A Review of Process Parameters of Incremental Sheet Forming and their Effects

Gopal Jee Mishra[1],Ajay [2], Vishal Gulati[3]

[1]M.tech in Dept. of Mechanical Engineering, Guru Jambheshwar University of Science and Technology Hisar (125001), Haryana, India

[2] Associate professor Dept. Of Mechanical engineering, Shree Guru Gobind Singh Tricentenary University Gurugram (122505),Haryana,India

[2]Professor Dept. of Mechanical Engineering, Guru Jambheshwar University of Science and Technology Hisar (125001), Haryana, India

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Abstract - *Incremental sheet forming process (ISF) is a process of forming sheets to produce customized products for medical and aerospace industries without using dies. This process is based on planned tool path and forming the sheets into desired shape incrementally. This incremental nature of force leads to lesser amount of force due to local straining at point of interaction of sheet and tool. This process can be used for producing customized product of medical and aerospace industries with desired flexibility without increasing the cost of forming by programming different tool path with same tool. However the ISF is not used fully in industries due to challenges like dimensional accuracy, spring back etc. These challenges to this process are directly related to process parameters of the ISF and so the present paper aims at giving researchers a brief review about process parameters of ISF and studying their effects in process*.

Key Words: **ISF, Process parameters, Hard to deform materials, HA-ISF**

1. INTRODUCTION

Incremental sheet forming (ISF) is one of the latest technologies in sheet metal forming manufacturing processes. While conventional sheet metal forming processes require dies, punches etc. and a lot of money and time to do a slight change, the ISF provides flexibility in product design and reduces cost by elimination of dies from forming processes.

In conventional sheet metal forming processes like blanking, shearing, bending, deep drawing, stretch forming etc. a lot of time and money is consumed in making of dies and punches. Moreover in ideal time these dies and punches create inventories which make these conventional processes uneconomical whenever small batch size production is required.

Due to its low cost tooling and flexibility in product, ISF has drawn attention of research world towards it.[1]. ISF is based on localized deformation of sheet with help of a gradually advancing tool following different trajectories like constant Z level tool path, helical tool path[2] according to need. This process is die-less process. The forming tool is programmed to follow to move along a CNC controlled path to deform the sheet layer by layer in required shape.

1.1. CLASSIFICATION OF ISF

Incremental sheet forming can be classified on basis of the following parameters.

1. On the basis of **forming method** ISF is classified as follows:
   a) Single point incremental forming (SPIF)
   b) Two point incremental forming (TPIF)
   c) Hybrid forming
2. On the basis of **forming temperature** ISF is classified as follows:
   a) Room temperature
   b) Elevated temperature
3. On the basis of **forming tool** ISF is classified as follows:
   a) hemispherical end
   b) roller ball end
   c) flat end
4. on the basis of **forming machinery** ISF is classified as follows:
   a) CNC milling machine.
   b) ISF machine
   c) Robots.
5. On the basis of **forming strategy** ISF can be classified as follows:
   a) Single stage.
      a.1) profile
      a.2) helical

   b) Multistage.

In **single point incremental forming (SPIF)** local stretching of sheet is done with the help of a single point tool without use of any die. It is also called negative Incremental forming. It is truly die-less forming. In **two point incremental forming (TPIF)** the sheet is being supported by partial die or full die for producing the desired surface in sheet. **Hybrid incremental forming** is combination of asymmetric incremental forming and stretch forming.

The **ISF Process** can be performed by using two strategies as single stage and multiple stages. In single stage forming the sheet is clamped in ISF fixture and deformation is caused with the help of rigid tool moving on a particular contour till the desired product is obtained. While in multistage strategy of SPIF hemi-ellipsoidal parts are formed using two sequential stages.

ISF can be used in formation of headlight casings, automotive panels, bio medical components like ankle supports, plate prosthesis etc.

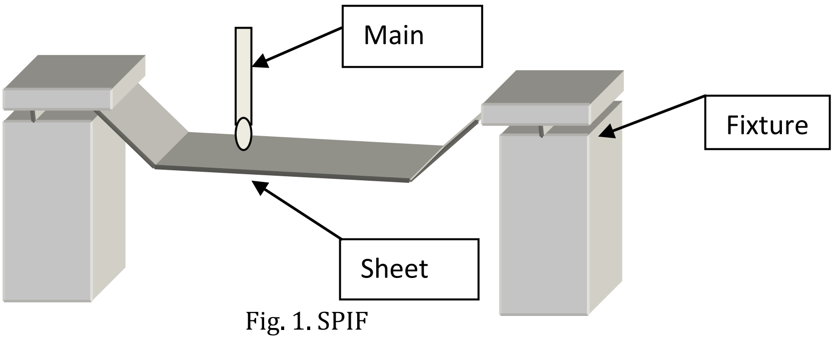

Fig. 1. SPIF

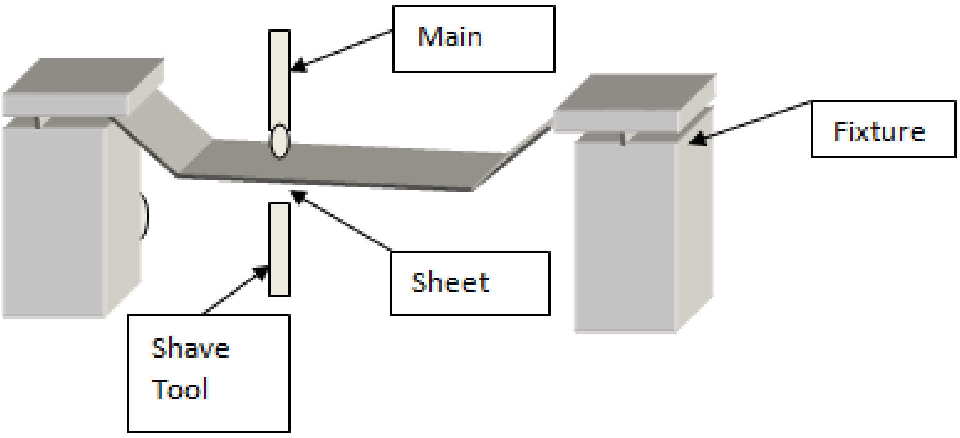

Fig. 2. TPIF (Using shave tool)

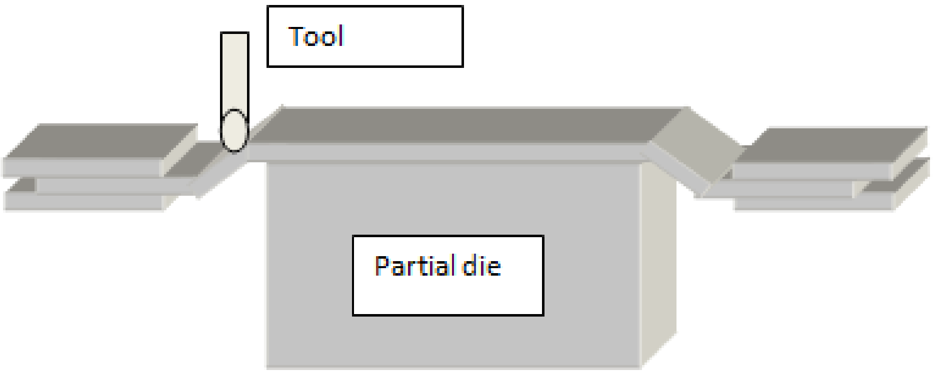

Fig. 3. TPIF (Using partial die)

2. AN OVERVIEW OF ELEVATED TEMPERATURE FORMING OR HEAT ASSISTED FORMING

From the above discussion we observe that temperature of forming is very important parameter for formability of paper. This allured several researchers to increasing the temperature by using several schemes for increasing the temperature. They increased the temperature of sheet by using halogen, oil, electricity, hot air blowers and induction etc.

On the basis of these schemes used these elevated temperature ISF are classified as shown below,

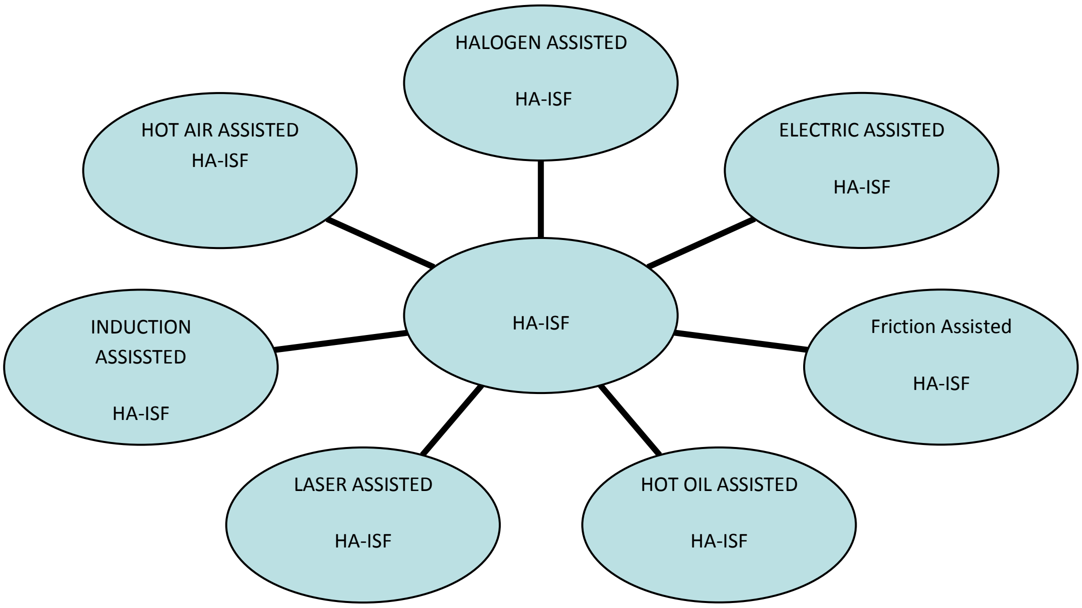

Fig.4. Classification of HA-ISF

2.1. BENEFITS OF HA-ISF

Incremental forming processes at elevated temperature are used for forming hard to form materials. Mg and Ti alloys are useful in aerospace and medical industries due to their high strength to weight ratio but they are hard to form elevated temperature forming is used for forming these materials. Increasing temperature leads to activation of more slip planes and thus formability of material is increased. Elevated temperature forming is observed to be increasing limit of forming of several alloys of magnesium, aluminum and titanium in the literature.

There are two methodologies of heating in HA-ISF, the first is local heating and second is global heating. In local heating the researchers tried to do the pointed heating at the point where the tool is contacting the sheet to be formed. And second method is global heating in which the researchers tried to increase the temperature of whole sheet by the help of some device.

2.2. LOCAL HEATING RESEARCHES AND METHODOLOGIES USED IN ELEVATED TEMPERATURE SPIF

The local heating method was use of laser assistance by Duflou et al.[17] in it laser was pointed at point of contact of tool and sheet and thus to heat the sheet material at desired temperature for forming. Kim et al.[23] also tried to heat the sheet locally with the help of moving halogen bulbs with the tool to heat the sheet material to be formed. Some authors [24,25] passed electric current through tool to locally heat the material to be deformed. These all researchers observed a common thing that is increase in formability of material and decrement in spring back of materials which are being deformed. Ambrogio et al.[26] used nitrogen cooling just after using induction assistance for heating and achieved good dimensional stability.

2.3. GLOBAL HEATING METHODOLOGIES USED IN ELEVATED TEMPERATURE SPIF

Galdos et al. [27] used heated fluid to heat the magnesium alloy AZ31B globally and formed it. They were able to achieve a temperature of 300^0 C due to properties of oil varied with increased temperature more than it. This arrangement was only limited to magnesium and aluminum alloys due to reactivity with other materials. Adams and Jeswiet [28] detected the impact of current density on SPIF. They detected that more the current density more will be the heating effect.

3. PROCESS PARAMETERS OF ISF AND THEIR EFFECT

There are several process parameters associated with ISF. Understanding of process parameters are very important to have a proper control on the process, better dimensional control and optimization of process. Following are some process parameters having considerable effect on process.

2.1. TOOL PATH

To deform the parts properly a movement of the tool on specified trajectory is very important. This trajectory is known as tool path in ISF. There are two kinds of tool paths commonly used according to the shape to be formed using ISF. First one is profile tool path and second is helical tool path [2].as the angle of deformation increase and tends to be 90^0 the straining in material approaches to infinity and fracture of material is caused. Generally aluminum and steel alloys can be deformed up to 70^0 [3].

2.2. TOOL SIZE

Kim et al.[4], in 2002 shown that the part manufactured properly with higher surface finish, tool size is a critical parameter. Ambrogio et al. [5] shown that tool size was considerably affecting the formability of part . Experiments conducted by various researcher shows that larger tool is having bigger contact zone which gives a support to sheet metal during forming. Furthermore larger tool increases the forming forces which increase the contact area between tool and the sheet metal. Fillice et al.[6] observed that smaller deformation zone is concentrated and higher strain is generated, which gives the higher formability . Kim et al. [7] observed that small tool radius forces were reduced and stresses were also decreased and this leaded to reduction in chance of failure. Less surface area of tool tip leaded to reduction in surface area of contact and concentration of force caused higher strain rates. Localized friction at tool tip leaded to local heating of sheet and thus increased formability by making strain flow easier.

In 2018 A. kumar et.al [8] had done experiments for optimization of forming forces in ISF and they observed that the size of tool is proved to be a great factor. They observed that increase in punch diameter increases forming forces due to greater contact zone but at the same time they observed the reduction in forming time. When they took tool with hemispherical end they observed decrease in forming forces due to increase in temperature due sheet tool interface has improved formability.

2.3. SHEET MATERIAL

Sheet material is proved to be very important process parameter of ISF as forming is to be done with this material. This drawn the attention of many researchers to investigate the effect of sheet material on ISF. Formability differs with the material stated by Fratini et al.[9]. Authors have tried to find out influence of material properties on formability. The formability of any material is highly influenced by strength coefficient (K) and hardening exponent (n). Higher the value of hardening coefficient higher is the formability of material.

2.4. TOOL ROTATION

Durante [10] explained that tool rotation influence the feed and feed rate in ISF. Various authors had dedicatedly done their research on the effect of tool rotation in manufacturing of sheet metal parts with higher accuracy. Kim and Park [11] explained that as the feed rate is decreased the formability is decrease. Attanasio et al. [12] observed that good results in terms of geometric accuracy and higher surface quality could be achieved by using a tool path with a feed rate depending upon geometry of part. Kim and park [12] observed that the friction at tool sheet interface improve formability. In 2018 Ajay Kumar and Vishal Gulati [13] had studied the effect of tool rotation on forming depth of conical frustums. They observed increase in formability with increase in tool rotation or spindle speed.

2.5. STEP SIZE

Step size is also a important parameter in ISF. Saad Arshad [14] had noticed that step size affect the formability. Kim [10] said that by increasing step size formability decreases. It had been also noted that the step size not only affected the outer and inner surface roughness but also had an effect on the duration of forming. Small step sizes required more time to form parts since increasingly more z-plane motions were necessary. The roughness influenced however tend to be coupled with the immediate forming angle of the particular part that was formed and also with the size of the tool .In 2018 Ajay Kumar and Vishal Gulati [15] observed the effect of step size on formability of material. They observed that formability was more at lower step size of material. As wall angle was increased they observed drastic effect of step size that is earlier fracture of sheet.

2.6. LUBRICATION

Lubrication has also effect on ISF . In 2018, by using ANOVA Ajay kumar and Vishal gulati [16] had observed an effect of 0.04% as parameter while deforming AA2024-O ALUMINIUM ALLOY sheet.

2.7. FORMING TEMPERATURE

Several researches had been carried out in recent past to detect the effect of temperature on forming. Duflou et al. [17] used a laser based heating system to do the pointed heating in the contact interface of sheet and tool. They observed decreasing trend of force with increasing temperature of sheet it means formability increased with temperature. Ji and Park [18] while doing incremental forming of magnesium sheets at heated condition. Fan et al. [19] used electric current for heating the hard to form material for doing their incremental forming. They observed that formability increased with increasing electric current used and thus increasing the heat supplied to the sheet to be formed. Liu et al. [20] also used electric assistance to form Ti6Al4V sheets to form and used noble cooling channels for maintaining dimensional stability of sheets being incrementally formed.

2.8. FORMING ANGLE

For measuring formability in SPIF forming angle is one of the parameters which have relevant effect. Ham and Jeswiet [21] experimented to find the effect of forming parameters on AA3003 aluminum compound. They observed that step size has lesser effect on maximum angle formed while tool diameter, sheet thickness and sheet material formed has considerable effect on formability of material. Bhattacharya et al. [22] observed decrease in maximum forming angle decreased with increasing tool size while forming Al5052 sheet. They also observed that step size did not have much effect on forming angle.

4. DISCUSSION AND DIRECTION OF FUTURE RESEARCH

From above discussion the tool size and temperature are observed to be most relevant factors for formability of materials. There effect has been elaborated graphically in the following articles and the effect of other parameters are tabulated below in table.1.

4.1. INFLUENCE OF TOOL SIZE

Formability of material decreased with decreasing tool size. This can be observed by following Fig drawn from data of Kumar et al. [16]. It means formability is effected greatly by the tool size and shape.

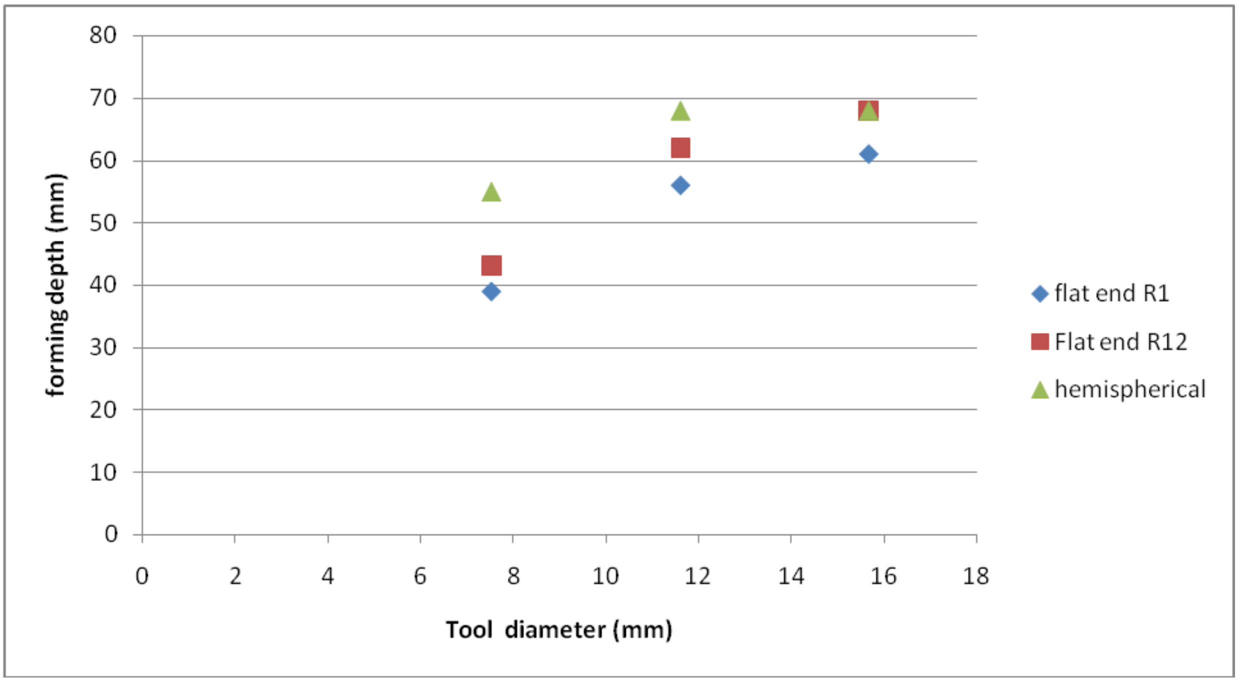

Fig.5. Variation of forming depth with tool shape and diameter

4.2. INFLUENCE OF TEMPERATURE

Formability was observed to be increased with rising temperature but dimensional inaccuracy and thermal properties change posed limitation on increasing temperature. Due to increased temperature tool life decreased and surface quality also posed a limitation on increasing temperature after a limit to increase formability of material.

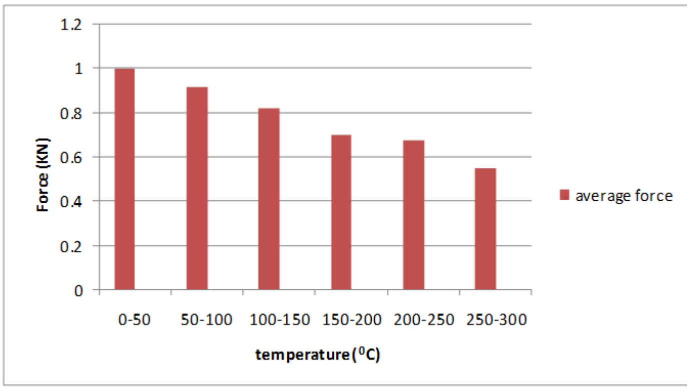

Fig.6. Variation of forming force with temperature [17]

Influence of parameters can be summarized as in following table

Table 1. Influence of Parameters

S.no.	**Process parameter**	**influence**
1.	Tool diameter	Formability increased and more forming force applied with increasing diameter[4-7]
2.	Temperature	Forming force decreased with increasing temperature[19,20]
3.	Step size	Forming force increased while forming time decreased with increasing step size.[10,14,15]
4.	Sheet material	Formability varied from material to material.[9]
5.	Tool path	Incorrect tool path step size lead to earlier fracture of sheet being formed.[2,3]

By above discussion we observe that optimization of the given parameters can be done to increase the applicability of this process in industries. This process eliminates the use of dies and hence can reduce the cost of product with desired level of flexibility.

5. POTENTIAL APPLICATIONS OF INCREMENTAL SHEET FORMING.

Aerospace industry: In aerospace industry ISF can be used to manufacture body panel, passenger sheet cover, instrument panel etc.
Automobile industry: In automobile industry ISF can be used to manufacture engine cover, door inlet outlet plate, hood etc.

Highly customized products: Ankle support, denature plate, cranial plates etc. are highly customized product can be produced by ISF.

6. CONCLUSION

Increasing tool speed with increasing sheet thickness will observe increasing formability and thus successful forming can be done by using these combinations. Formability will be decreased if step depth and wall angle will be increased simultaneously. More work is required to be done to detect the effect of these process parameters on fracture and fracture mechanisms during incremental forming are required to be detected. Forming temperature, Step size, tool size, sheet thickness and sheet material are the process parameters with considerable effect on formability of material. Very less literature was available on study of effect of lubrication because this parameter does not have any considerable effect on formability but for quality of surface of parts to be produced this becomes very relevant factor. Since elevated temperature SPIF is observed to be increasing applicability of ISF in forming of hard to deform material so more researches should be done in this direction.

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