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Formability Analysis in Incremental Sheet Forming Of Aluminium Alloy

Sagar Khairnar[1], Rahul Shelke[2]
[1,2] Department of Mechanical Engineering, Everest Educational Society`s Group of Institutions, College of Engineering & Technology, Aurangabad (Maharashtra)

***Abstract*: Non-corrosiveness and lightweight are the characteristics of aluminium due to which it is finding wider application in industries. However, forming aluminium sheet is difficult as compared to steel. Thus, emerging methods like incremental sheet forming in which formability is higher as compared to conventional method must be used for the purpose. In the current experimental work, effect of four forming parameters namely step size, wall angle, feed rate and rotational spindle speed is analysed n formability of aluminium alloy AA1100. The L9 orthogonal array is used to design the experiments. It was found that, formability is mainly affected by the wall angle. Lower feed rates are advisable for higher formability. The different modes of cracking revealed that the formability in the process is limited by necking as well as through thickness shear in the component which is due to serrated strain path resulting from cyclic plastic deformation.**
***Keywords*: Incremental sheet forming, Formability, Feed rate, Taguchi experiment design, Aluminum.**

I. INTRODUCTION

Sheet metal forming is one of the most extensively used manufacturing processes for the fabrication of a variety of products in many industries. The conventional sheet metal forming process need part dependent tooling, which costs in terms of time and money. Due to these factors, along with increasing variants, variety in the sheet metal fabrication, forming processes with high flexibility are being developed. The incremental sheet forming (ISF) is one of the emerging flexible forming technologies in the sheet metal engineering. The process setup is very simple. The forming tool is a rod with a spherical end. The sheet is mounted in a rig which allows forming of the sheet into the cavity of the rig. Below the sheet a supportive backing plate can be used to get a clear definition of the transition between the flange part and the formed part. SPIF is also called a die-less forming process since all information about the geometry comes from the path of the forming tool. In other words, no dedicated dies are being used. The tool path is controlled generally by a CNC machine and the tool imposes a series of local deformation on sheet. It is the result of these small deformations that a sheet is completely formed to required shape.

Kim and Park [1] performed a series of experimentation with this process and claimed that the formability is affected by the process parameters such as: by increasing the tool diameter, pitch and feed rate, the formability of metal decreases. Awankar et al. [2&3] claim that wall angle below 20° is not possible to form with single pass incremental forming for Aluminium AA1100. Multi-pass forming may be useful for that. The authors found that, at ends of sheet i.e. at upper and lower part the sheet thickness is higher as compared to the central region in formed part. This is due to the biaxial stretching mechanism at central region in contrast with uniaxial stretching at the ends of the sheet.

In SPIF the mode of deformation has come under heavy discussion and different authors have different opinions with some authors have the opinion that deformation occurs through shearing whereas others think it's due to stretching. G. Hussain, L. Gao [4] studied the formability and found that the FLC in ISF is significantly higher than FLC in conventional sheet metal forming processes (*e.g.* Stamping) by an approximation of 2.7 times. This is increase in formability is due to large amount of through thickness shear or due to serrated strain path resulting from cyclic plastic deformation.

V. Mugendiran, A. Gnanavelbabu [5] found that formability at smooth radius is higher than at sharp corners. Curved tool path is preferable for surface finish than straight path. Restrictions to tool path reduces flow of material thus decreasing the formability. Cone has higher forming limit than square pyramid.

In the present work effect of four forming parameters namely Step size, Wall angle, Feed rate and spindle speed is tested on formability of Aluminium AA1100 sheets in ISF process.

II. MATERIAL & METHOD

A. Material

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The aluminium material is finding wider applications in automotive industries due to its lightweight characteristics and as it is a non-corrosive metal. The forming force required for aluminium is less as compared to the steel. Thus, ISF finds greater application with aluminium material. The material used for the experimentation is Aluminium sheet AA1100 grade. This alloy is commercially pure aluminium with excellent forming characteristics. It is ideally suitable for cold working. It is commonly used in heat exchanger fins, sheet metal works, decorative parts, hollowware, name plates, architectural flashing lightly stressed panels, chemical handling equipment etc.

The physical properties of the material are density 2710 Kg/m3 yield strength 105 MPa, Young's modulus 70 GPa, tensile strength 110 MPa and 12% minimum elongation. This alloy contains minimum 99% of Aluminium, maximum 0.1% of Zinc, 0.05-0.2% Copper, 0.05% of Manganese Silicon. [6]

B. Parameters & Setup

The experiments are performed on CNC SURYA VF machine. A hemispherical tool with 10 mm diameter is chosen for the purpose. This kind of tool is easy to manufacture and the cost is also low. The geometry chosen for forming during this study is a truncated cone with base diameter 100 mm. The programing codes were generated for the Fanuc Oi Mate controller by using manufacturing module of UG-NX 7.5 and specially prepared post-processor according to requirements of the controller. The programming tool path used is of spiral shape. The 'Contour Mill' strategy was used during programming.

The parameters chosen for the study are step size, wall angle, feed rate and rotational spindle speed. Levels of the control factor are decided on the basis of literature review, CNC machine tool specifications and expert advice.

C. Experiment Design

Design of Experiments (DOE) techniques enables designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. DOE also provides a full insight of interaction between design elements; therefore, it helps turn any standard design into a robust one. Simply put, DOE helps to pin point the sensitive parts and sensitive areas in designs that cause problems in yield. Designers are then able to fix these problems and produce robust and higher yield designs prior going into production.

The L9 orthogonal array is used to design the experiments in this study so that total number of experiments needs to be performed will be reduced. The L9 orthogonal is chosen as in this study effect of four parameters with three level each need to be studied. Table I illustrates the experiment design with factor levels.

TABLE I
EXPERIMENTATION PLAN

Experiment	Step Size (mm)	Wall Angle (degrees)	Feed Rate (mm/min)	Rotational Speed (RPM)
I	0.1	65	500	100
II	0.1	55	1500	1000
III	0.1	45	2500	2000
IV	1.0	65	1500	2000
V	1.0	55	2500	100
VI	1.0	45	500	1000
VII	2.0	65	2500	1000
VIII	2.0	55	500	2000
IX	2.0	45	1500	100

III.RESULTS & DISCUSSION

In this section the results of experimentation carried out are discussed in detail. Aluminium being a difficult method to form, the sheets were cracked before reaching the desired depth. In the beginning of the forming process the distribution of tensile stresses is homogeneous all over the workpiece. However, after deformation large amount of strains might gather in small area thus reducing cross sectional area. This thinning phenomenon is called as Necking. The reason for necking is due to the fact that all real materials are imperfect, in the sense that they have small local variations in dimensions and composition, which lead to local fluctuations in

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stresses and strains. The type of crack generated is a measure of process characterization.

The sheet depths were measured using video measuring machine. The depth achieved before crack is initiated is listed in Table II. It is seen that sheets with same geometry cracked at different depths and with different modes of cracking, indicating ISF being very sensitive process.

TABLE III
SHEET DEPTH

Experiment	Depth (mm)
I	6.861
II	8.051
III	7.520
IV	7.853
V	7.739
VI	12.139
VII	4.012
VIII	10.794
IX	10.399

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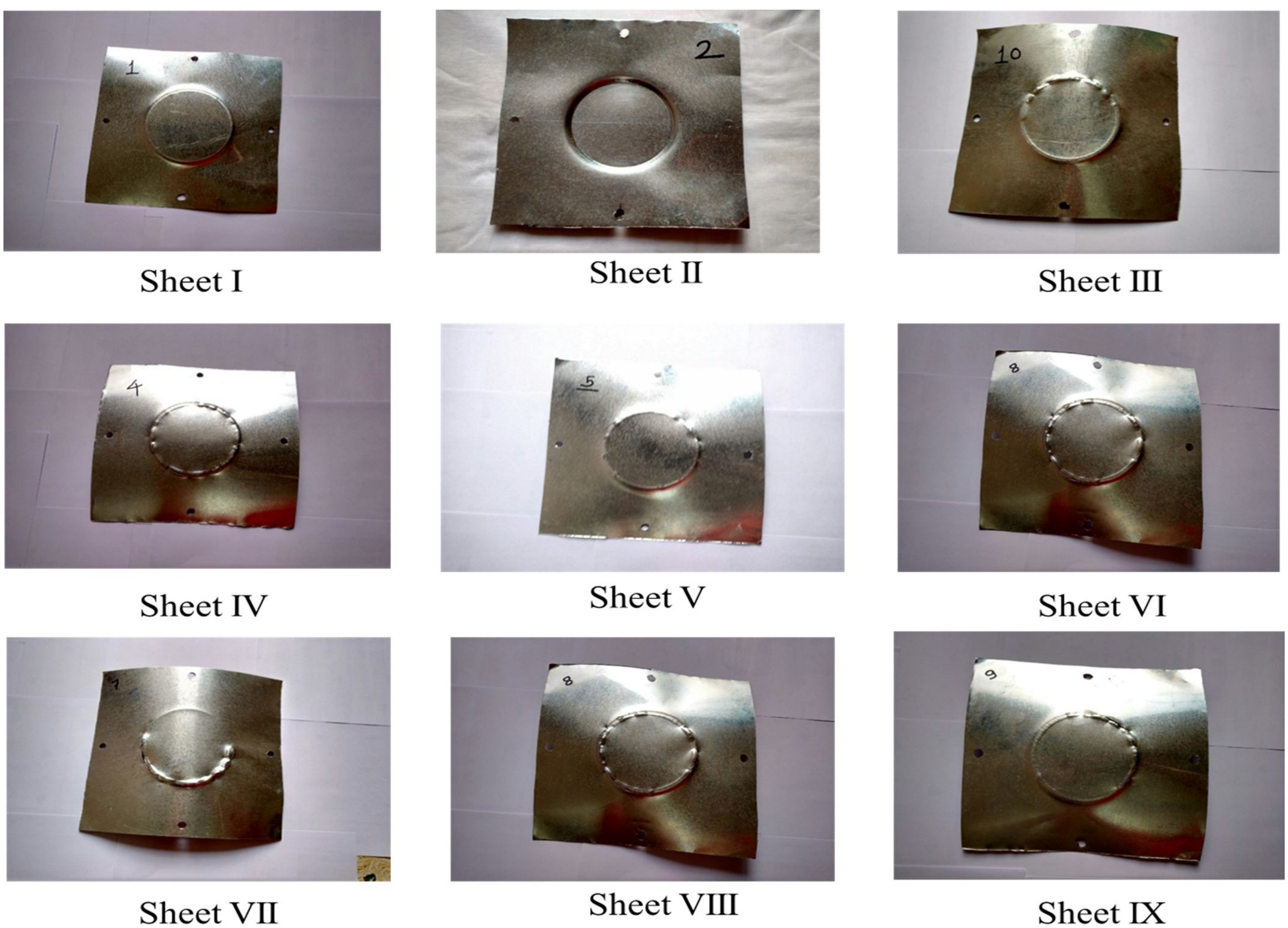

Fig. 1 Crack generated in the sheets

Refer fig. 1, a short transverse crack is visible in sheet I, which is circumferentially straight. A similar crack is observed in case of sheet II also. However, the crack in sheet II is initiated later than that of sheet I. In case of sheet III, the bottom is nearly torn off from all the sides with no wall forming. This kind of failure occurs when the forming tool is acting as a cutter. In general, stamping the remedy is to reduce the blank holder force or to increase the die entry radius. In incremental sheet forming, the bolt holding tension can be considered as equivalent to blank holding force (BHF). Thus, we can conclude that, the holding tension value is inappropriate for given process parameters.

In sheet IV, the crack is propagated in circumferential zig-zag manner. This may be explained as presence of foreign bodies in the sheet which causes thicker nodules to get pressed while forming thus disturbance is caused to flow stress resulting in this type of crack propagation. In sheet V, only a short wall stub is formed of the height of die edge curvature, the bottom started to tear off. Sheet VI is formed to considerable depth and then a crack is initiated at bottom flat of the sheet. There are two probable reasons for this. The first one is related to non-forming parameter of CNC program, the rate of tool penetration, if the rate is too high it will result in this type of crack. The reason which won't be applicable in this case is worn out die radius. Too high rate of penetration, i.e. tool lowering down at higher speed will cause localized deformation resulting in crack initiation.

Sheet VII is cracked prior to forming, this is due to non-suitable tool radius in context of the forming parameters. In case of sheet VIII, the crack observed in circumferential zig-zag in nature along with frayed wall edge and flattened wrinkles. The reason should be high value of through thickness shear stress resulting in such failure type. In sheet IX, the crack is initiated at bottom corner. Some bulging of bottom flat cab also be identified. This might be result of a localized pinch of sheet with tool.

The effect of individual factor was analysed using ANOVA. The fig. 2 shows the factor effect plot for sheet depth. It can be seen that the wall angle is the most prominent factor affecting the depth value, followed by feed rate. These two factors put together influence 88% of results. The other two factors viz. step size and rotational speed are not so dominant with their percentage contribution of 8% and 5% respectively.

As evident from the graph, wall angle is the most dominant factor affecting the depth, with increase in wall angle, the depth decreases. Decreasing feed helps achieving the larger depth. With increase in feed rate the depth tends to decrease, i.e. formability decreases. The effect of step size is not being linear, higher depth can be achieved with step value, 1.0 mm but a decrease is observed at end values which are and 2.0 and 0.1 mm. Similar is the case with rotational spindle speed, except middle value being inferior than end levels. Thus, we can say that effect of step size and rotational spindle speed may not be clear from the performed experiments.

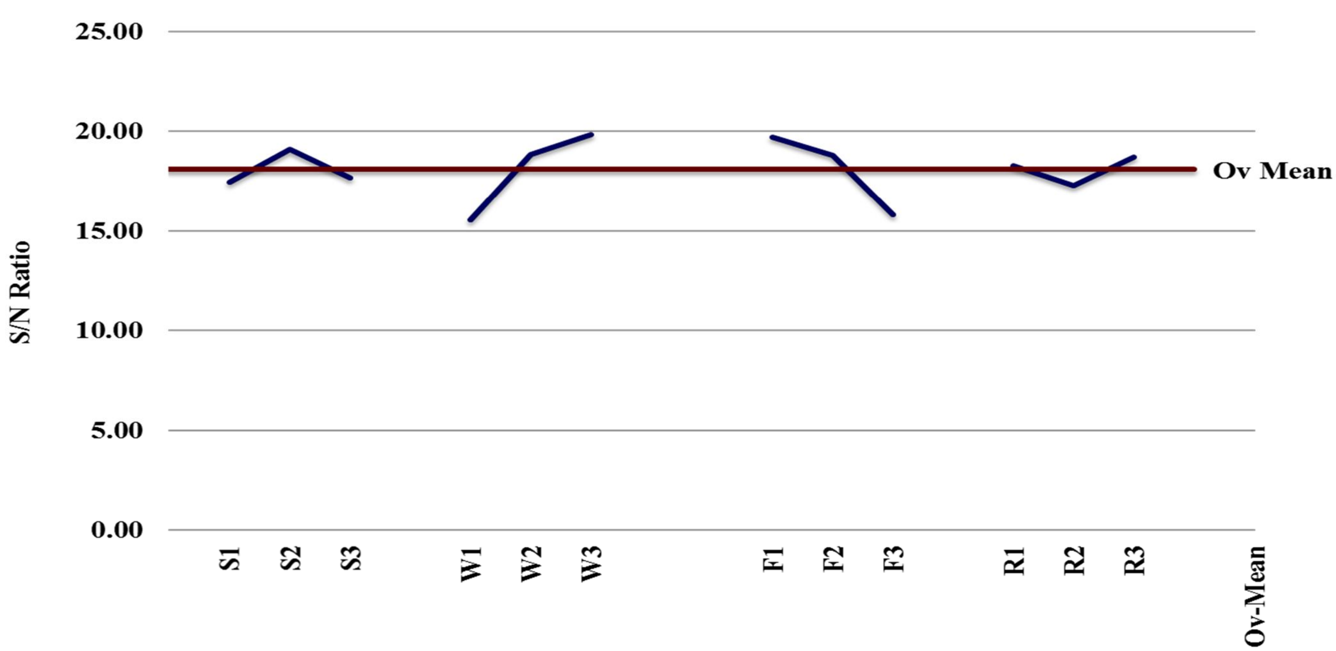

Fig. 2 Factor effect plot for formability of aluminium alloy

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IV. CONCLUSIONS

A. Following major conclusions can be drawn from current research work

1) The formability is mainly affected by the wall angle i.e. part geometry. Thus, designer should take proper care while designing a part for ISF process. Steep angles should be avoided as much as possible.
2) Lower feed rates are advisable for higher formability. This is due to a material property strain rate sensitivity. Which states that the stress strain curve of a material is not constant but changes with the rate of application of strain.
3) The different modes of cracking revealed that the formability in the process is limited by necking as well as through thickness shear in the component which is due to serrated strain path resulting from cyclic plastic deformation.
4) Too high or too low values of step size are not advisable from formability point of view.
5) For the selected range of spindle speed, formability first decreases with increase in spindle speed and after certain value it again starts increasing.

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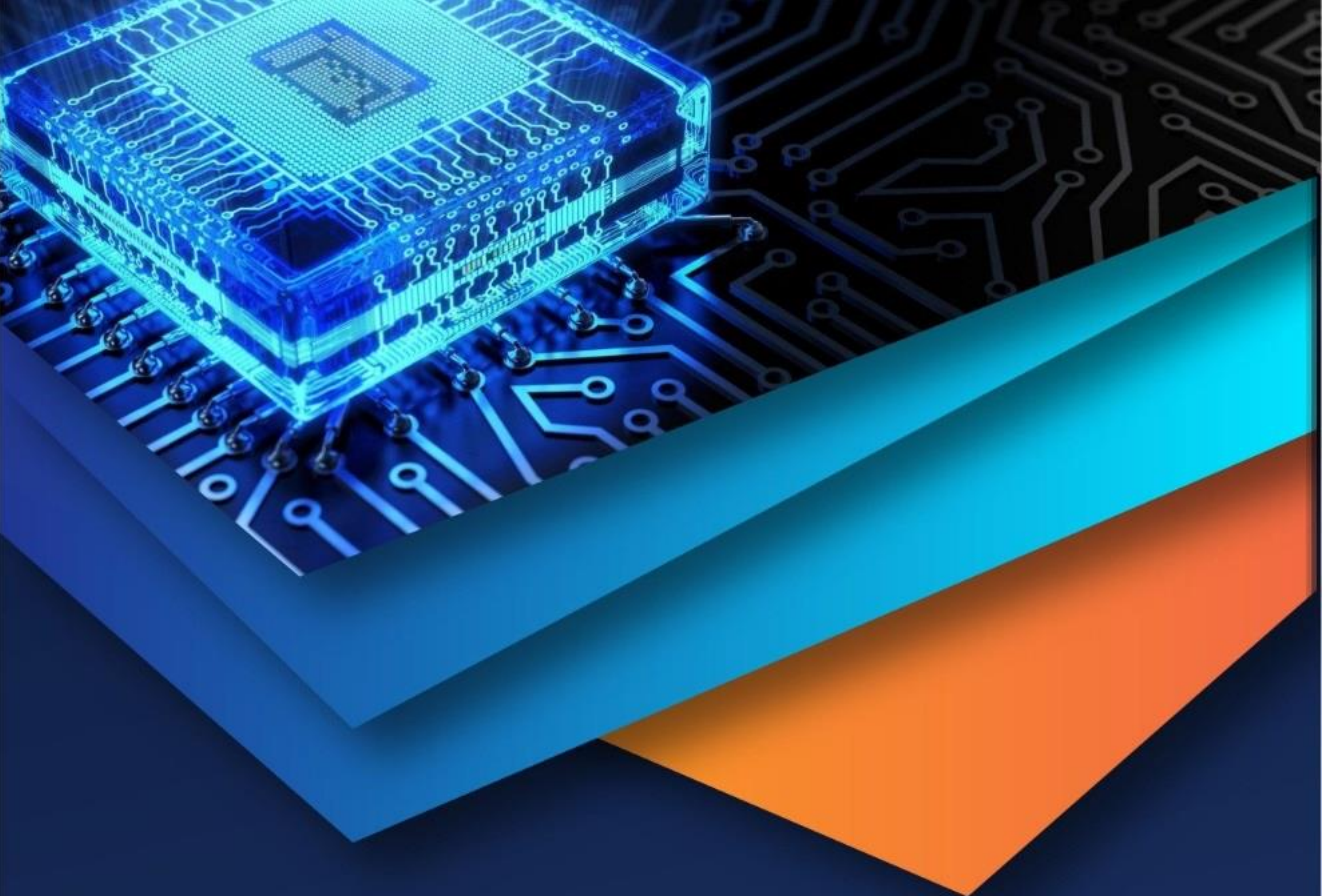

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