2 = \frac{F_{max}}{A_{i2}} \qquad \text{Eq. (2)}$$

Where,

σ_2 = True stress develop in thick portion at F_{max} ,

A_{i2} = Instantaneous c/s area of thick blank at F_{max} ,

$$\therefore K_2 \times \varepsilon_2^{n2} = \frac{F_{max} \times e^{\varepsilon 2}}{A_{02}} \quad \text{As, } A_{02}l_{02} = A_{i2}l_{i2}$$

Taking log on both sides,

$$\therefore \ln K_2 + n_2 \ln \varepsilon_2 = \ln F_{max} + \varepsilon_2 \ln e - \ln A_{02}$$

$$\therefore n_2 \ln \varepsilon_2 - \varepsilon_2 = \ln F_{max} - \ln A_{02} - \ln K_2$$

$$\therefore n_2 \ln \varepsilon_2 - \varepsilon_2 = \ln\left[\frac{F_{max}}{A_{02} \times K_2}\right]$$

From the above equation true strain [ε_2] developed in thick blank at F_{max} can be calculated. instantaneous length of TWB can be calculated by,

$$l_{iTWB} = l_{i1} + l_{i2}$$

$$l_{iTWB} = l_{01} \times e^{\varepsilon 1} + l_{02} \times e^{\varepsilon 2}$$

Using maximum true strain developed in thin portion and true strain develops in thick portion at F_{max} . The total

Where l_i indicates instantaneous length of subsequent portion. The Instantaneous length of weaker blank at the time of maximum force can be calculated by,

$$l_{i1} = l_{01} \times e^{\varepsilon 1}$$

So, Instantaneous Area of Weaker Blank;

$$A_{i1} = \frac{A_{01}l_{01}}{l_{i1}} = \frac{A_{01}l_{01}}{l_{01} \times e^{\varepsilon 1}} = \frac{A_{01}}{e^{\varepsilon 1}} \qquad \text{Eq. (3)}$$

The Instantaneous length of weaker blank at the time of maximum force can be calculated by,

$$l_{i2} = l_{02} \times e^{\varepsilon 2}$$

So, Instantaneous Area of Weaker Blank;

$$A_{i2} = \frac{A_{01} l_{02}}{l_{i2}} = \frac{A_{02} l_{02}}{l_{02} \times e^{\varepsilon 2}} = \frac{A_{02}}{e^{\varepsilon 2}} \qquad \text{Eq. (4)}$$

The engineering and true strain developed in TWB can be calculated by,

$$e_{TWB} = \frac{\Delta l_{TWB}}{l_{0TWB}} \qquad \text{Eq. (5)}$$

Where, $\Delta l_{TWB} = l_{iTWB} - l_{0TWB}$

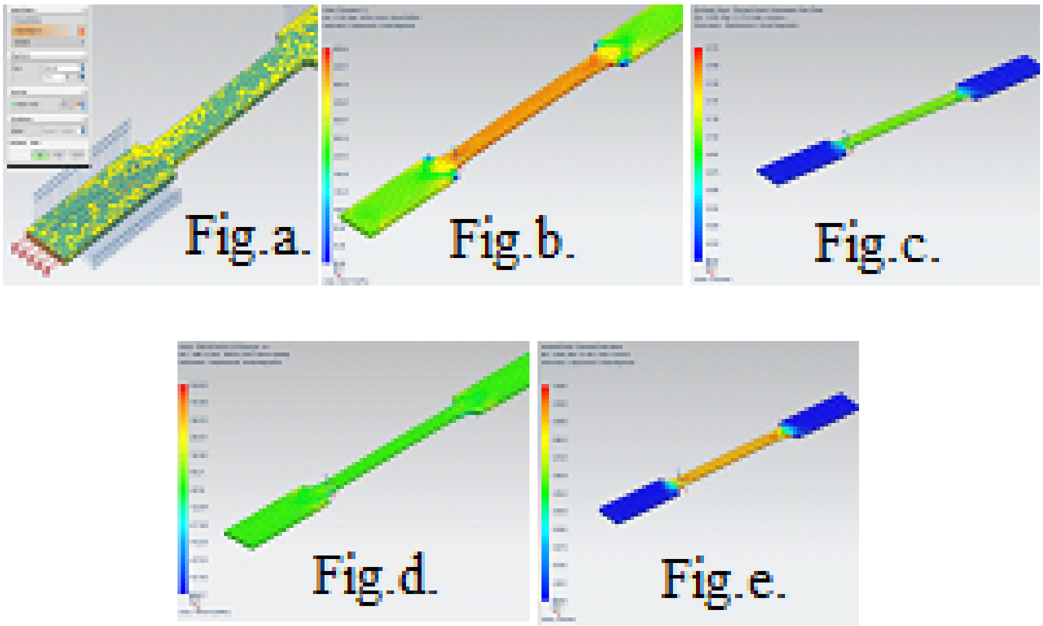

Fig. 8: Outcome Result of FEA Simulation 1mm Thickness

V. VALIDATION OF AN ANALYTICAL MODEL WITH EXPERIMENTS:

The proposed model/methodology described in previous section was validated by comparing values with experimental data. While comparing, various parameters were calculated at the maximum stress value recorded during experimentation. Table III shows the comparison.

Table III Results comparison for different thickness combination.

Specimen Size		Max. Force in [N]	Engg. Stress [N/mm2]	Engg. Strain	True Stress [N/mm2]	True Strain	Elongation [mm]
1mm Thickness	Analytical	2887. 13	481. 17	0. 144	490. 99	0. 135	5. 5
	Experimental	2902. 9	483. 8	0. 174	507. 3	0. 160	6. 6
	Simulation	2795	462. 64	0. 174	539. 53	0. 109	6. 612
1. 5mm Thickness	Analytical	4353. 4	483. 71	0. 1632	560. 28	0. 151	6. 2
	Experimental	4383. 7	487. 1	0. 2271	515. 8	0. 2046	8. 63
	Simulation	4309	483. 85	0. 133	553. 6	0. 125	5. 054
2mm Thickness	Analytical	4599. 2	383. 27	0. 1705	459. 92	0. 1575	6. 48
	Experimental	4932. 9	411. 1	0. 2326	437. 7	0. 2092	8. 84
	Simulation	4617	405. 51	0. 116	423. 97	0. 112	4. 408

From the above comparison it is found that results of proposed analytical model is in acceptable limit with that of experimentation. The proposed model is validated through simulation and experimentation, the comparison of results show good agreement and also confirms the validity of the proposed model.

VI. CONCLUSION:

The proposed Analytical model is validated through simulation (UNIGRAPHICS NX) and experimentation. The comparison of results show good agreement and also confirms the validity of proposed model. Approximate equation of true stress and strain does not provide exact behaviour of TWB as these parameters are found on the bases of thin section or weak section. In the present derivation only two blanks (i. e. dissimilar metals: S. S. 304 and M. S.) are considered but it is possible to derive similar equation for multiple blanks. It can be extended for n number of TWB dissimilar metals. NDT of Welded Joint has been performed to verify defect free weld joint.

VII. NOMENCLATURE:

σ_{1max} : Maximum True Stress in Base Metal1, [N/mm^2]
F_{max} : Maximum Force Withstand by TWB, [N]
A_i : Instantaneous Area of Blank, [mm^2]
l_i : Instantaneous Length of Blank, [mm]
A_o : Original Area of Blank, [mm^2]
l_o : Original Length of Blank, [mm]
ε : True Strain of given Blank,
K : Strength co-efficient of given Blank, [N/mm^2]
n : Strain Hardening Exponent of given Blank,
e : Engineering Strain of given Blank.

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