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# Optimization of multipoint incremental sheet metal forming of SS430 sheets using GRA

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Incremental sheet metal forming (ISF) is one of the best flexible manufacturing processes used to convert a sheet metal into required final shape using tool movement. In incremental sheet metal forming process, a single pointed forming tool is allowed to move over the sheet metal as per the pre-programmed numerical control of a computer. The advantage of making any complex part without die confirms its importance in the emerging automated industries. But this process has some limitations such as less formability and high surface roughness compared to the conventional forming process. Longer processing time is another drawback of the incremental sheet forming. This paper proposes a newly designed multi-point incremental forming (MPIF) tool to avoid the drawbacks faced by industry in increasing the formability and wall angle of the sheet metal with reduced time. The sheet metal stainless steel (SS) grade 430 has been used for forming process and the outputs obtained from MPIF and single point incremental forming (SPIF) have been compared with respect to wall angle, formability, surface roughness, spring back and forming time. Grey relational analysis (GRA) has been used to find the optimal value for the various responses obtained. The analysis of variance (ANOVA) calculation method has also been used to find the factors that influence the output responses. The responses obtained by the experiment have proved that the multipoint tool results better output.

**Keywords**: MPIF, SPIF, SS430, GRA, ANOVA.

## 1 Introduction

The SPIF of metal sheets is very flexible and economical process for small batch production. The main advantage of SPIF process is avoiding the die in forming the sheet blank, but it is quite slow compared to other conventional forming processes[1]. The incremental sheet metal forming overcomes all the drawbacks raised while working with the conventional forming process[2].The SPIF consists of a fixture and a hemispherical (or) ball ended tool which moves in a specified path monitored by pre-programmed computer numerical controlled (CNC) machine. In SPIF, parameters namely, speed, vertical step depth (VSD), feed rate of the tool, lubrication and type of tool plays a vital role in controlling the wall angle, formability, surface Roughness and forming time of the work piece[3]. Tool path also plays a vital role in improving the surface finish and reduce the forming time thus some researchers[4] optimize tool path to improve the formability of the material and to get a better surface finish. A few research works have been carried out to increase the formability by varying the temperature of the work piece[5] and also varying the vertical movement on stage by stage[6]. Raju *et al.*[7,8] have proposed a multiple sheets forming with Taguchi based GRA to optimize the parameters, namely forming time, wall angle, formability, spring back and also have analysed the mechanism of sheet failure. The maximum research works have been focussed on the parameters[9] used in the forming process and very less number of research works has focussed on the tool to improve the formability with less surface roughness in reduced stipulated time. A few research works like multi-directional tooling[10] and oblique roller tool[11] has been experimented to improve the formability, surface finish and reduce the spring back. Yanle Li *et al.*[12] have experimented on an Al sheet of 7075-O with four different tools in which three are sliding (hemispherical) tools and one is ball tool and he concluded that the ball tool produces a better surface finish than the sliding tool because the ball tool produces less wear compared to the sliding tool. Shanmuganatan *et al.*[13] proposed a mathematical approach using Al 303(O) using response surface methodology by various input parameters like tool diameter, step depth, spindle speed and feed rate. Mugendiran *et al.*[14] created a finite element model of truncated cone and compared it with the experimental model to analyze the formability and thickness distribution. The outputs obtained gives good agreement between the simulated and experimental work. Research with flat end tools are also made and experimentally compared with hemispherical ended tools and found that flat end tools give a better surface finish and formability with less forming force than the hemispherical tools[15]. Fei *et al.*[16] and Dejardin *et al.*[17] made an experimental analysis using analytical method of reducing the spring back effect in SPIF. Matthieu *et al.*[18] also proposed a work with tool path optimization in reducing the spring back effect. From the above literatures, it is evident that researchers are making a search to improve the formability of the sheet metal with reduced surface finish and forming time. The spring back effect also plays a vital role in improving the accuracy of the sheet metal. Whereas in the previous research works the process parameters and tool path has been mainly focussed to reduce the spring back. In this work, a MPIF was made and it was compared with SPIF using inputs like feed, speed, vertical step depth and lubrication. SS430 sheet was used as the material since proceeding works on this material is scant and its application towards automotive, aerospace industries and home appliances. It has also a good corrosion and chemical resistant as per literature survey. The Taguchi based L18 orthogonal array was selected and the experiment was conducted from which the outputs were obtained like formability, wall angle, surface roughness, spring back and time. These output Reponses were optimised by GRA. GRA is used to compare the unknown relationship between the process parameters and the output responses. The GRA can be converted into grey relational Grade by including weighting values[19]. Grey relational grade optimization process is used due to its better output for multi objective response[20-22]. The percentage contributions of the input parameters are also obtained from the ANOVA table.

## 2 Experimentation

The SS430 sheet was purchased and sheared to size 150 mm×150 mm×0.4 mm. The tool was made up of EN 18 material. The tool consists of 6 balls of diameter 12.7 mm. A patent for multipoint tool[23] used in this work has been filed with the Official Journal of the Patent Office. The SS430 blank was fixed on a forming fixture of dimension 196 mm×196 mm and it was clamped by a screw and nut type clamping. The hyperboloid shape shown in Fig. 1 is made with the pre-programmed tool movement in the vertical milling machine with the input parameters like type of tool (Multi point tool denoted as 'M' and Single point tool denoted as 'S' in the table given below), feed, vertical step depth, speed and lubrication. The experiments were carried out as per Design of Experiments (DOE) L18 standard Orthogonal Array (OA) to get the responses are shown in Table 1 & 2. The outputs are viz. Wall Angle (WA), Formability (F) or sum of strain, Surface Roughness (SR), Spring Back (SB) and forming time (T) were measured from the various levels of inputs. The forming time was measured for each experiment. The maximum wall angle and depth was measured using the Coordinate Measuring Machine (CMM) named Tesa Microhite 3D. The surface roughness was calculated using

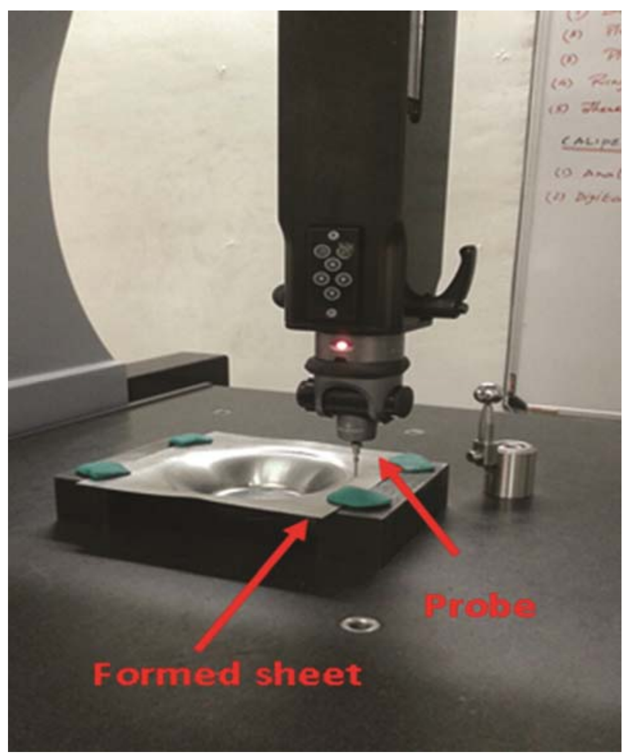


Fig. 1 — Image of the CMM while measuring the sheet formed using MPIF.

Table 1— Factors and levels.

| S.No | Factors | Units | Factors notation | Levels | | |
|---|---|---|---|---|---|---|
| | | | | **1** | **2** | **3** |
| 1. | Tool | ---- | A | Multi Point(M) | Single Point(S) | ---- |
| 2. | Feed | mm/min | B | 50 | 100 | 150 |
| 3. | Vertical Step Depth(VSD) | Mm | C | 0.1 | 0.2 | 0.3 |
| 4. | Speed | Rpm | D | 100 | 150 | 200 |
| 5. | Lubrication | ---- | E | Dry(D) | Oil(O) | Grease(G) |

Table 2 — Input parameters used.

| S.No | Type of tool | Feed (mm/min) | VSD (mm) | Speed (rpm) | Lubrication |
|---|---|---|---|---|---|
| 1 | M | 50 | 0.1 | 100 | D |
| 2 | M | 50 | 0.2 | 150 | O |
| 3 | M | 50 | 0.3 | 200 | G |
| 4 | M | 100 | 0.1 | 100 | O |
| 5 | M | 100 | 0.2 | 150 | G |
| 6 | M | 100 | 0.3 | 200 | D |
| 7 | M | 150 | 0.1 | 150 | D |
| 8 | M | 150 | 0.2 | 200 | O |
| 9 | M | 150 | 0.3 | 100 | G |
| 10 | S | 50 | 0.1 | 200 | G |
| 11 | S | 50 | 0.2 | 100 | D |
| 12 | S | 50 | 0.3 | 150 | O |
| 13 | S | 100 | 0.1 | 150 | G |
| 14 | S | 100 | 0.2 | 200 | D |
| 15 | S | 100 | 0.3 | 100 | O |
| 16 | S | 150 | 0.1 | 200 | O |
| 17 | S | 150 | 0.2 | 100 | G |
| 18 | S | 150 | 0.3 | 150 | D |

Table 3 — Output responses.

| Ex. No | Wall angle (Degrees) | Formability | Surface Roughness (µm) | Forming Time (Hrs) | Spring Back (mm) |
|---|---|---|---|---|---|
| 1 | 53.033 | 0.925 | 1.40 | 8.224 | 4.619 |
| 2 | 55.810 | 1.120 | 0.71 | 4.370 | 5.160 |
| 3 | 54.663 | 0.987 | 1.36 | 3.221 | 5.010 |
| 4 | 54.987 | 0.957 | 0.34 | 5.570 | 4.756 |
| 5 | 54.751 | 0.921 | 0.89 | 3.870 | 4.092 |
| 6 | 54.818 | 0.855 | 1.51 | 1.670 | 3.632 |
| 7 | 53.874 | 0.736 | 1.21 | 2.991 | 2.404 |
| 8 | 56.851 | 0.953 | 0.33 | 1.825 | 3.254 |
| 9 | 55.938 | 0.854 | 0.64 | 1.038 | 2.895 |
| 10 | 50.949 | 0.890 | 1.21 | 13.371 | 5.745 |
| 11 | 50.554 | 0.807 | 1.55 | 11.715 | 4.500 |
| 12 | 52.975 | 1.057 | 0.65 | 8.044 | 5.564 |
| 13 | 51.051 | 0.842 | 0.82 | 9.954 | 4.905 |
| 14 | 50.871 | 0.801 | 1.69 | 6.829 | 4.120 |
| 15 | 53.249 | 0.937 | 0.36 | 5.939 | 4.561 |
| 16 | 53.308 | 0.883 | 0.51 | 7.180 | 3.956 |
| 17 | 52.028 | 0.751 | 0.78 | 5.996 | 2.844 |
| 18 | 52.804 | 0.735 | 1.46 | 3.883 | 2.516 |

surface roughness tester, RUGOSURF 10G. The surface roughness has been measured and the average value reported in Table 3.The spring back was calculated using the following equation in which the difference between the depths measured in the profile using the CMM machine and the value measured by CNC machine.

$$\text{Spring back} = (\Delta_a - \Delta_o) \quad \ldots (1)$$

where, $\Delta_a$ is the depth value calculated from the CNC machine and $\Delta_o$ is the depth value measured using CMM.

The major strain and minor strain values of all the sheets were calculated using the video measuring machine shown in Fig. 2 and the formability (ε) was calculated using the formula given below:

$$\text{Formability (sum of strain) } (\varepsilon) = \text{major true strain } (\varepsilon_1) + \text{minor true strain} (\varepsilon_2) \quad \ldots (2)$$

where, major true strain and minor true strain are calculated[24] using the following formula:


Fig. 2 — Video measuring machine used for formability measurement.

Major true strain ($\varepsilon_1$) =ln ($\emptyset_{major}/\emptyset$) ... (3)

Minor true strain ($\varepsilon_2$) =ln ($\emptyset_{minor}/\emptyset$) ... (4)

where, $\emptyset_{major}$ is major diameter of the circular grid, $\emptyset_{minor}$ is minor diameter of the circular grid and $\emptyset$ is original diameter of the circular grid. The obtained results are shown in Table 3.

The experimental output data results were converted into a single objective function using GRA technique. The first step begins with S/N ratio which are shown in Table 4 where the wall angle, formability response larger the better, whereas surface roughness, spring back and forming time response smaller the better which was solved by using Eq. 5 and Eq. 6 which is followed by normalization. The normalized values are shown in Table 5 which was solved by Eq. 7.

(1) Convert the experimental data into S/N values

$$S/N\ ratio(\eta) = -10\log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n}\frac{1}{y_{ij^2}} \quad ...(5)$$

Where $y_{ij}$=response value and n=number of factors

$$S/N\ ratio(\eta) = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_{ij^2}\right) \quad ...(6)$$

(2) Normalize the S/N ratio

$$Z_{ij} = \frac{y_{ij} - \min(y_{ij})}{\max(y_{ij}) - \min(y_{ij})} \quad ...(7)$$

Table 4 — S/N ratio responses.

| Ex. No | Wall angle (Degrees) | Formability | Surface Roughness (µm) | Forming Time (Hrs) | Spring Back (mm) |
|---|---|---|---|---|---|
| 1 | 34.4909 | -0.6781 | -2.9226 | -18.3019 | -13.2910 |
| 2 | 34.9342 | 0.9844 | 3.0362 | -12.8096 | -14.2530 |
| 3 | 34.7539 | -0.1137 | -2.6388 | -10.1609 | -13.9968 |
| 4 | 34.8052 | -0.3809 | 9.3704 | -14.9171 | -13.5448 |
| 5 | 34.7678 | -0.7148 | 1.0611 | -11.7542 | -12.2387 |
| 6 | 34.7785 | -1.3607 | -3.5680 | -4.4543 | -11.2029 |
| 7 | 34.6276 | -2.6648 | -1.6557 | -9.5175 | -7.6187 |
| 8 | 35.0948 | -0.4154 | 9.6297 | -5.2253 | -10.2484 |
| 9 | 34.9541 | -1.3708 | 3.8764 | -0.3198 | -9.2330 |
| 10 | 34.1427 | -1.0122 | -1.6485 | -22.5231 | -15.1858 |
| 11 | 34.0751 | -1.8615 | -3.7786 | -21.3751 | -13.0643 |
| 12 | 34.4814 | 0.4840 | 3.8088 | -18.1090 | -14.9077 |
| 13 | 34.1601 | -1.4917 | 1.7237 | -19.9596 | -13.8128 |
| 14 | 34.1294 | -1.9273 | -4.5577 | -16.6877 | -12.2979 |
| 15 | 34.5262 | -0.5652 | 8.8739 | -15.4737 | -13.1812 |
| 16 | 34.5358 | -1.0808 | 5.8486 | -17.1225 | -11.9451 |
| 17 | 34.3247 | -2.4872 | 2.2028 | -15.5572 | -9.0786 |
| 18 | 34.4533 | -2.6731 | -3.2871 | -11.7833 | -8.0142 |

(3) Calculate the corresponding grey relational coefficients

$$GC_{ij} = \frac{\Delta_{\min} + \varphi_{\Delta_{\max}}}{\Delta_{ij} + \varphi_{\Delta_{\max}}} \quad ...(8)$$

(4)Grey relational grade with an equal weightage factor of value $\varphi$=0.2 is used

$$C_i = \frac{1}{k}\sum GC_{ij} \quad ...(9)$$

(5) Performing statistical analysis of variance (ANOVA)

(6) Select the optimal levels.

(7) Conduct confirmation experiments to verify the optimal parameters.

From the Table 6, it can be noticed that the experiment 2 has a maximum grey relational value and the mean response table shows that the optimal values are obtained from A1B1C2D2E2.

## 3 Results and Discussion

Minitab 16 statistical software was used to develop the ANOVA table for the output results of wall angle, formability, surface roughness, time and spring back to identify the significant parameters which are shown in Table 7. In the ANOVA table, the F-factor higher than 4 and P-Factor less than 0.05 shows that these factors influence more on the output value which is

Table 5 — Grey relational coefficient of experimental responses.

| Ex. No | Wall angle (Degrees) | Formability | Surface Roughness (µm) | Forming Time (Hrs) | Spring Back (mm) |
|---|---|---|---|---|---|
| 1 | 0.4078 | 0.5455 | 0.8847 | 0.8099 | 0.7782 |
| 2 | 0.8425 | 1.0000 | 0.4647 | 0.5625 | 0.9102 |
| 3 | 0.6657 | 0.6998 | 0.8647 | 0.4432 | 0.8750 |
| 4 | 0.7160 | 0.6267 | 0.0183 | 0.6574 | 0.8130 |
| 5 | 0.6794 | 0.5354 | 0.6040 | 0.5150 | 0.6338 |
| 6 | 0.6898 | 0.3588 | 0.9302 | 0.1862 | 0.4917 |
| 7 | 0.5418 | 0.0023 | 0.7955 | 0.4142 | 0.0000 |
| 8 | 1.0000 | 0.6173 | 0.0000 | 0.2209 | 0.3608 |
| 9 | 0.8621 | 0.3561 | 0.4055 | 0.0000 | 0.2215 |
| 10 | 0.0663 | 0.4541 | 0.7949 | 1.0000 | 1.0382 |
| 11 | 0.0000 | 0.2219 | 0.9451 | 0.9483 | 0.7471 |
| 12 | 0.3985 | 0.8632 | 0.4103 | 0.8012 | 1.0000 |
| 13 | 0.0833 | 0.3230 | 0.5573 | 0.8845 | 0.8498 |
| 14 | 0.0533 | 0.2039 | 1.0000 | 0.7372 | 0.6420 |
| 15 | 0.4424 | 0.5763 | 0.0533 | 0.6825 | 0.7631 |
| 16 | 0.4518 | 0.4354 | 0.2665 | 0.7568 | 0.5936 |
| 17 | 0.2448 | 0.0508 | 0.5235 | 0.6863 | 0.2003 |
| 18 | 0.3709 | 0.0000 | 0.9104 | 0.5163 | 0.0543 |

Table 6 — Grey grade coefficients, Grey grade and rank of the GRG.

| Ex. No | Wall angle (Degrees) | Formability | Surface Roughness (µm) | Forming Time (Hrs) | Spring Back (mm) | GRG | Rank |
|---|---|---|---|---|---|---|---|
| 1 | 0.4578 | 0.5238 | 0.8127 | 0.7245 | 0.6927 | 0.6370 | 5 |
| 2 | 0.7605 | 1.0000 | 0.4830 | 0.5333 | 0.8477 | 0.7158 | 1 |
| 3 | 0.5993 | 0.6248 | 0.7871 | 0.4731 | 0.8000 | 0.6490 | 4 |
| 4 | 0.6378 | 0.5726 | 0.3374 | 0.5934 | 0.7278 | 0.5677 | 9 |
| 5 | 0.6093 | 0.5184 | 0.5580 | 0.5076 | 0.5773 | 0.5511 | 11 |
| 6 | 0.6171 | 0.4381 | 0.8776 | 0.3806 | 0.4959 | 0.5601 | 10 |
| 7 | 0.5218 | 0.3338 | 0.7097 | 0.4605 | 0.3333 | 0.4718 | 17 |
| 8 | 0.9999 | 0.5664 | 0.3333 | 0.3909 | 0.4389 | 0.5449 | 12 |
| 9 | 0.7838 | 0.4371 | 0.4568 | 0.3333 | 0.3911 | 0.4799 | 16 |
| 10 | 0.3487 | 0.4781 | 0.7092 | 1.0000 | 1.0826 | 0.7072 | 2 |
| 11 | 0.3333 | 0.3912 | 0.9010 | 0.9063 | 0.6641 | 0.6345 | 6 |
| 12 | 0.4539 | 0.7851 | 0.4588 | 0.7155 | 1.0000 | 0.6690 | 3 |
| 13 | 0.3529 | 0.4248 | 0.5304 | 0.8124 | 0.7690 | 0.5709 | 8 |
| 14 | 0.3456 | 0.3858 | 1.0000 | 0.6555 | 0.5827 | 0.5908 | 7 |
| 15 | 0.4728 | 0.5413 | 0.3456 | 0.6116 | 0.6786 | 0.5250 | 13 |
| 16 | 0.4770 | 0.4696 | 0.4054 | 0.6727 | 0.5516 | 0.5127 | 14 |
| 17 | 0.3983 | 0.3450 | 0.5120 | 0.6145 | 0.3847 | 0.4505 | 18 |
| 18 | 0.4428 | 0.3333 | 0.8481 | 0.5083 | 0.3458 | 0.4956 | 15 |

Table 7 — ANOVA table for output responses.

**ANOVA for Wall Angle**

| Source | DF | Adj SS | Adj MS | F value | P value | PC |
|---|---|---|---|---|---|---|
| Tool | 1 | 40.3082 | 40.3082 | 485.19 | 0.000 | 66.25% |
| Feed | 2 | 4.1835 | 2.0917 | 25.18 | 0.000 | 6.88% |
| VSD | 2 | 4.3744 | 2.1872 | 26.33 | 0.000 | 7.19% |
| Speed | 2 | 0.2783 | 0.1391 | 1.67 | 0.247 | 0.46% |
| Lub | 2 | 11.0334 | 5.5167 | 66.4 | 0.000 | 18.13% |
| Error | 8 | 0.6646 | 0.0831 | | | 1.09% |
| Total | 17 | 60.8423 | | | | 100 |

R-Sq = 98.33% R-Sq(adj) = 97.41%

**ANOVA for Formability**

| Source | DF | Adj SS | Adj MS | F value | P value | PC |
|---|---|---|---|---|---|---|
| Tool | 1 | 0.020294 | 0.020294 | 27.41 | 0.001 | 10.68% |
| Feed | 2 | 0.063815 | 0.031907 | 43.09 | 0.000 | 33.60% |
| VSD | 2 | 0.00315 | 0.001575 | 2.13 | 0.182 | 0.016% |
| Speed | 2 | 0.002966 | 0.001483 | 2 | 0.197 | 1.56% |
| Lub | 2 | 0.093784 | 0.046892 | 63.32 | 0.000 | 49.38% |
| Error | 8 | 0.005924 | 0.000741 | | | 3.12% |
| Total | 17 | 0.189933 | | | | 100 |

R-Sq = 96.88% R-Sq(adj) = 93.37%

**ANOVA for SR**

| Source | DF | Adj SS | Adj MS | F value | P value | PC |
|---|---|---|---|---|---|---|
| Tool | 1 | 0.0229 | 0.0229 | 2.43 | 0.158 | 0.64% |
| Feed | 2 | 0.32069 | 0.16034 | 17 | 0.001 | 8.99% |
| VSD | 2 | 0.02368 | 0.01184 | 1.26 | 0.336 | 0.66% |
| Speed | 2 | 0.19915 | 0.09958 | 10.56 | 0.006 | 5.58% |
| Lub | 2 | 2.92657 | 1.46329 | 155.15 | 0 | 82.01% |
| Error | 8 | 0.07545 | 0.00943 | | | 0.021144 |
| Total | 17 | 3.56844 | | | | 100 |

R-Sq = 97.89% R-Sq(adj) = 95.51%

(*Contd*.)

Table 7 — ANOVA table for output responses. (*Contd.*)

**ANOVA for Time**

| Source | DF | Adj SS | Adj MS | F value | P value | PC |
|---|---|---|---|---|---|---|
| Tool | 1 | 89.471 | 89.471 | 119.14 | 0 | 44.08% |
| Feed | 2 | 56.963 | 28.481 | 37.93 | 0 | 28.06% |
| VSD | 2 | 46.102 | 23.051 | 30.69 | 0 | 22.71% |
| Speed | 2 | 2.724 | 1.362 | 1.81 | 0.224 | 1.34% |
| Lub | 2 | 1.706 | 0.853 | 1.14 | 0.368 | 0.84% |
| Error | 8 | 6.008 | 0.751 | | | 2.96% |
| Total | 17 | 202.974 | | | | 100.00 |

R-Sq = 97.04% R-Sq(adj) = 93.71%

**ANOVA for SB**

| Source | DF | Adj SS | Adj MS | F value | P value | PC |
|---|---|---|---|---|---|---|
| Tool | 1 | 0.4637 | 0.4637 | 28.77 | 0.001 | 2.60% |
| Feed | 2 | 13.8754 | 6.9377 | 430.4 | 0 | 77.68% |
| VSD | 2 | 0.597 | 0.2985 | 18.52 | 0.001 | 3.34% |
| Speed | 2 | 0.2085 | 0.1042 | 6.47 | 0.021 | 1.17% |
| Lub | 2 | 2.5888 | 1.2944 | 80.3 | 0 | 14.49% |
| Error | 8 | 0.129 | 0.0161 | | | 0.72% |
| Total | 17 | 17.8624 | | | | 100 |

R-Sq = 99.28% R-Sq(adj) = 98.47%

**ANOVA for GRG**

| Source | DF | Adj SS | Adj MS | F value | P value | PC |
|---|---|---|---|---|---|---|
| Tool | 1 | 0.000025 | 0.000025 | 0.04 | 0.84 | 0.02% |
| Feed | 2 | 0.094693 | 0.047346 | 81 | 0 | 86.96% |
| VSD | 2 | 0.001118 | 0.000559 | 0.96 | 0.424 | 1.03% |
| Speed | 2 | 0.006297 | 0.003148 | 5.39 | 0.033 | 5.78% |
| Lub | 2 | 0.002081 | 0.00104 | 1.78 | 0.229 | 1.91% |
| Error | 8 | 0.004676 | 0.000585 | | | 4.29% |
| Total | 17 | 0.10889 | | | | 100.00% |

R-Sq = 95.71% R-Sq(adj) = 90.87%

also shown using percentage contribution (PC) in the last column of the Table 7.

The $R^2$ value of wall angle, formability, surface roughness, time and spring back and GRG are 98.33%, 96.88%, 97.89%, 97.04%, 99.28% and 95.71%, respectively. This shows that all the values are higher than the confidence value (> 95%). The ANOVA table also shows that the type of tool is the factor that affects maximum for obtaining higher wall angle. This is due to the reason of increasing the contact area between the tool and the sheet metal by increasing diameter of the forming tool. When the contact area between the tool and the sheet metal is increased the axial force created by the tool on the sheet is reduced[10]. The lubrication also plays a vital role in increasing the wall angle. The lubrication is influencing more in formability and surface roughness.

Therefore, the lubrication reduces the friction between the tool and the sheet metal and thus improves the formability of the sheet. In addition, the reduced friction reduces the surface roughness produced by the tool on the sheet. The type of tool, feed and vertical step depth are the factor that affect the forming time. Since the diameter of the tools used is more it will obviously reduce the forming time taken to produce the product. Similarly, the increased feed rate and vertical step depth speed up the process and reduces the working time[2]. The feed acts as the major affecting factor in the spring back with higher percentage contribution. In the overall GRG analysis the feed, speed, lubrication is the major affecting factor. The regression equations obtained from ANOVA using MINITAB 16 is used as predicted values which was compared with the actual value obtained through GRA is shown in Fig. 3 which shows that the values fit closer to each other.

The response table for GRG resembles that the maximum affecting factor is feed and speed whereas the least affecting factor is tool which is also shown in

ANOVA Table 8. The Fig.4 shows the mean effect graph which is plotted by using larger-the-better output response in order to compare the input parameters using the GRG values. From the mean effect plot it can be noticed that the multipoint tool gives higher mean values than the single point tool which shows that multipoint tool gives better outputs when compared to single point tool. This may be due to the increased surface contact of the tool and the sheet metal which improve the formability. When the formability gets increased the wall angle gets increased. Similarly, the surface roughness is highly reduced by using multipoint tool since more number of balls are used which will compress the gouges produced due to the tool movement. The spring back is also reduced by the multipoint tool which may be due to the tensile load given by the tool rather than producing compressive load by the single point tool[2].

Table 8 — Mean response table for the GRG value.

| Level | Mean Values of GRG Factors | | | | |
|---|---|---|---|---|---|
| | Tool | Feed | VSD | Speed | Lub |
| 1 | 5.1774 | 4.0126 | 3.4673 | 3.2947 | 3.3899 |
| 2 | 5.1561 | 3.3656 | 3.4876 | 3.4908 | 3.5351 |
| 3 | -- | 2.9554 | 3.4615 | 3.5647 | 3.4086 |
| Delta | 0.0213 | 1.0572 | 0.0260 | 0.2700 | 0.1452 |
| Rank | 5 | 1 | 4 | 2 | 3 |

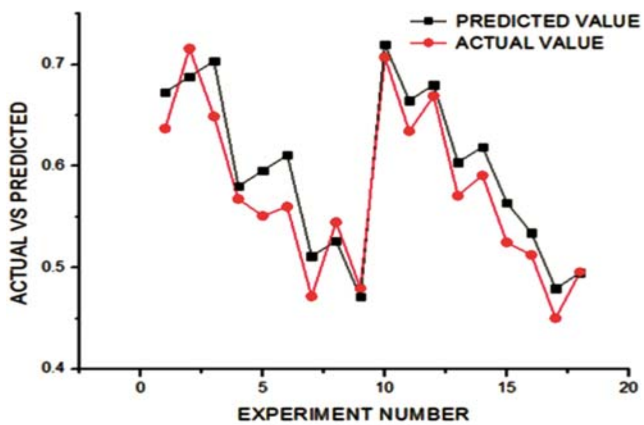


Fig. 3 — Actual value versus predicted value.

### 3.1 Confirmation test

The confirmation experiments were done to predict the exactness of the optimization at optimal levels. The results are shown in Table 9 which shows the GRG values are improved from 0.6370 to 0.7362 which is 13.4% improvement.

Table 9 — Results of confirmation experiment.

| | Initial Values | Optimal Values | |
|---|---|---|---|
| | | Predicted | Experimented |
| Levels | A1B1C1D1E1 | A1B1C2D2E2 | A1B1C2D3E2 |
| Wall Angle | 53.033 | | 56.861 |
| Formability | 0.925 | | 1.520 |
| Surface Roughness | 1.40 | | 0.61 |
| Time | 8.224 | | 4.020 |
| Spring Back | 4.619 | | 4.86 |
| GRG | 0.6370 | 0.7158 | 0.7362 |

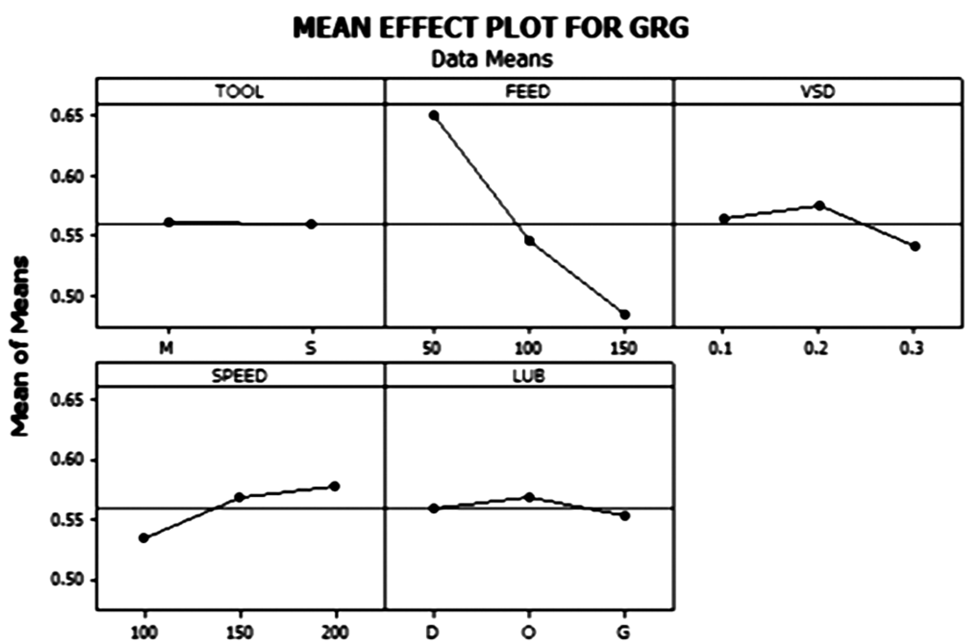


Fig. 4 — Main effect plots for grey grade outputs.

Table 10 — Influencing order of input parameters from maximum value to minimum value with respect to percentage of contribution.

| Output responses | Influencing factor (Max to min) | PC (%) |
|---|---|---|
| Wall angle | Tool | 66.25% |
| | Lubrication | 18.13% |
| | VSD | 7.19% |
| | feed | 6.88% |
| | Speed | 0.46% |
| Formability | Lubrication | 49.38% |
| | Feed | 33.60% |
| | Tool | 10.68% |
| | Speed | 1.56% |
| | VSD | 0.02% |
| Surface roughness | Lubrication | 82.01% |
| | Feed | 8.99% |
| | Speed | 5.58% |
| | VSD | 0.66% |
| | Tool | 0.64% |
| Forming time | Tool | 44.08% |
| | Feed | 28.06% |
| | VSD | 22.71% |
| | Speed | 1.34% |
| | Lubrication | 0.84% |
| Spring back | Feed | 77.68% |
| | Lubrication, | 14.49% |
| | VSD | 3.34% |
| | Tool | 2.60% |
| | Speed | 1.17% |

## 4 Conclusions

The following was concluded from the experimentation of ISF process by comparing SPIF and MPIF with GRA technique using SS430 sheet metal.

(i) The order of the most influencing factors from maximum value to minimum value in percentage contribution for getting the better output responses are shown in Table 10.

(ii) The feed, speed, lubrication, VSD and tool were the factors affecting order for the GRG. From the mean values of MPIF it is observed that the multipoint tool gives better formability which gives increased wall angle and the surface finish is also improved when compared with SPIF. It is also observed that the spring back is lesser for MPIF. The Multipoint tool creates reduced stress on the forming sheet than the single point tool due to this the spring back effect is reduced.

(iii) In MPIF Time is very much reduced since the contact surface is more compared to the SPIF which will reduce the processing time of the sheet metal.

(iv) The optimal parameters for wall angle, formability, surface roughness, time and spring back are obtained as A1B3C2D3E2, A1B1C2D2E2, A1B3C2D3E2, A1B3C3D1E3, and A1B3C1D2E1 respectively. From this it can be noticed that from all the optimal parameters obtained from the S/N ratio the multipoint tool (A1) is showing better outcome comparative to the single point tool. Therefore, this shows that multipoint tool gives better output than single point tool.

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