Analysis of Dimpled Sheet and its Optimization using Taguchi Method

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Abstract – *The dimpling process converts plain sheet into a dimpled sheet which gives higher energy absorption performance in various materials. In this paper effect of dimpling process on mechanical properties like tensile strength, a Yield strength of mild steel, stainless steel and aluminum was studied experimentally and numerically. First sheets were analyzed experimentally by using Taguchi's optimization method. Experimentally the manufacturing of the dimpled sheet was done by a punch and die tools. In this paper mild steel, aluminum and stainless-steel dimple sheet properties were evaluated for various properties numerical simulation of dimpling process was done in Ansys software. The simulation of the dimpling process and tensile test of the plain and dimpled specimens predicted similar behavior to experimental measurements and tests*.

Keywords – **Taguchi method, orthogonal arrays, S/N ratio, DOE**

I. INTRODUCTION

The dimpling process is a cold roll forming process which includes dimpling of a flat strip. It is done to improve the material properties of the respective strip or material and its structural properties also maintaining minimum strip thickness. In this process punch and die, the method is used because it allows better flexibility regarding to size, dimension and efficiency. Solid metal pie is used in operation of punch an die, a punch is situated vertically above the die. Dimpling process is thus done by using a punch and die method. Proper material selection was done for better design and its optimization. Thus, by looking at various parameters aluminum, stainless steel and mild steel were selected. Various tests like chemical composition, tensile test, stress-strain graph have been concluded before the optimization. First tests have been done of a plain sheet and later on for dimpled sheet. After all these processes, the Taguchi method is used for optimization. Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods and more currently also applied to engineering, biotechnology, marketing and advertising. However, Taguchi got to know methods of identifying those noise sources, which have the greatest effects on product variability. After applying the same, optimum values have been found out for each material. As it is trial and error method aim was to increase the strength of the dimpled sheet as the dimpling process increases the strength of the material.

II. METHODOLOGY:

1. MATERIAL SELECTION:

Material selection is the main part or step in the design of the component or selection of the component. It is the easiest and simple step but it is the main step which has a huge impact or drastic change on the extreme performance of the component. It is the most effective step in design engineering. The industrialization and commercialization of the final component rely on proper material selection. If a proper material selection is not done than even the best design can be failed. Criteria for material selection: Material selection can be done on the basis of their properties and depending upon our needs for the design of the component. For the best outcome, the proper material combination is selected. Properties like mechanical properties, wear and corrosion, ability to manufacture, economically feasible, availability in suitable sizes. The material must have strength and stiffness values. Should be anti-corrosive should not be extremely prone to corrosion. The material should be able to machine at a minimum cost. We should try to ensure the required sizes of material which are easily available.

2. MATERIAL TESTING:

I. MILD STEEL:

Mild steel is lighter in weight as compared to stainless steel since it has less carbon content. Mild steel is also relatively cheaper than other materials with similar mechanical properties.

1.1 Properties:

Grade – 40800

Standard – IS: 737-2008

1.2 Chemical Properties:

Tensile Test:

Yield strength	186
Tensile strength	310
% elongation	34.7

II. ALUMINIUM:

Aluminium is extremely strong in spite of its lightweight as its density is almost one-third of that of steel. The surface of aluminium oxidises immediately when it comes in contact with oxygen from the air and protects the material underneath against corrosion. Thus, aluminium is corrosion resistant and protects itself. Aluminium can even withstand extreme temperatures without its properties being compromised. In extreme cold aluminium becomes even tougher and its hardness increases.

2.1 Properties:

Grade – 40800

Standard – IS: 737-2008

2.2 Chemical Properties:

Tensile Test:

Yield strength	154
Tensile strength	168
% elongation	4.42

III. Stainless steel:

Stainless steel is low carbon steel that must have a minimum of 10% chromium. The addition of chromium to the steel causes the formation of a chromium-oxide film which gives stainless steel its unique properties such as its resistance to corrosion and its ability to heal itself when in the presence of oxygen.

3.1 Properties:

Grade – X 04 Ci 19 Ni 9

Standard – IS: 6911:1992/AISI 304

3.2 Chemical Properties:

Tensile Test:

Experimental Procedure for UTM:

1. Place the metal sheet correctly under Universal Testing Machine (UTM).

2. Place the load applying tool in UTM.

3. Fix correctly the tool to avoid any irregularities or errors.

4. Bring the load very close to the specimen.

5. Align the specimen with respect to the load applying tool.

6. Bring the indicator to absolute zero.

7. Start applying load on the specimen.

8. As we apply load on the specimen, the body starts to deform.

9. Perform this experiment for required loads

Tensile test for plain sheets:

The tensile test is carried out on a Universal testing machine.

Dimensions of the test specimen are as follows

Length=300 mm

Breadth = 30 mm

Thickness= 1mm

The following results on Ultimate tensile strength and yield strength were obtained.

Material	UTS (Kg-N/mm2)	Yield Strength (Kg-N/mm2	% Elongation
Stainless steel	578	323	30.76
Mild steel	310	186	34.7
Aluminium	168	154	4.42

Yield strength	373
Tensile strength	578
% elongation	30.76

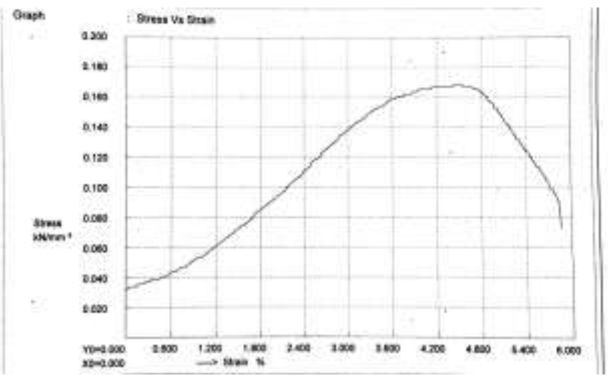


Fig: Stress Vs Strain graph for plain aluminium sheet

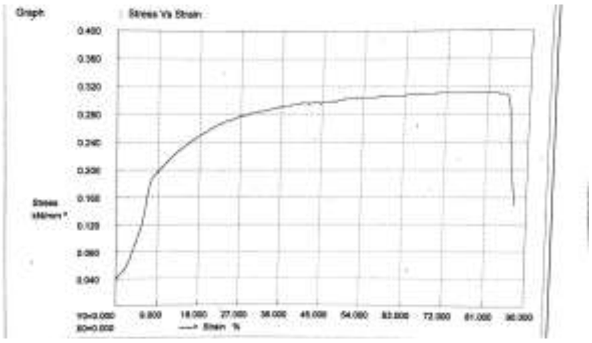


Fig Stress Vs Strain graph for plain Stainless-Steel sheet

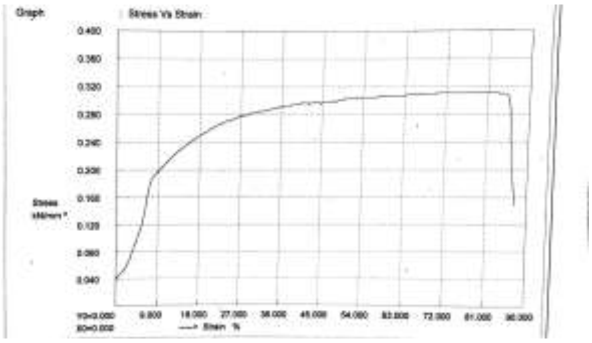


Fig. Stress Vs Strain graph for plain mild Steel sheet

Taguchi Method

The Taguchi method is a powerful tool for designing high-quality systems. The approach is based on the Taguchi method, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) are employed to study the performance characteristics. The Dimpling process is a novel cold roll forming process that involves dimpling of a rolled flat strip prior to the roll forming operation. This process is done to upgrade the material properties and the subsequent product`s structural performance while maintaining a minimum strip thickness.

Taguchi Methodology

Taguchi's method is a powerful technique for the design of a high-quality system. It provides not only, an efficient, but also a systematic way to optimize designs for performance and quality.

The methodology used:

• Identify the quality characteristics and select process parameters to be evaluated.

• Select the appropriate orthogonal array and assign these parameters to the orthogonal array & design the matrix.

• Conduct the experiments as per the design matrix based on the arrangement of the orthogonal array. & Recording of responses

• Analyse the experimental results using the signal to noise(S/N) ratio and analysis of variance (ANOVA) by using Design Expert software.

Taguchi specified three situations

Based on a Design of Experiments (DOE) methodology for determining parameter levels DOE is an important tool for designing processes and products. A method for quantitatively identifying the right inputs and parameter levels for making a high-quality product or service.

1) Larger the better (for example, agricultural yield)

2) Smaller the better (for example, carbon dioxide emissions); and

3) On-target, minimum-variation (for example, a mating part in an assembly).

Orthogonal Arrays

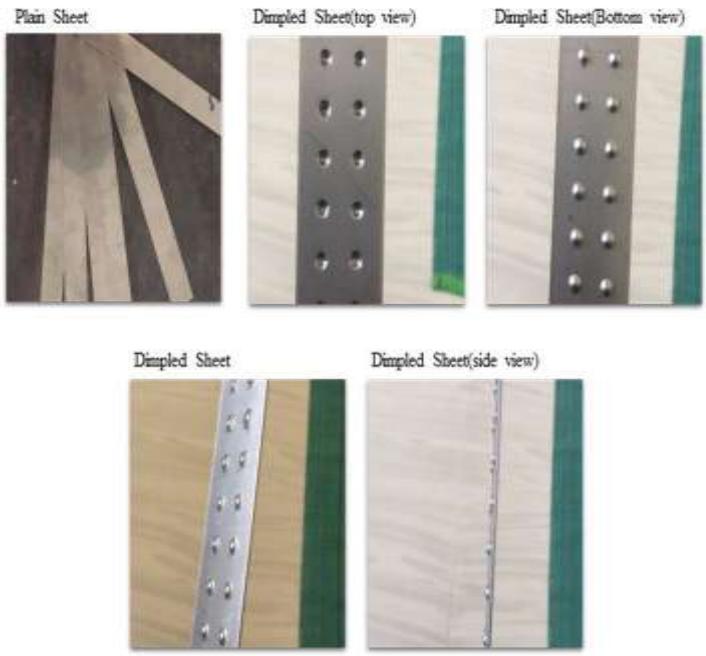
Taguchi's orthogonal arrays are highly fractional orthogonal designs. These designs can be used to estimate main effects using only a few experimental runs. Consider the L4 array shown in the next Figure. The L4 array is denoted as L4(2^3). L4 means the array requires 4 runs. 2^3 indicates that the design estimates up to three main effects at 2 levels each. The L4 array can be used to estimate three main effects using four runs provided that the two factor and three-factor interactions can be ignored.

Depth	Centre distance	Diameter
1	10	2
2	12	3

Fig: Original variation Table

Sr. No	Depth	Distance	Diameter
A	1	10×10	2
B	1	12×12	3
C	2	10×10	3
D	2	12×12	2

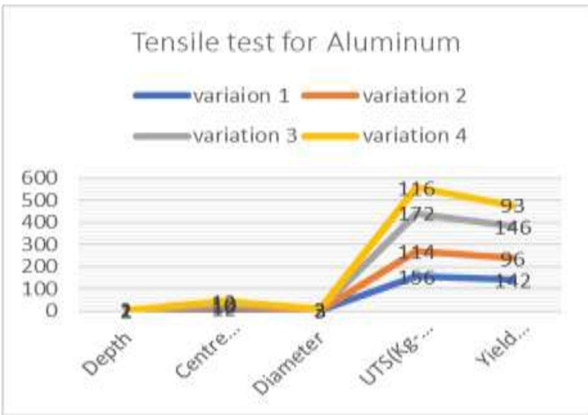
Thus, we manufacture dimpled sheets for the above variations for the three selected materials. After manufacturing of these dimpled sheets for the 4 given variations, we performed a tensile test for all the manufactured specimens on UTM.



Tensile test for dimpled sheets:

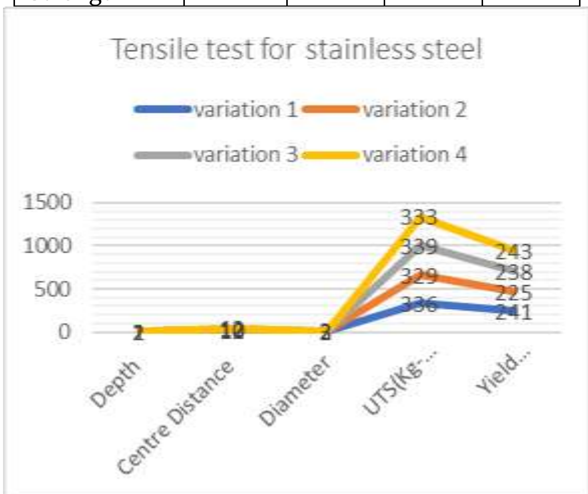
1. Aluminium:

Sr.no	**1**	**2**	**3**	**4**
Depth	1	2	1	2
Centre Distance	12	10	10	12
Diameter	3	3	2	2
UTS	156	114	172	116
Yield Strength	142	96	146	93



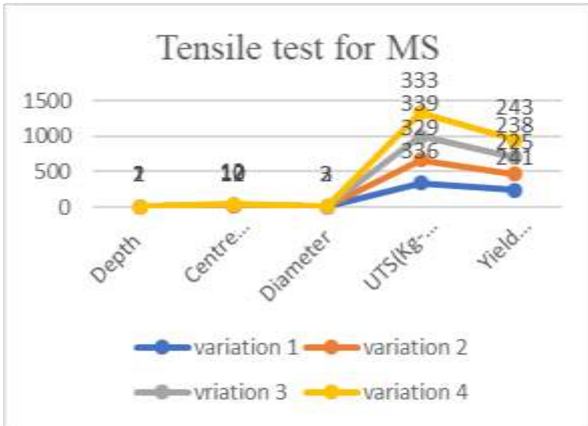
2. Stainless Steel:

Sr.no	1	2	3	4
Depth	1	2	1	2
Centre Distance	12	10	10	12
Diameter	3	3	2	2
UTS	564	567	582	582
Yield Strength	279	259	259	295



3. Mild Steel:

Sr.no	1	2	3	4
Depth	1	2	1	2
Centre Distance	12	10	10	12
Diameter	3	3	2	2
UTS	336	329	339	333
Yield Strength	241	225	238	243



Optimization by Taguchi Method:

Optimization of the process parameters is done to have great control over quality productivity and cost aspects of the process. For optimization process values obtained of UTS for respective material has been added. UTS Results for Mild Steel, Analysis of created Taguchi Design Selection of analysis of Taguchi's design in Minitab software. For designing high-quality system Taguchi's method is a powerful tool.

III. RESULT

The result has been obtained for the three material i.e. Aluminium, mild steel and stainless steel. The value for the S/N ratio and standard deviation has been found out for all three. Their values can be used for the optimization process. The S/N ratio in the table was evaluated by using the equation. The evaluated mean S/N ratio with various factors at the various level are summarized in the S/N ratio response table, the procedure was also followed for aluminium and stainless steel.

1. **Aluminium:**

Table no 4.7 Optimization for Aluminium using Minitab software:

↓	C1	C2	C3	C4	C5
	depth	dist	dia	uts	SNRA1
1	1	10	2	172	44.7106
2	1	12	3	156	43.8625
3	2	10	3	114	41.1381
4	2	12	2	116	41.2892

2. **Mild Steel:**

Table no 4.8 Optimization for Mild Steel Minitab software:

	A	B	C	D	E	F
1	depth	distance	diameter	uts	SNRA1	MEAN1
2	1	10	2	339	50.60399	339
3	1	12	3	336	50.52679	336
4	2	10	3	329	50.34392	329
5	2	12	2	333	50.44888	333

3. **Stainless steel:**

Table no 4.9 Optimization for Stainless Steel Minitab software:

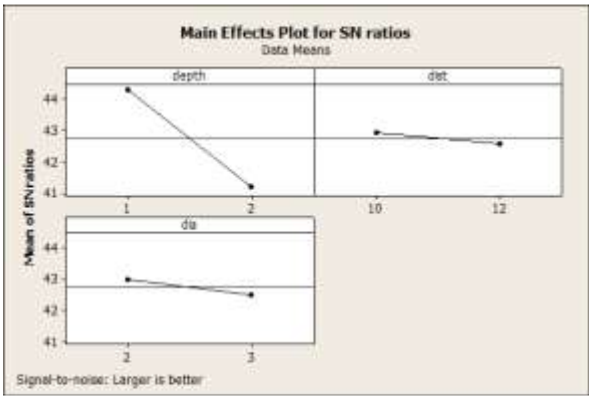
↓	C1	C2	C3	C4	C5
	depth	dist	dia	uts	SNRA1
1	1	10	2	582	55.2985
2	1	12	3	564	55.0256
3	2	10	3	567	55.0717
4	2	12	2	582	55.2985

IV. RESULT AND DISCUSSION

Aluminium: The values of the signal to noise ratio for aluminium for larger is better criteria are given in the table below.

Table no.5.1 Response Table for signal to noise ratio

Levels	Depth	Centre distance	Diameter
1	44.29	42.92	43.00
2	41.21	42.58	42.50



Graph no. 5.1 Mean of SN Ratio of Aluminium

The figure shows that S/N ratio is highest at lower level i.e. 1mm for depth and at 2mm diameter. The plot for distance is almost horizontal showing that S/N ratio is unaffected by the change in the level of distance. Hence it shows that the combination of a high level of depth and diameter along with any level of distance can give the minimum S/N ratio in the design. From the above table no.5.1, we can see that the best combination occurs for level 1 at depth, centre distance and diameter. The values of these parameters at the given level are noted in the table below.

Table no.5.2 Optimized values of selected parameters

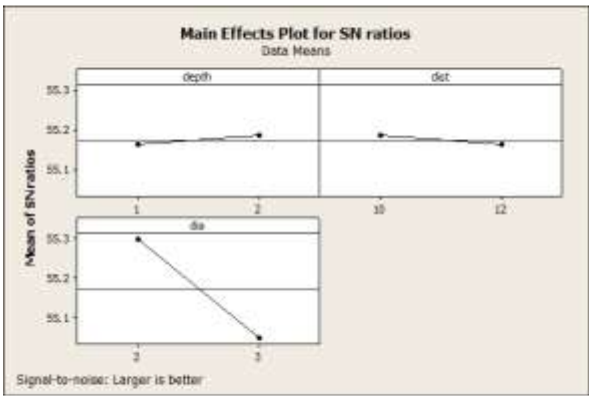
Depth(mm)	Centre distance(mm)	diameter	UTS (Kg-N/mm2)
1	10	2	172

Stainless steel:

The values of the signal to noise ratio for Stainless Steel for larger is better criteria are given in the table below:

Table No: Response Table for the signal to noise ratio

Levels	Depth	Centre Distance	Diameter
1	55.16	55.19	55.30
2	55.19	55.16	55.05



Graph no. 5.2 Mean of SN Ratio Stainless steel

In order to minimize the variability, the aim is to minimize the standard deviation. Fig shows signal to noise ratio is lower at a higher level, i.e. 1mm depth and at 2mm diameter. The plot of distance is almost horizontal that S/N ratio is unaffected by the change in the level of distance. Hence it shows that the combination of the low level of depth and diameter along with any level of distance can give maximum S/N ratio in the design. From the above table, we can see that the best combination occurs for level 2 at depth, level 1 for centre distance and diameter. The values of these parameters at the given level are noted in the table below.

Table no.5.4 Optimized values of selected parameters

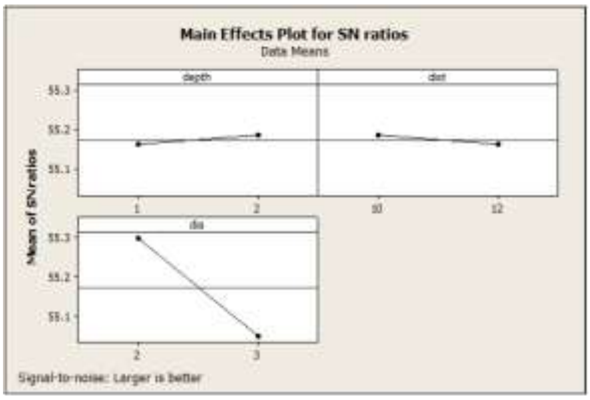
Depth	Centre distance	Diameter	UTS (Kg-N/mm2)
2	10	2	582

Mild Steel:

The values of the signal to noise ratio for Mild Steel for larger is better criteria are given in the table below.

Table no.5.5 Response Table for signal to noise ratio

Levels	Depth	Centre Distance	Diameter
1	50.57	50.47	50.59
2	50.40	50.49	50.44



Graph no.5.3 Mean of SN Ratio of mild steel

The figure shows that S/N ratio is highest at lower level i.e 1mm for depth and at 2mm diameter. The plot for distance is almost horizontal showing that S/N ratio is unaffected by the change in the level of distance. Hence it shows that the combination of a high level of depth and diameter along with any level of distance can give the minimum S/N ratio in the design. From table no. we can see that the best combination occurs for level 1 at depth, level 2 for centre distance and diameter. The values of these parameters at the given level are noted in the table below [15].

Table No: Optimized values of the selected parameter

Depth	Centre distance	Diameter	UTS (Kg-N/mm2)
1	12	3	336

V. CONCLUSIONS

This project illustrates the application of the parameter design (Taguchi method) in the optimized results of a dimpled sheet. The conclusions can be drawn based on the above experimental of this study are that:

- For Mild Steel Taguchi design has been successfully applied to obtain a design which gives the better result of the dimpled sheet as compared to a plain sheet. The analysis suggests that the combination of depth 1mm, centre distance 12mm and diameter 3mm with the UTS value of 582 results into the design of optimum value.

- For Aluminium Taguchi design has been successfully applied to obtain a design which gives the better result of the dimpled sheet as compared to the plain sheet. The analysis suggests that the combination of (Taguchi method) in the optimization of the dimpled sheet. The conclusions can be drawn based on the above experimental results of this study is that Taguchi's Method of parameter design can be performed with the lesser number of experimentations as compared to that of full factorial analysis and yields similar results. It is found that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for optimizing the process parameters.
- For Stainless Steel Taguchi design has been successfully applied to obtain a design which gives the better result of the dimpled sheet as compared to the plain sheet. The analysis suggests that the combination of depth 2mm, centre distance 10mm and diameter 2mm with the UTS value of 336 results into the design of optimum value. For Mild Steel Taguchi design has been successfully applied to obtain a design which gives the better result of the dimpled sheet as compared to the plain sheet. The analysis suggests that the combination of depth 1mm, centre distance 12mm and diameter 3mm with the UTS value of 582 results into the design of optimum value.

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