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INVESTIGATION OF SPRING BACK BEHAVIOR OF SS-304 STEEL AND ITS BI-LAYER MATERIAL IN V BENDING

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ABSTRACT

Components press formed from layered or laminated metallic materials have wide engineering application in aerospace, automobile, electrical, electronic and process industries. High strength ferrous metals are widely used in automobile industries for utilization of its high strength to weight ratio. Such high strength metals offer poor formability. Formability of such metals can be improved by applying a layer of metal having higher formability. This paper deals with springback behavior of a laminated stainless steel and aluminum in V bending. Investigation of bending characteristics like thickness ratio and bending angles of sheet before/after springback is carried out in this paper. First part of this paper is on numerical analysis for springback prediction of laminated sheet. In second part, experiments are performed for different cases on V bending machine. The experimental results show that springback of sheet metal laminate is greatly affected by relative position of strong/weak layers and thickness ratio of each layer.

Keywords

Springbach; High strength steel; Layered material; V bending;

1. INTRODUCTION

Now days, there is a high demand of high strength steel as they offer superb strength to weight ratio. They are widely used in automobile and aerospace application for improving strength to weight ratio. Sheet metal forming of high strength steel is itself a critical issue. To solve this problem, it is compulsory to improve formability of such high strength steels. Formability of high strength ferrous material can be improved by applying the layering of the higher formability materials. Springback is the most important and common characteristic related to bending and it is not avoided for accuracy of final product. Springback is a phenomenon in which the strip unbend itself after forming. Insufficient allowance for springback often result in the formed component being out of tolerance, introducing problem during final assembling or installation [1].

The amount of springback for the ultra-high-strength steel sheet in the V-shaped bending was much larger than that for the mild steel sheet, and the amount was decreased by making laminated strip consisting high strength steel and aluminum. In this paper, the laminated sheet is developed by joining SS – 304 and AL-6101T6.

Figure 1. Bimetallic strip for experimentation

According to Kim and Yu [2], in previous years, with the demands for the laminated sheet metals which are made of dissimilar material components are increasingly being used because of their excellent mechanical and functional properties. Hino et al. [3] investigated springback of two-ply sheet metal laminates (pure aluminum (JISA1100)) and ferritic steel (JIS Sus430)) subjected to draw bending using numerical and experimental techniques. The residual curvatures after springback of the laminates were measured. They compared residual curvatures with the experimental result. From comparisons they found results that springback of sheet metal laminates is strongly affected by the strength difference the component layer. Anish H.Gandhi, and Harit K. Raval [4] reported that springback is one of the major problem in fabricating component of high strength steel (i.e. SA-36, SA-299, SA-515 grade 70, SA-724 grade B) using finite element of air V-bending. Analytical springback simulations of hypothetical layered materials are presented. They concluded that, (i) combination of the material property parameters controls the springback; (ii) layer of the high ductility steel on the high strength steel greatly suppresses the springback. Hino, Yoshida et al. [5] investigate the effect of bending characteristic such as sheet thickness and bending angle of sheet before and after springback. M. A. Osman et al. [6] suggests a methodology for the prediction of springback ratio in V-die bending. They develop theoretical model for air bending using true strain and neutral fiber position that satisfy continuity of the radial stress. Kim et al. [7] develop the analytical model to predict the springback and bend allowance simultaneously in air bending and development of program BEND. According to Hoffman et al. [8] there will be largest reduction of springback when stretching and bending is applied simultaneously to the sheet. S.A.Kagzi, et al. [9] reported that springback is highly influenced by work hardening. So for accurate prediction of springback the work hardening must be taken in to account.

Many researchers done worked for reduction in springback by considering the, factor responsible for it, influence of process parameter like punch velocity, thickness ratio, young modulus of bend material. Some of them developed analytical model for prediction of springback which is limited to monolithic material. Such analytical model for monolithic material is not giving satisfied result for bi–layered material. Yuen developed analytical model for bi-layered material without considering Bauschinger effect. According to Gau and Kinzel [10], we must consider Bauschinger effect for accurate prediction of springback. They developed new hardening model for springback prediction in which the Bauschinger effect is considered. Gau and Kinzel [11] experimentally investigate the influence of the Bauschinger effect on springback in sheet metal forming. They concluded that the influence of the Bauschinger effect on springback is more significant for aluminum than for steels.

Good quantum of work is reported on the finite element analysis of springback, on the process of V-bending sheet metal forming, U-bending, air V-bending etc. There is steep rise in the slope when the hardening is taken into consideration, showing that the springback is highly influenced by work hardening and for accurate prediction of springback the work hardening effect must be taken into account. This is in line with the results and conclusion drawn in published literature.

Based on the findings from the literature it is observed that spring back in bending is critical issue. Especially for high strength materials spring back is found to be very high. Because of discussed phenomena, it become difficult to control the dimensions of final product obtain using bending/forming. Hence, attempt to study the spring back phenomena for different five cases of SS-304 and Al-6101T6 with (1) both metal single and thickness of both metals are 5mm (2) combination of SS-304 4mm thickness with Al-6101T6 1mm thickness (3) combination of SS-304 3mm thickness with Al-6101T6 2mm thickness (4) combination of SS-304 2mm thickness with Al-6101T6 3mm thickness and (5) combination of SS-304 1mm thickness with Al-6101T6 4 mm thickness.

2. ANALYTICAL MODEL

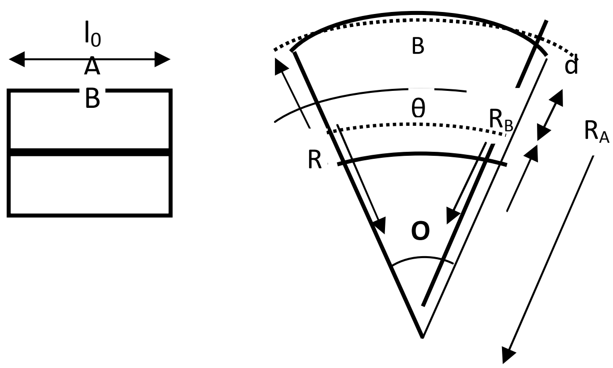

Figure 2. Schematic of bent sheet metal

The bent sheet metal is shown in figure. 2. Let r be the radius of curvature measured to the mid-plane and z be the distance of any element from the mid-plane. The engineering strain at z can be derived by consider arc lengths, L measured parallel to the x-axis. The arc lengths of mid-plane, L_0 does not change during bending and may be expressed as $L_0 = r\theta$, where θ is the bend angle. At z, the arc lengths is L = (r+z) So the engineering strain is $e_x = (L-L_0)/L_0 = z\theta/r\theta = z/r$. the true strain is,

$$\varepsilon_x = \ln\left(1+\frac{z}{r}\right) \quad (1)$$

Now, consider z=y, r=ρ and w = b,

But, often the strains are small enough and this can be approximate to

$$\varepsilon_x = \frac{y}{\rho} \quad (2)$$

With sheet materials, b>>t. so width changes are negligible. Therefore, bending can be considered as approaching a plane strain operation, where $\varepsilon_y = 0$, $\varepsilon_z = -\varepsilon_x$. the value of ε_x varies linearly from $-t/2\rho$ at the inside (y=-t/2) to zero at the mid plane (y=0) to $t/2\rho$ at the outside (y = t/2)

$$\sigma = K\varepsilon^n$$

$$\sigma = F\,K\,\frac{y^n}{\rho} \qquad \left[\varepsilon \cong \frac{y}{\rho}\right]$$

$$\text{Force, } dF = \sigma\, b\, dy$$
$$\text{Bending Moment } M = \text{Force} \times \text{Distance}$$
$$= dF \times y$$

For unit width,
Therefore Total Bending Moment,

$$M = \int_{-\frac{t}{2}}^{\frac{t}{2}} \sigma\, y\, dy$$
$$M = 2\int_{0}^{\frac{t}{2}} F\, K \left(\frac{y}{p}\right)^{n} dy$$
$$M = \frac{2\,F\,K}{p^{n}} \int_{0}^{\frac{t}{2}} y^{n+1}\; dy$$
$$M = \frac{2\,F\,K}{p^{n}} \left[\frac{y^{n+2}}{n+2}\right]_{0}^{\frac{t}{2}}$$
$$M = \frac{2\,F\,K}{p^{n}} \left[\frac{\left({}^{t}/_{2}\right)^{n+2}}{n+2} - 0\right]$$
$$M = \frac{2(FK)t^{n+2}}{(n+2)\,p^{n}2^{n+2}}$$
$$M = \frac{2\,K^{\mathsf{I}}t^{n+2}}{(n+2)p^{n}2^{n+2}}$$
$$\text{Where, } K^{\mathsf{I}} = (1.1547)^{(n+1)}\, K$$
$$M = 2K^{\mathsf{I}} \left(\frac{1}{p^{n}(n+2)2^{n+2}}\right) t^{n+2} \quad (3)$$

Where, p is the radius of neutral surface and for plane strain and isotropy,

$$\boldsymbol{K}^{\mathsf{I}} = (1.1547)\ (n+1)\ K$$

In practice, plates are often cold formed. Cold formed parts suffer from a phenomenon known as springback. To maintain the final part dimensions overcoming the springback, the radius through which the plate is actually bent must be smaller than the required radius. Assuming linear elastic recovery law and plane strain condition, for unit width or the plate, the relation between unloaded radius(R_f) and corresponding loaded radius (or radius of bending)(R) was derived to the form given by(5) from the moment curvature relationship as per (3)[12][13].

$$\frac{1}{R_f} = \frac{1}{R} - \frac{1}{R_e}$$

Where, R_e = Elastic Radius = $\left(\frac{\boldsymbol{E}^{\mathsf{I}}\boldsymbol{I}}{\boldsymbol{M}}\right)$

$$\frac{1}{R_f} = \frac{1}{R} - \frac{M}{EI}$$

Where,

$$\left(E^{\mid} = \frac{E}{1 - v^{2}}\right) \left(I = \frac{bt^3}{12}\right) (For\ unit\ Width)$$

$$\frac{1}{R_f} = \frac{1}{R} - \frac{12(1 - v^2)M}{E(t^3)}$$

$$\frac{R}{R_f} = 1 - \left[\frac{12\ R\ M}{t^3}\right]\left(\frac{1 - v^2}{E}\right) \quad (4)$$

$$\frac{R}{R_f} = 1 - \left(\frac{12\ R}{t^3}\right)\left(\frac{2\ K^{\mid} t^{n+2}}{(n+2)\ R^2 2^{n+2}}\right)\left(\frac{1 - v^2}{E}\right)$$

$$\frac{R}{R_f} = 1 - \left[\left(\frac{6\ K^{\mid} t^{n-1}}{(n+2)\ R^{n-1} 2^{n}}\right)\left(\frac{1 - v^2}{E}\right)\right] \quad (5)$$

Where, $\boldsymbol{v}$ is Poisson's ratio and E is Young's modulus.

3. EXPERIMENTATION

In this paper, the bending is done of a bi-layered material (SS-304 + Al-6101T6) with different thickness ratio using the V- bending machine. Bending is also done on monolithic material of SS-304 and AL-6101T6.

3.1. Material specification:

Table 1. Specification of SS-304 and AL-6101T6

No.	Specification	Material	
		SS-304	**AL-6101T6**
1	Ultimate Tensile strength (MPa)	505	221
2	Yield strength σ_y (Mpa)	215	193
3	Percentage elongation (%)	40	19
4	Strain hardening exponent n	0.44	0.06
5	Strength coefficient K (Mpa)	1400	62
6	Young Modulus E (Gpa)	193	68.9
7	Poisson's ratio, $\boldsymbol{v}$	0.29	0.33

3.2 Experimental procedure

The V-bending test device and the experimental procedures are illustrated in Fig 3, where punch width and die width and die angle is 90° and punch radius is 12mm. the dimensions of the V-bending specimens are 100mm long and 25 mm wide. The specimen is set on the die and the punch is pushed in vertical direction and given punch stroke, and angle of straight portion of the bent specimens before spring back θ is measured. It is showing in fig 6.4. After removing the punch the angle of the bent sprcimen after springback θ_f is measured. It is showning in fig 4. Thus the change in bending angle due to springback ratio is obtained as $\Delta\theta=\theta_f/\theta$ (here after it is called springback). The bending is under V-bending condition, where the clad sheet contact only with die shoulders and punch corner .

Figure 3. Under loading

Figure 4. After loading

In this paper we discuss two different cases.

Case 1. Monolithic Material and Same thickness

Table 2. Monolithic material with same thickness

Material Type	Thickness
SS-304	5 mm
AL6101-T6	5 mm

Case 2. Bi-layered material and different thickness ratio

Table 3. Bi-layered material with different thickness ratio

Material Type	Thickness (mm)
SS-304 + AL6101-T6	4+1
SS-304 + AL6101-T6	3+2
SS-304 + AL6101-T6	2+3
SS-304 + AL6101-T6	1+4

Total eight experiments are conducted for each sheet thickness-bend radius combination. in this eight experiments, first four reading for the bi-layered strips and remaining two for the monolithic strip. The loaded and unloaded bend angles are measured ten times on each of the upper and lower sheet surfaces for each experiment and then averaged. The resultant spring-back ratio for each sheet thickness-bend radius is then obtained by averaging the values of the spring-back ratios for the three experiments.

4. RESULTS AND DISCUSSION

After completion of eight experiments on V- bending machine, data were collected for bending angle, radius for under loading, radius after loading, punch velocity, and load on metal strips during bending. Such data were arranged and plot the graphs for effect of thickness ratio on springback ratio and springback angle before and after of loading.

Table 4. Springback angle for bi-layered material with different thickness ratio

Sr. No	SS-304 + AL6101T6 (in mm)	Loaded Angle	Unloaded angle	Springback angle
1	1+4	105	109	4
2	2+3	102	110	8
3	3+2	125	134	9
4	4+1	130	140	10

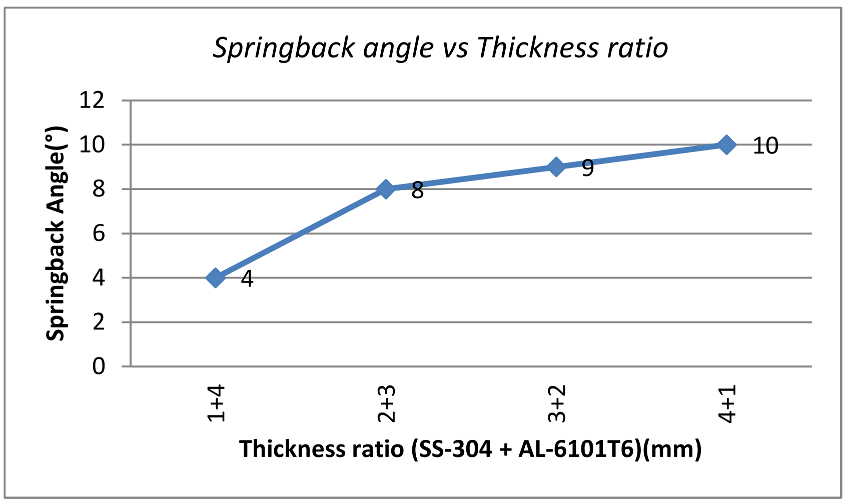

Figure 5. Effect of thickness ratio on springback angle in bi-layered material

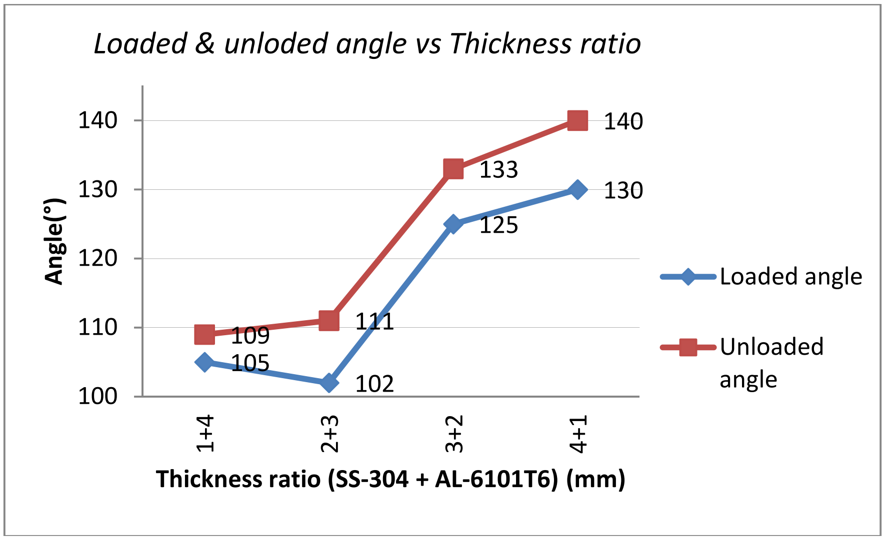

Figure 6. Effect of thickness ratio on loaded & Unloaded angle in bi-layered material

From above table and charts we can easily say that, in bilayered matrial thickness play very important role to reduce springback. In our experiment in total 5mm thick strip if we take 4mm AL6101T6 and 1 mm SS-304, the difference between loded angle and unloded angle will be small and on other hand this willl be high if we take 4 mm SS-304 and 1 mm AL6101T6.In this case springback angle is 4° for (4+1) mm (SS+Al) and 10° for (1+4) mm(SS + Al) thickness ratio.

If we consider only monolithic material instead of bi-layered material, we can easily say from the result that, springback of ductile material is always less compared to high strength steel. in our case springback of AL6101T6 is less compared to SS-304. But only single layer of soft and ductile material can not give proper strength. To obtain required strength we have make bi-layered material which offer good strength and also experience less springback.

Table 5. Springback angle for monolithic material of same thickness

Sr No:	Monolithic Material (5 mm)	Loaded Angle	Unloaded angle	Springback angle
1	SS-304	133	146	13
2	AL-6101T6	102	109	7

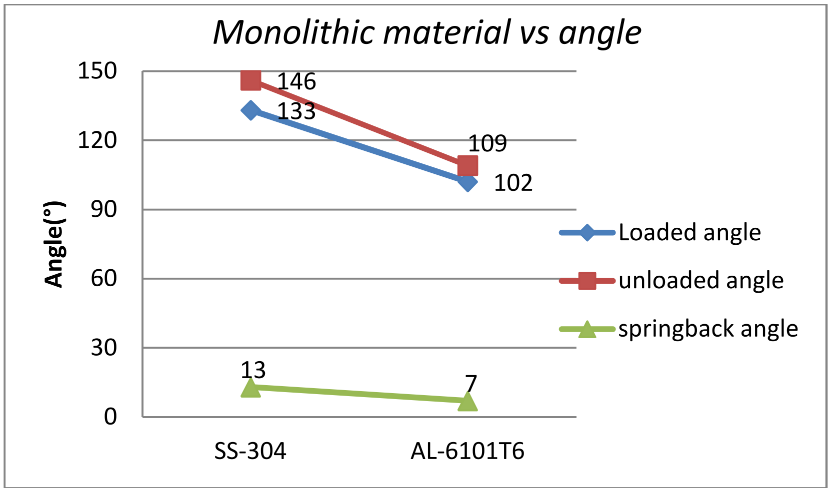

Figure 6. Springback angle of a SS-304 and AL-6101T6

5. CONCLUSIONS

From above results of experiments it can be concluded that,

- The springback behavior of bi-layered material is strongly affected by relative position of layer and thickness of stronger/weaker layer of material.
- When thickness of AL-6101T6 is more than SS-304, springback of a bi-layered strip is less.
- When thickness of SS-304 is more as compare with Al-6101T6, springback radius ratio is nearly same as in case of monolithic SS-304.
- The analytical model for prediction of springback will be improved by considering Bauschinger effect.
- Finite element model also will be prepared for this analysis and results will be compared with experimental data and analytical data.
- Same experiment will be carried out with considering Bauschinger effect, which give more accurate result.

REFERENCES

[1] W.Y.D. Yuen (1996), "A generalized solution for the prediction of springback in laminated strip", Journal of metal processing technology-61,254-264.

[2] Kim, J.K., Yu, T.X., (1997) " Forming and failure behavior of coated, laminated and sandwiched sheet metals: a review" Journal of Materials Processing Technology 63, 33–42.

[3] Hino, R. Goto, Y. and Yoshida, F. (2003), Spingback of sheet metal laminates in draw-bending.Journal of materials processing technology, 139, pp, 341-347.

[4] Gandhi A H and Raval H K,(2010)"Springback simulation of monolithic and layered steel used for pressure equipment ", World academy of science, Engineering and Technology 70.

[5] Ryutaro Hino, Yoshihiro Goto, Fusahito Yoshida(2010) "Air bending and springback of stainless steel clad aluminum sheet" Journal of material processing technology 210, pp 272-278.

[6] M.A. Osman, M. Shazly, A. El-Mokaddem, A.S. Wifi, (2010) "Springback prediction in V-die bending: modelling and experimentation", Journal of Achievements in Materials and Manufacturing Engineering Volume 38 Issue 2 February 2010, pp 179 – 186.

[7] Kim, H., Nargundkar, N., Altan, T., (2007). "Prediction of bend allowance and springback in air bending" Journal of Manufacturing Science and Engineering, Trans. of ASME (2007) 129, pp 342-351.

[8] Schilp, H., Suh, J., Hoffmann, H. (2011), "Reduction of springback using simultaneous stretch-bending processes", International journal of material forming, 2011

[9] S. A. Kagzi, A. H. Gandhi , H. K. Raval(2012) , "Effect of Material Properties on Springback of Layered Strip: An Analytical Study". Proce. Of 1st national conference on TFMS, Surat, pp 398-402.

[10] Jenn-Terng Gau, Gary L. Kinzel, (2001) "An experimental investigation of the influence of the Bauschinger effect on springback predictions" Journal of material processing Technology, 108 pp 369-375.

[11] Jenn-Terng Gau, Gary L. Kinzel(2001) , "A new model for springback prediction in which the Bauschinger effect is considered" Journal of material processing Technology, 43, pp 1813 – 1832.

[12] Kim, J.K. and Yu, T,X. (1997), Forming and failure behavior of coated ,laminated and sandwich sheet materials: A review Journal of Material Processing Technology ,63,pp.33-42.

[13] Kim Hyunok, Nargundkar Ninand, Altan Taylan (2002)," prediction of bend allowances and springback in air bending",Trans of ASME,J,Mfg.Sci.ENG. Bend works,olaf diegel,complete design,

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