"Analysis of Spring back Variation in V-bending using Taguchi Technique of Al-5251 H24 alloy"

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Abstract **:** Bent parts with high accuracy are required in daily life applications. While bending generally metal sheets, polymers or laminate sheet materials are used. In this study particular focus is on Aluminium grade material Al-5251 H24 having application in marine structures, aircraft parts, etc. by conducting test in V-bending die as it is economical and variation due to different factors can be studied easily. Spring back in simple terms means elastic recovery of the material. Every material has its own elastic properties, due to which it will exhibit spring-back or spring-go effect after unloading the tool force. In research study of spring back it is found that spring-back is affected by material properties, tool geometry and process parameters etc. With the help of Taguchi approach to minimize the no. of experiments by using Orthogonal Array and ANOVA technique to determine spring back affecting parameters and thus optimize it, also the focus is to determine the most affecting parameters.

Index Terms **:** Spring back, V-bending, Taguchi approach, Orthogonal array, ANOVA.

I. INTRODUCTION :-

Sheet metals have been in great use since ancient times for various purposes. Earlier hand hammered sheets were prepared for household or architectural purposes. With the discovery of different metals, they were incorporated to achieve desirable properties such as high strength, wear resistant, light weight, anti-corrosion, etc. With the development of industrial system sheet metals gained more importance in different applications, therefore different metals were molten and mixed together in proportions which are also known as alloys to achieve combinations that can fulfill certain function.

V-BENDING PROCESS :-

In this method both punch and die are V-shaped, the punch pushes the sheet into the "V" shaped groove causing it to bend. V bending is an economical process to check the spring back behavior of the material as the same angle is used on both the punch and die.

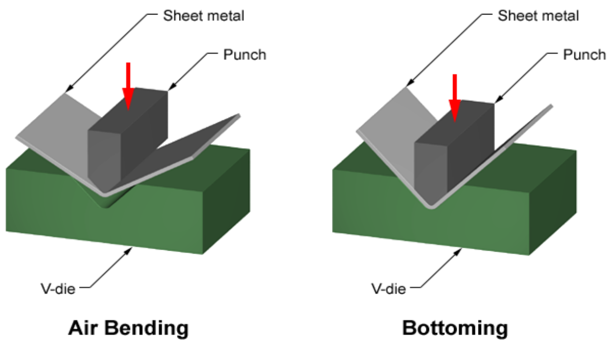

Figure 1: V-Bending Operations

If the punch does not force the sheet to bottom of cavity leaving some space or air underneath, it is called "air bending" whereas if the punch forces the sheet to bottom of cavity then it is known as "bottoming"

II. PRINCIPLE OF SPRING BACK :-

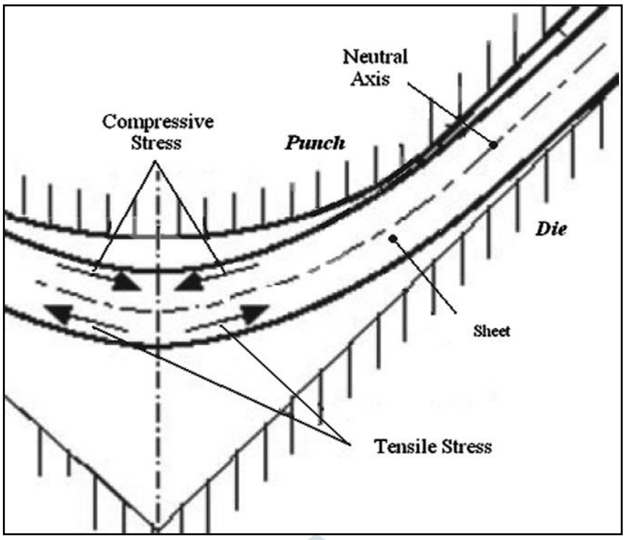

Figure 2 : Stress distribution before unloading in bending process, spring back phenomenon.

Figure 2 illustrates the stress distribution on the sheet in the bending process before the unloading stage which brings about the spring-back phenomenon. The material on the punch side is under compressive stresses, whereas the material on the die side is under tensile stresses. As a result of the stress distribution, the material in the compressive zone tries to enlarge and the material in the tension zone tries to shrink owing to the existence of elastic band through the sheet thickness. Consequently, the material in the bending area tries to spring-back and the bended work piece slightly opens.

SPRING BACK IN V-BENDING :

Spring back depends on parameters related to material as well as bending process and varies with their variation.

- Factors related to material are its material type, thickness, hardness, etc.
- Factors related to bending process are punch angle, punch radius, applied force, etc.

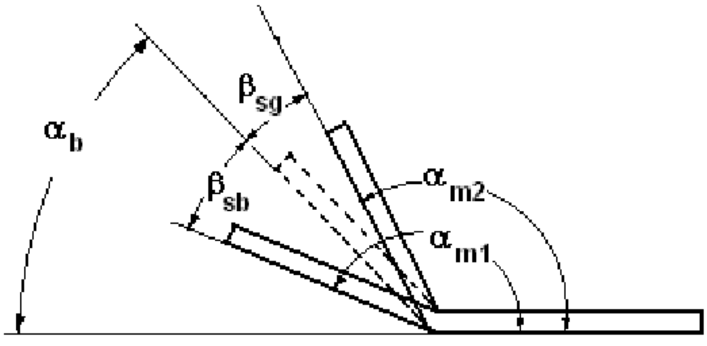

Figure 3 : Spring Back & Spring Go effect in bending

α_b	Bending angle
β_{sb}	Spring back angle
β_{sg}	Spring go angle
α_{m1}	Measured angle 1
α_{m2}	Measured angle 2

Due to elastic recovery spring back angle either increases or decreases. The increase in angle of V-bending is termed as "Spring Back" and the reduction in angle is termed as" Spring Go". In this study, focus is on V-bending

III. Aluminium -5251 H24 :-

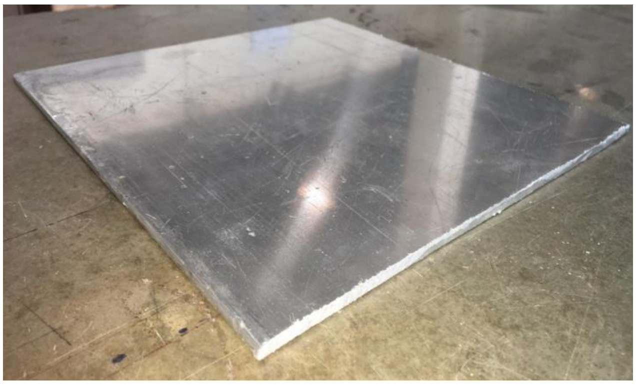

Figure 4 : Aluminium 5251 H24

Aluminium 5XXX series are alloyed with (Mg) Magnesium offering good corrosion resistance. Aluminium alloy 5251 is a medium strength alloy possessing good ductility and therefore good formability. Alloy 5251 is known for work hardening rapidly and is readily weldable. It also possesses high corrosion resistance particularly in marine environments.

3.1 Al 5251 H24 in this designation system:-

5 - means that it is from magnesium alloy series
2 - indicates modifications to original alloy
51 - identifies different alloys in the group
H24 - means it is work hardened and partially annealed to half hard

3.2 Applications of Al-5251 is found in :-

- Boats
- Paneling and pressings
- Marine structures
- Aircraft parts
- Vehicle panels
- Furniture tubing
- Silos (a structure for storing bulk materials such as grains or fermented feed)
- Containers.

IV. Methodology of Experiment :-

4.1 Taguchi Method :-

Taguchi method consists of a plan of experiments with the objective of acquiring data in a controlled way, executing these experiments and analyzing data, in order to obtain information about the behavior of a given process. It uses orthogonal arrays to define the experimental plans and the treatment of the experimental results is based on analysis of variance (ANOVA).

Taguchi method is not only used for reducing the no. of experiments but also for systematic combination of factors of experimentation. This method also suggests analyzing variation using an appropriately chosen signal-to-noise ratio.

Taguchi experiments often use a 2-step optimization process.

- In step 1 use the signal-to-noise ratio to identify those control factors that reduce variability.
- In step 2, identify control factors that move the mean to target and have a small or no effect on the signal-to-noise ratio.

4.2 Design of Experiments (DOE) :-

The purpose of product development is to improve the performance of the product or process relative to that of customers need and expectations. The purpose of experimentation should be to understand how to reduce and control variation of a product or a process. Design of experiments (DOE) helps to evaluate two or more factors that would affect the output average or variation in the process characteristics.

4.3 Orthogonal Array :-

It is a highly fractional orthogonal design that is based on a design matrix proposed by Dr. Genichi Taguchi and allows you to consider a selected subset of combinations of multiple factors at multiple levels. Orthogonal arrays are balanced to ensure that all levels of all factors are considered equally.

A full factorial experiment is an experiment whose design consists of two or more factors and considers all possible combination. It also allows to study the effect factor on the responsible variable.

No of factors : 03
No of levels : 02
Array= level $^{(factors)}$

Table 1 : Standard L8 orthogonal array

Experimental runs	Factor A	Factor B	Factor C
1	Low	Low	Low
2	Low	Low	High
3	Low	High	Low
4	Low	High	High
5	High	Low	Low
6	High	Low	High
7	High	High	Low
8	High	High	High

4.4 Signal-to-Noise (S/N) Ratio :-

In Taguchi designs, a measure of robustness used to identify control factors that reduce variability in a product or a process by minimizing the effects of uncontrollable factors (noise factors). Control factors are those design and process parameters that can be controlled.

S/N ratios are derived from quadratic loss function and three are considered to be standard and widely applicable. They are as follows :-

- Lower the better
- Higher the better
- Nominal the best

Table 2 : Signal to noise ratios

Signal- to-noise ratio	Goal	Data characteristics	Formulas
Smaller is better	Minimize the response	Positive	$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=0}^{n} y^2\right)$
Nominal the best	Target the response	Positive, zero or negative	$\frac{S}{N} = -10\log(s^2)$
Larger is better	Maximize the response	Non-negative with a target value of zero	$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=0}^{n} \frac{1}{y^2}\right)$

4.5 Analysis of Variance (ANOVA) :-

ANOVA is an important technique for analyzing the effect of factors on a response. Depending upon the type of analysis, it can determine which factors have a significant effect on the response and how much of the variability in the response attributing to each factor. It is useful for determining the influence of any given input parameter for a series of experimental results.

4.6 Actual Experimental Design :-

4.6.1 Experimental L8 array :-

Table 3 : Levels of parameters selected for the V-bending experiment

	Material Thickness (mm)	Punch Radius (mm)	Bend Angle (deg)
Level 1	3	2	35
Level 2	5	3	65

Table 4 : Actual experimental array for selected levels

Experimental runs	Bend Angle (deg)	Punch radius (mm)	Material Thickness (mm)
1	35	2	3
2	35	2	5
3	35	3	3
4	35	3	5
5	65	2	3
6	65	2	5
7	65	3	3
8	65	3	5

4.6.2 Test material Al-5251 H24 properties:-

Table 5 : Physical properties of the material

Property	Value
Density	2.69 g/cm³
Melting Point	625 °C
Thermal Expansion	25 x10-6 /K
Modulus of Elasticity	70 GPa
Thermal Conductivity	134 W/m.K
Electrical Resistivity	0.044 x10-6 Ω .m

Table 6 : Mechanical properties of the material

Sheet & Plate-0.2mm to 12.5mm	
Property	**Value**
Proof Stress	140 Min Mpa
Tensile Strength	210 - 250 Mpa
Hardness Brinell	62 HB

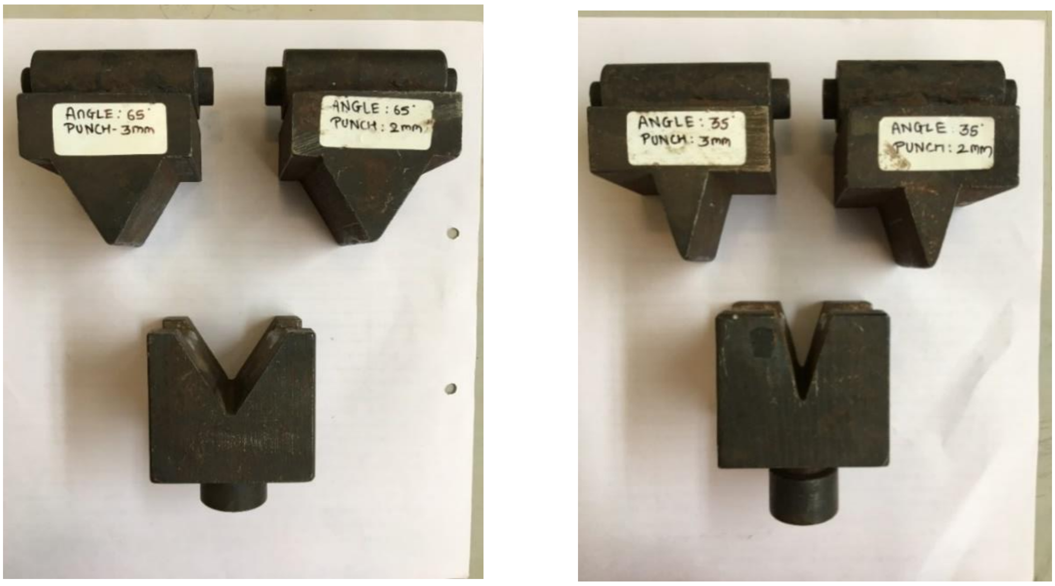

Figure 5 : Punch & die sets with different bend angles available for experimentation

V. Analysis :-

Analysis is the final phase of experimental design done for the obtained response values. It helps to identify the contribution of the factors involved in the process.

Minitab was used to calculate S/N ratios, plot the charts, calculate response tables, also One-way ANOVA was used to calculate significance of each factor

Observations :-

Figure 6 : Bent test pieces for 8 combinations

Note : Load was applied gradually in the bending process, the load values mentioned in the table is the maximum load experienced by the test piece.

Table 7 : Amount of Spring go by actual experimentation

Sr. No.	Punch Angle (deg)	Punch radius (mm)	Sheet Thickness (mm)	Load (kN)	Spring Go
1	65	2	3	1	2.367
2	65	3	3	0.8	1.334
3	65	2	5	4.1	1.267
4	65	3	5	4.1	1.833
5	35	2	3	1.7	1.067
6	35	3	3	1.7	1.567
7	35	2	5	11.5	2.034
8	35	3	5	11.5	1.45

Since the minimum amount of spring go is desired, hence –

Criteria: Smaller is better

Formula :

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y^2\right)$$

Table 8 : S/N ratios for all 8 combinations

Sr. No	1	2	3	4	5	6	7	8
S/N Ratio	-7.4839	-2.5031	-2.0555	-5.2632	-0.5632	-3.9013	-6.167	-3.2273

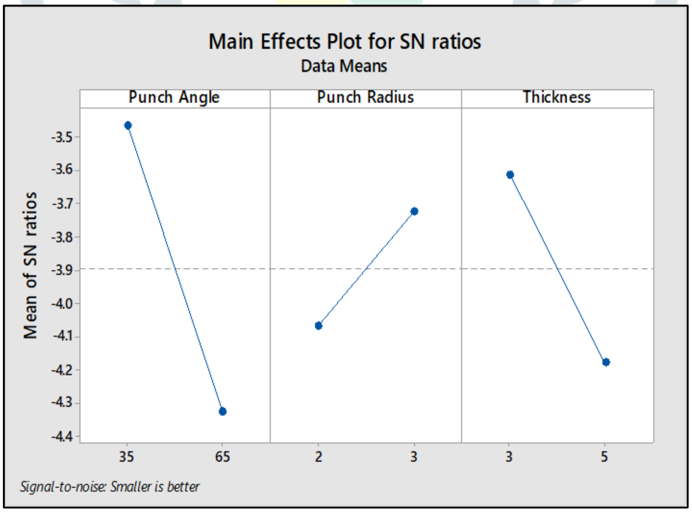

Figure 7 : Main effect for S/N ratios

Table 9 : Response Table for Signal to Noise Ratios

Level	Punch Angle (deg)	Punch Radius (mm)	Sheet Thickness (mm)
1	-3.465	-4.067	-3.613
2	-4.326	-3.724	-4.178
Delta	0.862	0.344	0.565
Rank	1	3	2

Table 10 : Analysis of Variance for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
Punch Angle	1	1.4851	1.4851	1.4851	0.17	0.699	62.91
Punch Radius	1	0.2362	0.2362	0.2362	0.03	0.876	27.07
Material Thickness	1	0.6392	0.6392	0.6392	0.07	0.799	10.006
Residual Error	4	34.4214	34.4214	8.6053			0.014
Total	7	36.7819					100

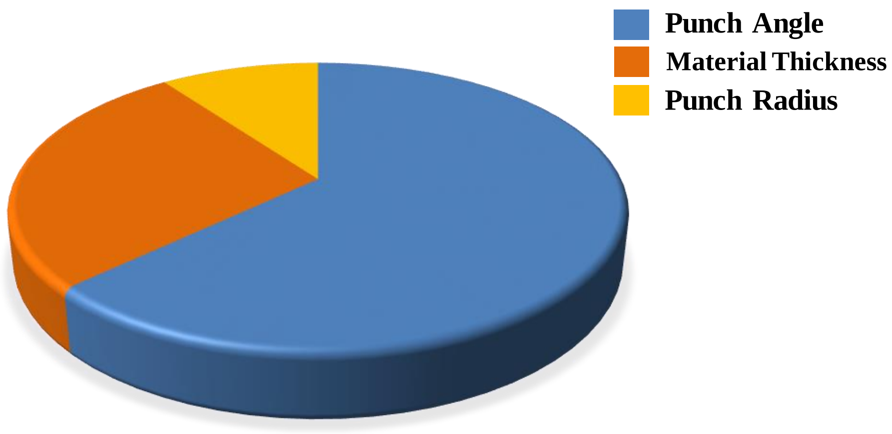

Figure 8 : Contribution of each factor in Spring-go effect of Al-5251 H24 alloy

VI. CONCLUSION

In the forming process spring back can be considerably minimized by design parameters. The spring back also depends on the factors related to materials i.e. material thickness, punch angle, punch radius, etc.

The contribution of punch angle is 62.91%, material thickness is 27.07% and punch radius is 10.006% respectively. Thus, the most affecting parameter is bend/punch angle in case of Al-5251 H24 alloy.

VII. ACKNOWLEDGEMENT

We would like to express our deep gratitude towards our institution, **Finolex Academy of Management Technology, Ratnagiri.** We would also like to express our sincere thanks to our Project Guide, **Prof. Mahadev L. Naik** and who have spared their precious time to deliberate to silent features in "**Spring back effect of Materials**". We are also grateful to **Prof. Gayatri J. Abhyankar** for guiding in details of **Taguchi technique** and its implementation.

We would like to thank to **Prof. Prabodh Horambe** and **Prof. Hemant V. Chavan**,lab in-charge for allowing us to use lab equipment's for project work and also the faculty members **of Mechanical Engineering Department** who have richly contributed by making of useful suggestion & critical discussions during the course of study. We would also grateful to **Dr. Milind S. Yadav**, Head of Mechanical Dept. and respected Principal **Dr. Kaushal Prasad** throughout the course of the project.

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