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Factors Affecting Weld Line Movement in Tailor Welded Blank

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***Abstract*—**Tailor Welded Blanks (TWB) are utilized in automotive industries widely because of their advantage of weight and cost reduction and maintaining required strength and structural integrity. TWB consist of two or more sheet having dissimilar or similar material and thickness; welded together to form a single sheet before forming it to desired shape. Forming of the tailor welded blank is affected by ratio of thickness of blanks, ratio of their strength, etc. mainly due to in-homogeneity of material. In the present work the relative effect of these parameters on weld line movement is studied during deep drawing of TWB using FE simulation using HYPERWORKS. The simulation is validated with results from the literature. Simulations were than performed based on Taguchi orthogonal array followed by the ANOVA analysis to determine the significance of these parameters on forming of TWB.

***Keywords*—**ANOVA, Deep drawing, Tailor Welded Blank, TWB, Weld line movement.

I. INTRODUCTION

BLANKS that consist of two or more sheet pieces differing in materials, thickness, coating, and/or material properties that are welded together before forming into the required part are termed as the tailor welded blanks (TWBs) [1]. Blanks in TWBs are welded by various processes like electron beam welding, induction welding, laser welding, mesh welding and friction stir welding [2]. The most popular welding methods are laser and mesh seam welding reason being low heat input applied by these methods which does not cause much thermal distortion. Fig. 1 show the cross sectional view of tailor welded blank of two material having thicknesses T_1 and T_2, yield strengths YS_1 and YS_2 welded together with weld material of yield strength YS_w.

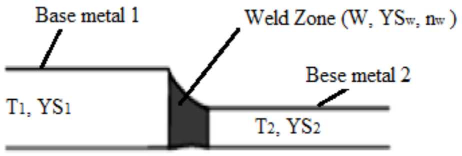

Fig. 1 Tailor Welded Blank (TWB) [15]

The advantages of using TWBs are numerous as they ensure that the components are light, stronger, and provide required functionality at lower cost 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 [3]. However, the disadvantages of TWB are related to the heterogeneous nature of the blank (due to the 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. In terms of applications, TWBs were first used to overcome design challenges with the available material [4]. Currently most chassis/body structural members are being made as TWBs. TWB-parts are assembled with other parts, hence location of weld line in the final product may affect the assembly [5].

Lesser weld line movement and lesser strain values in circular drawing are noted rather than square shape [6]. The drawing force decreases with decrease in the distance of initial weld line from the centre and the movement of weld line can be controlled using draw-bid [7]. It was noted that weld orientation has its insignificant effect on forming behavior [8]. Also it was noted that formability of dissimilar combination is reduced compared to similar combination in TWB. Different mismatch ratio was studied for four different combinations of Al alloys and it was found that preferential straining due gauge mismatch can be controlled by manipulating the material strength of thin and thick sheet [9]. Limit dome height of TWB is found to be lower than that of parent materials and failure occurs across the weld and weld line moves towards stronger metal [10]. Weld line moves towards the stronger base metal and the limit dome height of TWB in un-lubricated condition in lower as compared to lubricated condition [10]. Later the experimentation was reported showing pronounced influence of thickness difference on formability of TWB [11]. In the stamping process of the part, a higher strain zone occurs on weaker material close to the laser seam [12]. It was noted that the failure of the weaker material in TWB can be reduced by applying lower blank holding force at stronger material [13]. The failures of TWB when direction of principle stress is parallel to weld line and failures expected in most of the forming processes were also reported [14]. A methodology for predicting the drawing behavior of TWBs is reported by means of an expert system with artificial neural network (ANN) along with simulation performed for studying forming behavior. Blanks with steel grade and aluminum alloy as base materials were used. The

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output data generated in the simulation were used for training the ANN [15].

As tailor welded blank is an inhomogeneous blank. During deep drawing, it produces unequal forces on punch while deforming resulting in movement of weld line from the centre. Present work aimed in studying the effect and significance of various parameters on weld line movement. This parameter includes strength ratio, thickness ratio and weld strength. Weld orientation and width were kept constant. Analysis is performed in HYPERWORKS environment and solved using RADIOSS. To verify the simulation procedure, the material properties, dimensions and conditions were taken as reported in literature [15] and their reported results were compared with present simulation results. To study the significance of various parameters simulations were performed based on L_9 Taguchi orthogonal array followed by ANOVA analysis.

II. SIMULATION

In present work setup with square cup model is considered. The 3D modeling of punch and blank was performed in CATIA as per the dimension reported in literature [15] (Refer Fig. 2) and imported in HYPERWORKS environment as IGES files. While die and blank holder were generated in HYPERFORM module. The selections of this reported setup for present simulation enable the comparison and verification of present result with reported results. Blank surface was divided into three zones namely two zones each for different base metals and one for weld zone (Refer Fig. 3). Complete punch was meshed with element size of 5mm except the critical corner radius where mesh size was kept 2mm. Similarly, base metal zone of the blank was meshed with mesh size of 5mm, while weld zone with 2mm. The shell thickness of the tools was taken as default thickness of 0.1mm, while that of blank were taken as per Table I for validation of FEA model and Table III for further analysis.

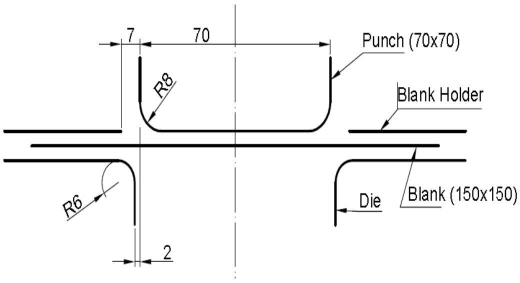

Fig. 2 Dimension for blank and tool considered for deep drawing

Using build tool component the die and blank holders were generated in hyper-form module itself. Blank holder, punch and die were considered as the rigid body, while each zone of the blank was considered as elastic-plastic materials with their material properties discussed in successive sections. For the validation punch travel was taken as reported in literature [15] (Refer Table II) and for further analysis it was kept as 17mm. The velocity of the punch was kept as 200mm/s. Binder load was kept as 10^4 N optimizing minimum loads at which no wrinkles occur. Contact Type 7 was used to determine the contact between different zones of the blank and tool and coefficient of friction was kept as 0.12. The analysis was done using RADIOSS as the solver.

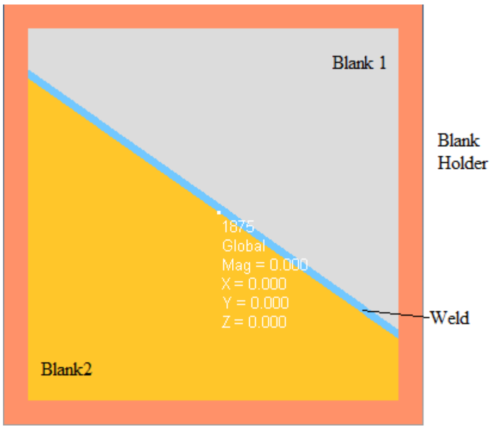

Fig. 3 Different zones of the blank under consideration

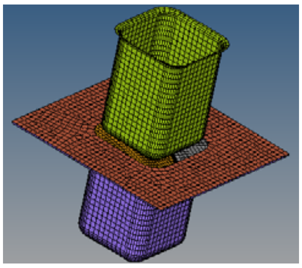

Fig. 4 Meshed model for deep drawing

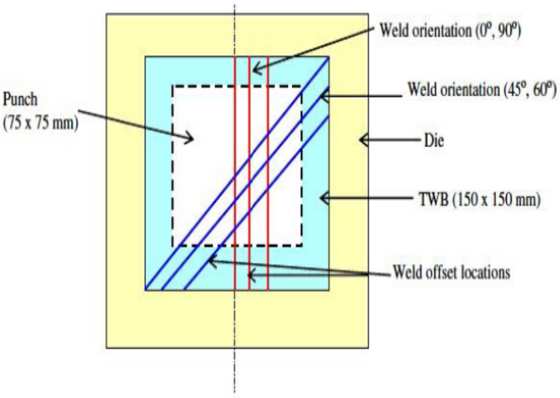

Fig. 5 Dimension, weld line location and orientation considered in simulation [15]

Fig. 5 shows the different weld line orientation and its location for TWB. Zero degree weld orientation indicates the weld line is parallel to vertical axis while oblique weld orientation makes an angle with the vertical. Weld location indicates its normal distance from line parallel to weld and passing through centre. In present study the weld orientation, weld location and weld width is kept as constant for further analysis after validation. Measurement of weld line movement was done in post processing unit HYPERVIEW.

III. VALIDATION

Before studying the various parameters affecting the weld line movement the verification of the present simulation is necessary. Hence, the present simulation was validated with the reported results [15]. A simulation corresponding to case B was carried out with geometrical and material properties reported in literature [15], as shown in Table I and Fig. 2.

Figs. 6 (a), (b) shows the weld line movement for successive two frames with increasing punch displacement, for case B (Table I). Punch displacement occurs in Z-direction, while X and Y coordinate indicate the weld line movement in X-Y plane from its initial location for respective punch displacement in Z-direction. The value of weld line movement for required intermediate punch displacement can be obtained by linear interpolation. The results obtained from this simulation along with the reported results [15] are as shown in Table II.

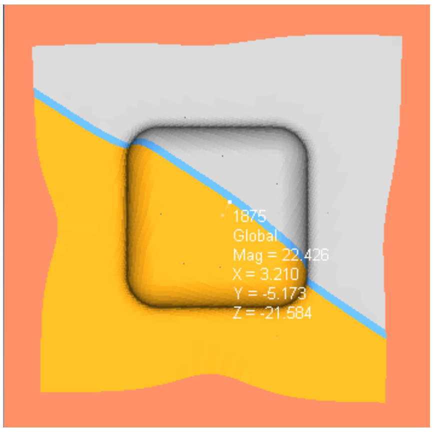

Fig. 6 (a) Movement of weld line during frame 50 for case B

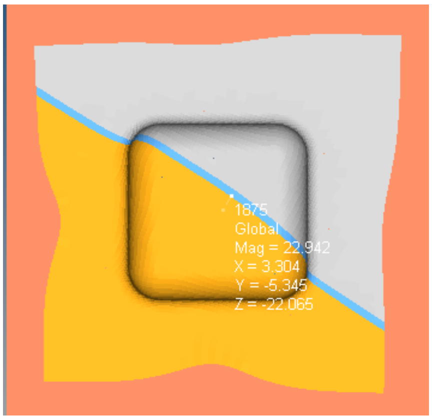

Fig. 6 (b) Movement of weld line during frame 51 for case B

It can be seen that the absolute error between the present simulation and reported literature is less than 10 percent. Hence, this simulation can be considered for further analysis discussed in successive section. For the further analysis the weld line movement was found out for desired punch displacement.

IV. ANALYSIS

Three parameters effecting the weld line movement which includes thickness ratio, strength ratio and weld strength with three levels for each were taken into consideration. The parameters with the values of their respective levels taken arbitrarily for analysis are as shown in Table III.

TABLE I
VARIOUS PARAMETERS CONSIDERED FOR SIMULATION AS PER [15]

Sr. No.	Parameters	Unit	Case B
1.	Thickness T_1, Thickness ratio (T_1/T_2)	mm	1.35, 0.9
2.	Yield Strength YS_1, Strength Ratio (YS_1/YS_2)	MPa	210, 0.7
3.	Weld Orientation	degree	55°
4.	Weld Location	mm	6
5.	Weld Yield Strength	MPa	225
6.	Weld Width	mm	3.7

TABLE II
COMPARISON OF PRESENT SIMULATION RESULTS AND REPORTED RESULTS

Simulation (punch Travel in mm)	Weld line movement(mm)		% Error
	Reported Result [15]	Present Result	
B (21.73)	6.3	6.14	2.4

TABLE III
PARAMETERS AND THEIR VALUES AT DIFFERENT LEVELS CONSIDERED FOR ANALYSIS

Sr. No.	Parameters	Parametric values at each level		
		1	2	3
1.	(T_1/T_2), T_1 (mm)	0.5, 0.75	0.75, 1.125	1.0, 1.5
2.	(YS_1/YS_2), YS_1 (Mpa)	0.5, 150	0.75, 225	1.0, 300
3.	Weld Yield Strength (Ys_w) (Mpa)	125	250	500

Weld orientation, weld location and weld width is taken as 35°, 16mm and 4mm respectively for all simulations. The simulations were performed based on Taguchi L_9 array considering above mentioned levels of parameters. To have the effect of each parameter on the weld line movement an ANOVA analysis was performed. Signal to noise ratio (*S/N* ratio) was determined using (1) on smaller the better basis as the weld line movement should be as small as possible. Results in terms of weld line movements and *S/N* ratio are shown in appendix (Table A).

$$S/N = -10\log\left(\frac{\sum(y_i^2)}{n}\right) \tag{1}$$

$$S = \sum(S/N)_j^{\,2} - C_f \tag{2a}$$

$$C_f = \left(\frac{\left(\sum(S/N)_j\right)^2}{n_j}\right) \tag{2b}$$

The total magnitude of deviation of the experimental data set can be expresses as in (2a). Here *i* is the number of a trial and *n* is total number of trials. In present work the analysis is carried out with one simulation trial for each combination and hence *n=1*. Where, *j* is the combination under consideration and let n_j is the total number of combination. For L_9 array n_j =9. The correction factor C_f is defined in (2b). The level total of *S/N* ratio for all the factors (S_T) can be expressed as in (3) where S_k is expressed in (4).

$$S_T = \sum S_k \tag{3}$$

$$S_k = \sum \left(\frac{k_m^2}{n_{km}} \right) - C_f \tag{4}$$

$$S_e = S - S_T \tag{5}$$

$$V = {S_k} \Big/ {(n_{km} - 1)} \tag{6}$$

Also k_m is the total of *S/N* ratio obtained under the factor *k* with level *m* and n_{km} is the number of *S/N* ratio under the factor *k* with level *m*. Thus the error variation (S_e) can be expressed as in (5). For each factor the degree of freedom is (n_{km} -1) and total degree of freedom is (n_j -1). Hence, Variance (*V*) is calculated as per (6). In present case value of n_{km} is 3. Percentage contribution can be obtained from the ratio S_k to S_T. The Fisher's value (*F* value) was obtained from the ratio of S_k to S_e.

TABLE IV
CONTRIBUTION OF EACH FACTOR IN WELD LINE MOVEMENT

Factors	*F* value	Percentage contribution	Rank
Thickness ratio (T_1/T_2),	8634	95.5	1
Strength Ratio (YS_1/YS_2)	391	4.3	2
Weld Yield Strength	9	0.2	3

From Table IV, it can be seen that the maximum contribution in movement of weld line in forming of tailor welded blank is of thickness ratio followed by Strength ratio. Weld yield strength has its least contribution on weld line movement. These results can also be predicted from value of *F*, which is maximum for thickness ratio, while least for weld strength.

V. CONCLUSION

For studying the weld line movement in TWB the modeling was done in CATIA and FEA modeling was successfully done in HYPERWORKS. Using Radioss as solver analysis was performed and later the work was validated with the results available from the literature.

Successively the analysis of weld line movement was performed. From the analysis it can be concluded that the weld line movement in TWB always occurs towards the stronger metal. Also, strength and thickness has significant effect, while strength of the weld does not have its greater impact on weld line movement.

APPENDIX

TABLE A
RESPONSE IN TERMS OF WELD LINE MOVEMENT AND S/N RATIO

Trials corresponding to (L_{25})	Weld line movement (mm)	SN Ratio
1	8.014077	-18.0771
2	7.947846	-18.005
3	7.578224	-17.5913
4	5.979811	-15.5337
5	5.881379	-15.3896
6	5.587299	-14.944
7	6.822279	-16.6786
8	6.6218	-16.4195
9	6.406285	-16.1321

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