

EXPERIMENTAL AND NUMERICAL STUDIES ON SPRING BACK IN U-BENDING OF TAILOR WELDED BLANKS

Submitted to **Delhi Technological University** in partial fulfilment of the requirement for the
award of the degree of

Master of Technology

In

Production Engineering

By

ASHISH KUMAR SHUKLA (2K12/PIE/04)

UNDER THE SUPERVISION OF

Shri Vijay Gautam

Assistant Professor

Mechanical Engineering Department



Delhi Technological University

Bawana Road, Delhi-110042, INDIA

July-2014

Certificate

Date: - ____/____/____

This is to certify that report entitled “**Experimental And Numerical Studies On Spring Back In U-Bending of Tailor Welded Blanks**” by **Mr. Ashish Kumar Shukla** is the requirement of the partial fulfilment for the award of Degree of **Master of Technology (M.Tech.) in Production Engineering** at **Delhi Technological University**. This work was completed under my supervision and guidance. He has completed his work with utmost sincerity and diligence. The work embodied in this project has not been submitted for the award of any other degree to the best of my knowledge.

Shri Vijay Gautam

(Assistant Professor)

Department of Mechanical Engineering

Delhi Technological University, Delhi

Student's Declaration

I hereby declare that this thesis entitled “**Experimental And Numerical Studies On Spring Back In U-Bending of Tailor Welded Blanks**” is my own research except as cited references. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Name : ASHISH KUMAR SHUKLA

Roll no. : 2K12/PIE/04

Date : 16 JULY 2014

Acknowledgement

There are many person who given me a reason to thank them, firstly, I am grateful to **Prof. Navin Kumar**, Head Of Department (Mechanical Engineering) for giving me an opportunity to work with **Shri Vijay Gautam**. I wish to express my deep sense of gratitude to my supervisor, **Shri Vijay Gautam** for his encouragement, guidance, advices, motivation and friendship to make this thesis become reality. Without his continuous support this thesis would not be completed.

I am also thankful to staffs of Mechanical Engineering department lab of Delhi Technological University for the guidance and support during this thesis in making. My special acknowledgement also goes to my family, and my colleagues for their full support either morale or materials in helping me to finish up this thesis. I also sincerely acknowledge the help of all people who directly or indirectly helped me in my project work and constantly encouraged me.

Ashish Kumar Shukla

(2K12/PIE/04)

Abstract

Tailor welded blank (TWB) is an advancement in the field of sheet metal forming in which multiple blanks are welded together to create a single blank prior to forming process. Springback behaviour of TWBs in bending is complex due to thickness, material combination and rolling direction of sheet metal which shows variation with different Punch corner radius. In this Thesis, the effect of punch profile radius on the springback of Parallel to length welded strips has been investigated in U-bending operation with Tool bend angle of 90° and using punches with three different punch profile radii of 7.5 mm, 10 mm and 12.5 mm. TWBs were prepared by laser welding of interstitial-free steel blanks with a thickness combination of 0.8 mm and 1.5 mm. The Tensile properties of parent materials and tailored blanks were evaluated by Tension test as per ASTM-E8M standard. The bend samples with transverse weld line were prepared to a size of 20mmX130mm to ensure plane strain bending. The different naked eye observations of tailoring Pattern with one sheet to other sheet lead to modelling of TWBs Cross-section. After Proper modelling Finite element (FE) simulations were performed for TWBs Model with and without Weldline property. Whereas in with Weldline property as per Width provided by ASTM-E8 for subsized and micro specimens used for simulation using Abaqus. All FEA Specimens in Abaqus are divided on the basis of material orientation and section assignment for Centre line TWBs cross-section Integration model, for top surface shell element analysis, with anisotropy and without anisotropy were found to be in good agreement with the experimental results

TABLE OF CONTENTS

Particulars	Page
TITLE PAGE	i
CERTIFICATE	ii
DECLARATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
TABLE OF CONTENTS	vi-viii
LIST OF FIGURES	ix-xi
LIST OF TABLES	xii
LIST OF SYMBOLS	xiii-xiv
LIST OF ABBREVIATIONS	xv
SPECIMEN NOMENCLATURE	xvi
Chapter 1: Introduction.....	01
1.1 Tailor Welded Blanks.....	01
1.2 Material Characterization.....	03
1.2.1 Microstructure and Hardness of TWB.....	03
1.3 Spring-Back.....	04
1.4 Finite Element Modelling and simulation.....	05
1.5 Problem and Motivation.....	06

1.6 Objective.....	07
Chapter 2: Literature Review.....	08
2.1 U-Bending.....	09
2.2 Progress in Tailor Welded Blank Applications.....	10
2.3 Tailor Blanking of Steel.....	13
2.4 Factors influencing Spring Back of Parent material and TWBs.....	13
2.5 Application of Numerical Methods for TWBs.....	16
Chapter 3: Materials selection and Preparation of TWBs.....	18
3.1 Selection of Materials.....	18
3.2 Preparation of Tailor welded Blanks.....	19
3.3 Metallurgical Examination.....	19
3.3.1 Sample Preparation of TWB.....	19
3.1.1 Optical Microscopy and SEM Analysis of TWB.....	22
3.4 Microhardness Examination of TWB.....	23
3.5 Tensile Testing of Specimen.....	24
3.5.1 Strain Hardening Of parent and TWB.....	29
3.5.2 Anisotropy of parent material.....	30
3.6 U-Bending Tool (Die-Punch).....	34
3.7 Spring-Back Measurement.....	28
3.8 U-Bending Experimental setup.....	29

Chapter 4: Experimental Results.....30

4.1 Material Characterization.....30

 4.1.1 Metallurgical analysis.....30

 4.1.2 Microhardness analysis.....32

4.2 Uniaxial Tensile testing.....33

 4.2.1 Uniaxial tensile testing Parent materials and Subsize TWBs.....34

4.3 Reaction force v/s punch displacement Diagram of Parent Materials U Bending.....34

4.4 U Bending of TWB.....40

4.5 Comparison of Spring-back.....44

 4.5.1 Comparison of Spring-Back of Parent materials.....44

 4.5.2 Comparison of Spring-Back of TWBs.....49

Chapter 5: Finite Element Modelling and Simulation.....54

5.1 Introduction.....54

5.2 Finite element modelling of parent materials and TWBs.....54

5.3 U-Bending Simulation of Specimens in 3-D.....61

5.4 Discussion on Finite Element Modelling and Simulation.....63

Chapter 6: Conclusions and Future Scope.....130

6.1 Conclusions.....130

6.2 Future Scope.....133

References.....(i-iv)

List of Figure

Sr. No.	Particulars	Page No.
01	Figure: 1.1 Tailor Welded Blanks Prepared for the U-Bending Experiment and 3-D Tailor welded blank for simulation	01
02	Figure 1-2 various tailor welded blank Component used in an automotive structure [1]	02
03	Figure 1.3: Hardness and corresponding microstructure of TWB using 22MnB5.	03
04	Figure: 1.4 Spring-Back Phenomenon in Bending [4]	05
05	Figure: 1.5 FEA models for specimen with weld line perpendicular to bending moment: (a) 3D shell element w/o weld; (b) 3D shell element w/ weld; (c) 3D solid element w/ weld. Et.al. K.M. Jhao	06
06	Figure: 2.1 Comparison of shapes after U-channel forming and springback of an AHSS (DP 600) and traditional high-strength steel (HSLA 450) is having equal yield stresses (IISI, 2006).	09
07	Figure: 2.2 Initial Blank Used for the Hot Stamping of the Rear side Member	09
08	Figure: 2.3 Use of Tailor welded blanks in automobiles	10
09	Figure: 2.4 Process Parameters for the preparation of Tailor welded blanks for U- bending	16
10	Figure: 3.1 Micro Structure of IF Steel <i>et. al. Christian Mathis</i>	18
11	Figure: 3.2. Abrasive cutter	20
12	Figure: 3.3 Mounting Press	20
13	Figure: 3.4 Sample Polishing Machine	21
14	Figure: 3.5 Scanning Electron Microscope	22
15	Figure: 3.6 Minimum Recommended spacing for Knop and Vickers Indentations	23
16	Figure: 3.7 Tinius Olsen H50KS Universal Testing Machine	24
17	Figure: 3.8 ln True stress v/s ln true strain Plot for determination of Strength Coefficient and Strain Hardening Exponent	25
18	Figure: 3.9 elongated tensile test specimen for anisotropy	27

19	Figure: 3.10 U-Bending Tool, Dies-and Punches	28
20	Figure 3.11: Vision inspection machine for measurement of spring back in U Bending	28
21	Figure: 4.1 Microstructure of TWB cross-sections	31
22	Figure: 4.2 SEM analysis of TWB's cross-section	32
23	Figure: 4.3 Hardness value v/s distance along the TWB's Cross-section	32
24	Figure: 4.4 ASTM E-8 Standard size Tensile Specimen	33
25	Figure: 4.5 True stress v/s true strain of Parent material and Subsize specimens	34
26	Figure: 4.6 a, b, c, Comparison of Effect of Rolling Direction on reaction force v/s punch displacement plot of sheet thickness 0.8mm on punch corner radius 7.5mm, 10mm, 12.5mm	35
27	Figure: 4.7 Comparison of Effect of Rolling Direction on reaction force v/s punch displacement plot of sheet thickness 1.5mm on punch corner radius 7.5mm, 10mm, 12.5mm	37
28	Figure: 4.8 a, b, c Comparison of Effect of Punch corner radius 7.5mm, 10mm, 12.5mm on sheet thickness 0.8mm	38
29	Figure: 4.9 a, b, c, Comparison of Effect of Punch corner radius 7.5mm, 10mm, 12.5mm on sheet thickness 1.5mm	39
30	Figure: 4.10 a, b, c Comparison Plot of Effect of Punch Corner Radius on rolling direction for weld line partitioned, Sub-size partitioned Bending Specimen	41
31	Figure: 4.11 a, b, c Effect of rolling direction w.r.t weld line partitioned, micro partitioned, and subsize partitioned bending specimen on punch corner radius 7.5mm, 10.0 mm, & 12.5mm	43
32	Figure: 4.12 a, b, c Effect of rolling direction on spring Back at PCR 7.5mm, 10mm and 12.5mm of sheet thickness 0.8mm	45
33	Figure: 4.13 a, b, c Effect of rolling direction on spring Back at PCR 7.5mm, 10mm and 12.5mm of sheet thickness 1.5mm	46
34	Figure: 4.14 a, b, c Effect of Punch Corner Radius of on spring back of 0.8mm sheet thickness in 0, 45, 90 degree of rolling direction	47
35	Figure:4.15 a, b, c Effect of Punch Corner Radius on spring back of 1.5mm	48

	sheet thickness in 0, 45, 90 degree of rolling direction	
36	Figure: 4.16 a, b, c Effect of Rolling direction on TWB Springback and Punch corner radius of 7.5mm, 10mm, 12.5mm for Subsize partitioned, and micro partitioned bending specimen w.r.t. Experimental Values	50
37	Figure: 4.17 a, b, c Effect of Punch Corner Radius on Springback of TWBs and its rolling direction for Subsize partitioned, and micro partitioned bending specimen w.r.t. Experimental Values.	51
38	Figure: 5.1 U-bending FEA model assemblies	57
39	Figure: 5.2, 3-D U-Bending Simulation Assembly	61
40	Figure: 5.3 overlay Plot of Springback Perspective view	62
41	Figure: 5.4 overlay Plot of Springback Parallel view	62
42	Figure: 5.5 overlay Plot of Springback Front view	63

List of Table

Sr. No.	Particulars	Page No.
01	Table: 3.1 mounted Specimen parameters for Fine Grinding and polishing	21
02	Table: 4.1 Elemental Composition of Selected Material (IF Steel)	30
03	Table: 4.2. Specimen Specification as per ASTM E-8 Standard	33
04	Table: 4.3 Mechanical Properties of Sheet Metal and TWBs	52
05	Table: 4.4 Springback comparison of experimental and simulation results	53
06	Table: 5.1 No. of nodes, elements, & Variables of Blanks Node set	58
07	Table: 5.2 List of Potential of parent material	59
08	Table: 5.3 Amplitude of step time of Simulation for Punch Displacement on Displacement Basis	60

List of Symbols

α = bend angle (in radians)

R = Bend radius

t = sheet thickness

K = Strength coefficient

n = Strain hardening exponent

e_o = Strains the outer fibres

e_i = strains inner fibres

F_{max} = Maximum bending force

L = length of the part

R_i = Bend radius before spring back

R_f = Bend radius after spring back

K_s = Spring-back ratio

θ_i = Bending angle before springback

θ_f = Bending angle after springback

z = The distance of an element from neutral axis in the bend region

L_0 = Arc length at the mid-plane

e = Engineering strain

ϵ_x = True strain in x-axis

ϵ_y = True strain in y-axis

ϵ_z = True strain in z-axis

M = Bending moment

σ_x = Stress in x direction

S = Plane strain yield stress

E' = Modulus of elasticity in plane strain

μ = coefficient of friction

ϵ_w = Strain in width direction

ϵ_t = Strain in thickness direction

ν = Poisson's ratio.

E = Young's modulus

Y = Distance from middle surface to stress at some distance

ρ = Radius of curvature of sheet of a cylindrical bent region

σ = Representative/effective or equivalent stress

r_p = Plastic strain ratio

\bar{R} = Normal anisotropy (R-BAR)

r_0 = Plastic strain ratio in rolling direction

r_{45} = Plastic strain ratio in diagonal direction

r_{90} = Plastic strain ratio in transverse direction

θ_{tool} = Angle of die

List of Abbreviations

ASTM	American Standard for Testing and Materials
CAD	Computer-aided design
IF Steel	Interstitial Free Steel
FEA	Finite Element Analysis
FEM	Finite Element Method
UTM	Universal Testing Machine
UTS	Ultimate Tensile Stress
YS	Yield Stress
ST	Standard size Tensile Specimen
SS	Sub-sized tensile Specimen
SEM	Scanning Electron Microscope
SIM	Simulation
TWB	tailor Welded blanks
RD	Rolling Direction
PCR	Punch Corner Radius
SB	Spring-Back

Specimen's Nomenclature

T	Thickness
T1	Thickness of thinner Sheet Metal 0.8mm
T2	Thickness of thicker Sheet Metal 1.5mm
T1-T2	TWB of both the sheet

T1 – T2 – XX – YY (1)

T1 – XX – YY (2)

T2 – XX – YY (3)

XX	Rolling Direction of TWB or orientation of joined sheet w.r.t. weld line
XX	0 ⁰ Parallel to rolling direction, 45 ⁰ to rolling direction and 90 ⁰ perpendicular to the rolling direction
YY	Dimension of specimen size mentioned only in case of Sub-sized and micro-sized specimens
YY	Sub-sized Specimen Width 6.0mm
YY	Micro-Sized Specimen Width 2.0mm

Note: Similar sequence Followed in parent, TWBs, bending and Simulation, With Further Property of Test incorporated