

# *Parametric Review of Incremental Sheet Forming Process for Various Applications*

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## **Abstract**

*Incremental sheet forming is an advanced and efficient technique for performing forming operations when complex forming shapes or mass production for formed products is taken into consideration. ISF is widespread due to its flexibility in experiments and economically it is much more preferable. Unlike traditional forming methods tool in ISF is controlled numerically by CNC machines and therefore is preferred by great many industries for its applications in forming. For example, light weight alloys are used hugely in automobile industry, so it needs fast and cost efficient process to design and manufacture complex shapes like door frames and bumpers with great geometrical accuracy and good surface quality. This work presents various researches regarding experiments performed in ISF with different areas of focus such as tool geometry, sheet metal thickness, surface finish, sheet material etc. Tool geometry plays a vital role in ISF process when it comes to unusual and complex shapes and hence more and more optimization is in dire need for today's researchers. Therefore, this literature review would offer a clear idea as to how much success is achieved in ISF and how much work is yet to be done regarding optimization of tool geometries in Incremental Sheet Forming process.*

**Keywords:** - *Incremental sheet forming, tool geometry, light weight sheets, FLD (forming limit diagram), Single Point Incremental Forming (SPIF).*

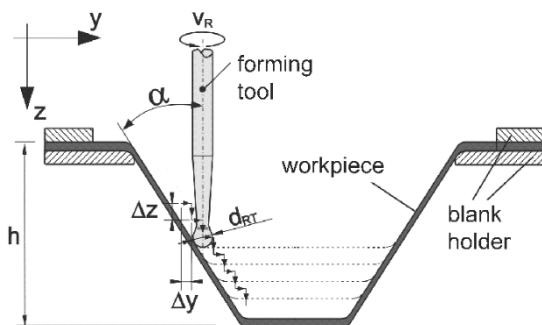
## **INTRODUCTION**

In today's fast growing industries everyone is running behind giving the best product as soon as possible. And metal forming sector is no different. Traditional sheet metal forming processes have been in implementation for a long time now but a new process has emerged in its place as the need for speed and success in complexly manufactured

formed products arose researches were conducted to invent an absolutely new way to form materials into any desired shapes regardless its complexity or material or sheet thickness. And researchers got an idea to get rid of the traditional die punch method first.

There came the idea of taking help of an automatic approach for the operations performed for formed products. And what better than computer numeric controlled (CNC) machines.

Incremental sheet forming can be done on any universal milling machine having at least 3-axis CNC control system. Thus, the basic elements of incremental forming processes are likely the material to be formed, a blankholder clamping the blank, the very simple, universal forming tool and the forming machine with the CNC control. It has been the idea of making ISF the very process which helps in small batch mass production and reduce overall cost for it. Due to the fact that this process is possible on any 3-axis CNC machine its parts can be directly produced in the CAD data filing software such as (CREO, Solidworks, ANSYS).



**Figure 1. Sheet Metal Forming (Basic diagram)**

While conventional forming technologies are more suitable for mass production, ISF is more appropriate for small scale manufacturing. It also gives a quick response for modifications compared to more traditional technique. ISF requires less complex tools: CNC machine which is nowadays available at larger scales. The tool of CNC machines is continuously in contact with the sheet surface while the sheet edges are pressed/ fixed

with a blank holder to avoid sliding or shifting of tool contact.

In past years ISF was mainly adopted by small scale productions and prototypes for automobiles industries, but at present times it has served a great application in in aerospace and biomedical industries as well.

The most important parameters involved in the forming process are: Sheet material and thickness, Tool material, shape and diameter, spindle rotation, feed rate, tool path, force applied, working temperature and lubrication.

Nature and thickness of the sheet is very affective on the process parameters: like is the sheet thickness is increased the force required for the forming of sheet increases as well and vice versa. The interaction between the tool and the sheet to be processed determines the force that has to be applied and on the basis of the friction, a suitable lubrication is needed, in order to reach a good sheet-surface finishing properties and to avoid any stress formation during the whole forming process. One of the approach which made ISF a flexible technique is due to the possibility to employ the process for different materials.

## LITERATURE SURVEY

Zinan Cheng et al., 2020 [1] have presented an overview of ISF for different kinds of materials and implants. It also presents how manufacturing has grown in decades that now even if a human body has experiences a fractured bone, new manufacturing technologies help the body with such innovative materials and complex shaped implants that it does not see any difference in an actual human part or an implant. In biomedical field it was first believed that the forming

deformation mechanism of ISF was pure stretching and the forming limit curve of ISF process was fitted based on the experiments. The main factor to be considered in implementing ISF in biomedical field is that A high geometric accuracy is essential for an eligible implant to fit properly to the original bone, which is beneficial to the recovery of the patients. But due to the complexity springback and fracture of the formed shape affected the geometric precision directly.

Felice Rubino et al., 2020 [2] and their team has thought of a different perspective in ISF integrating manufacturing combining welding and forming of aluminum sheets. SPIF process is used for friction stir welded AA6082 aluminum sheets. The welded sheets are 220 mm in length, 110 mm

in width and 2 mm in thickness. The blanks were butt-welded along the longer dimension. Several joints were produced by FSW and by tungsten inert gas (TIG) welding. The friction stir welds were performed using an HSS cylindrical tool with a shoulder diameter of 20 mm and a conical pin characterized by an angle of 15° and a height of 1.8 mm. The surfaces of the blanks were marked before the forming process, in order to evaluate the local deformation after SPIF. Performing this experiment, a maximum depth of 40mm is achieved in aluminum sheets. The results are quite surprising as they state that in good quality welds, the material failure during SPIF occurs in the base material, evidencing that the mechanical properties of the welds are equal or better than the ones of the original material.

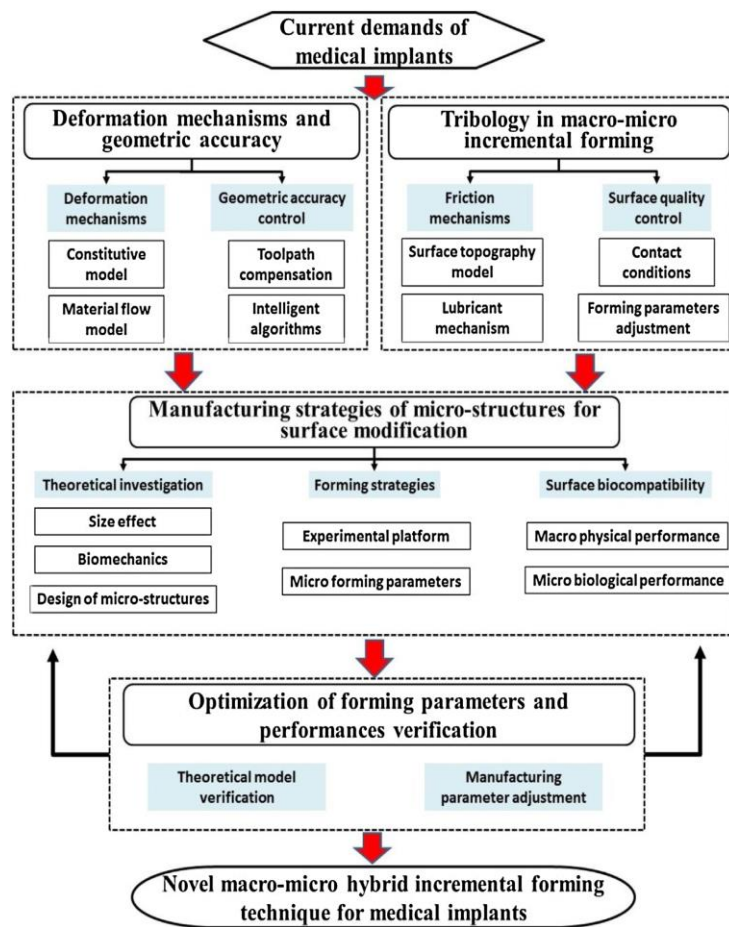


Figure 2 Manufacturing Strategies for ISF in Biomedical [1]

Tyler J Grimm et al., 2020 [3] has given a good new idea on innovating a traditional tool path and testing it experimentally through simulation to determine its viability in improving formability. The toolpath investigated travels radially through the center of the work piece, rather than along its periphery, in order to generate a more uniform thickness profile. Experimental testing of the radial toolpath is performed using 0.8 mm thick 1008 cold rolled steel sheets. Material was constrained in a circular clamping fixture with a diameter of 200 mm. Process parameter ranges were largely selected randomly for this new experiment. The step sizes selected for the radial toolpath were approximately twice and four times the baseline step size value. Rather than driving the tool tangentially with step-down or constant axial feed, the tool is instead driven in the radial direction, across the center of the work piece. An increase in formability of more than 20% over the baseline case is observed.

Sören Scheffler et al., 2019 [4] and team has put their main focus on the study will be on the chain of conceptual design, experimentation and subsequent work processes, right through to the final assembly of car exterior skin parts of a streamlined vintage concept car. Two-point incremental forming (TPIF) is selected for the respective experiment as the researchers wish to work on multiple sheets together for this conceptualized car design. The die is provided with stepped holes for clamping on the machine table and with grooves for positioning in x and y direction. Components like doors, front bonnet and flaps, front spoiler, rear bonnet and flaps, rear mudguard, side spoiler etc. After forming, the sheet is first roughly trimmed using hydraulic

guillotine shears and then finely trimmed using hand cutting equipment. The investigations showed that it is possible for the selected automotive outer skin and its layout of parts to produce a large percentage of the sheet metal forming parts using TPIF. But while outer skins are easily manufactured through TPIF it seems quite complex to manufacture the entire outer skin of the passenger car, since there are simpler and also much more cost-effective forming processes for single-curved surfaces, such as the rolling selected here.

Yanle li et al., 2019 [5] and his team of researchers have focused on selection of machine tools and process parameters which play a crucial role in energy consumption in processes like ISF. They claim that the analysis of how the process parameters influence the energy required during ISF processes will not only provide opportunity to reduce the environmental consequences, but also reduce economic cost. The main idea behind this research is that “Energy consumption is one of the key concerns in sustainable manufacturing. By using electricity, the machine tool produces carbon dioxide indirectly, which has a direct impact on the environment”. In this research the power composition during ISF process were analyzed based on the measured power curves, then the key process parameters that affect the power.

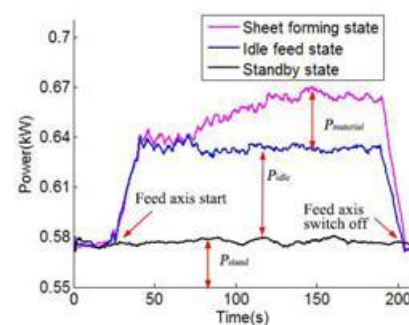


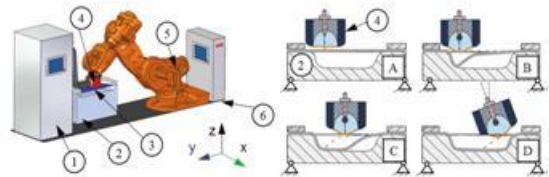
Figure 3 Process Parameters in ISF [5]

Different aluminum alloys are experimented upon and thickness of all the sheets is common (i.e. 2mm) respectively. The effects of step-down size, sheet thickness, material type, feed rate and tool diameter on the power and energy consumption are analyzed in detail. The influence of a single parameter on ISF energy consumption is obtained, which have great significance to energy saving and sustainable development. The calculated powers used for sheet deformation during the forming process increase significantly as the increase of step-down size, sheet thickness, yield strength and feed rate. But still, these variations have limited influence on the processing power consumed by the milling machine due to the large standby power.

Mats Sigvant et al., 2019 [6] has focused on surface roughness and strain rate with respect to friction in ISF process. Research states that friction conditions are dependent on fundamental factors of forming like applied sheet material, lubrication, coating and tooling material and forming process conditions. This paper presents results from studies on the influence on the sheet metal forming simulation results from stamping die surface roughness and introduction of strain rate sensitivity in the sheet material model. It is established by the author that the tool surface roughness has a significant effect on simulation accuracy.

M. Linnemann et al., 2019 [7] has presented a potential for high speed forming. For many materials they offer advantages such as low tool cost, high tool flexibility and extended forming limits at room temperature. Hence, stringent emission regulations can be fulfilled and essential resources are saved. The limited forming zone,

however, makes it impossible to achieve flexible, cost-efficient production of complex large-surface parts by high-speed forming alone. In order to overcome this problem, this paper suggests two different innovative forming parts by high-speed forming alone. It presents electrohydraulic forming and electromagnetic forming respectively.



**Figure 4 EHIF & EMIF process [7]**

In the EHIF and EMIF processes, the sheet is formed by a sequence of local deformations via either EHF or EMF. In between the individual forming steps work piece and tool are moved relatively to each other. The relative movement can be realized either via displacement of the tool or via displacement of the work piece. The tool concept also included a system for the automated positioning and relative movement between the work piece and shaping tools.

Maheshwar Dwivedy et al., 2019 [8] presents a good research on forming forces with respect to process parameters used in ISF into consideration. Researchers have taken the reference that wall angle, tool diameter and step depth significantly affect surface roughness of parts while sheet thickness and tool diameter significantly affect formability into account for this research. They observed that for a given step depth, surface roughness decreased with each increase in tool diameter and wall angle. They also reported that up to a certain critical wall angle, an increase in step depth resulted in the increase of surface roughness and this trend reversed beyond the critical wall angle. Extra Deep Drawing (EDD)

steel sheets of 250 mm X 250 mm and varying thickness were used for incremental forming on a high precision 3-axis CNC milling machine. Fixtures were mounted on the CNC machine table to hold the blank for conducting a set of SPIF experiments. The effect of five control factors like tool diameter, sheet thickness, feed, spindle speed and depth of indentation are focused in their experiments. The objective focused is to optimize any two to three of the above mentioned control factors. The influence of different process parameters on forming forces were investigated in detail by the Taguchi experimental design approach. Sheet thickness was found to be the most important process parameter that influences average radial and peak radial forming forces.

Marlon Hahn et al., 2019 [9] has focused on residual stresses that are present in the formed components which then affect the mechanical properties like ductility and toughness in the component. The main reason behind this is said to be the tool path. The influence of the tool path strategy on the resulting residual stress state is investigated for linear groove geometries manufactured from aluminum alloy 5083 sheets. Unidirectional and bidirectional tool path strategies were used for that. A numerical model was used to assess the forming mechanisms during the forming process. Basically, the influence of the tool path strategy for more complex shaped parts on the forming mechanisms located in several different measuring points is investigated.

Hongyu Wei et al., 2019 [10] has highlighted low precision problem in his research. The main reason for the lack of precision observed by the researcher is springback effect in the material after the forming experiment. The researcher has preferred

numerical analysis and has tried to increase the precision for the formed shape. A problem of insufficient stiffness of the forming tool the work piece is deviated from its position. But due to this incident in the experiment it gets clear that precision is not at all dependent on springback effect moreover it is established that forming angle is inversely proportional to the springback effect (i.e. larger the forming angle the lesser will be the springback effect).

Peter Ildiko et al., 2019 [11] and team has researched upon different materials other than aluminum like low carbon steel and pure titanium alloy. The material has been rolled into sheet form by the researcher itself. A lubrication of water-oil suspension has been implemented. Researcher has cut the sheet deformed into parts to study the microstructure of the formed cross section of the sheet. Granular layer has been observed among both the sheets formed. After the analysis it has been observed and noted that steel has better formability compared to other materials used in the process. In case of titanium alloy if the desired shape is small then only ISF is considered a good option.

Rajiv Malhotra et al., 2018 [12] has observed how incremental depth, metal thickness and polymer thickness affect formability and failure information based on a real time basis and, necessarily, much more efficient. In this context, capacity optimization modes during SPIF of adhesively bonded metal-polymer laminate sheets. An SPIF setup with a forming area of 130 x 130 mm was assembled on a CNC machine. This setup included the clamped metal-polymer laminate, the clamping fixture and a 5 mm diameter forming tool mounted on the CNC tool

holder. To investigate the effect of polymer and metal sheet thickness, two different aluminum sheet thicknesses (0.8 mm and 1.0 mm) and five different polyamide sheet thicknesses (0.79, 1.19, 1.58, 1.98 and 2.38 mm) were used to make the laminates. Failures like delamination of metal-polymer layers and wear and tear of aluminum sheet along the edge's direction is observed through the experiment.

Xiaobing Dang et al., 2018 [13] says that for thin and small sheet metal, incremental forming can be used. But for thick and large sheet metal, it is not applicable and thus they present a new flexible sheet metal forming method of incremental bending based on minimum energy principle. In the presented method, sheet metal is formed by continuous bending operations. A kind of variable curvature sheet metal has been formed. Incremental bending is highly focused in this research.

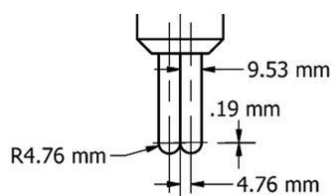
Xiaoqiang Li et al., 2017 [14] has investigated the influence of process parameters on surface roughness and a good research has been done into improving surface quality of the formed components. In order to obtain the surface quality of the work piece a surface roughness tester is used. The result states that the decrease in step depth increases the processing time in spite of improving surface quality efficiently.

William L Edwards et al., 2017 [15] has dedicated this research to reducing springback effect after removing fixture from the formed shape. Parameters like rotational spindle speeds and feed rate are more focused in this research. The material used here is polycarbonate which is a thermoplastic. Thermoplastics are widely used in automobile and aerospace industries. Researcher

has denoted that the formability resulting from SPIF of several different polymers is mainly related to sheet thickness, tool diameter, and the ductility of the material. This study shows that increasing initial drawing angle and increasing thickness of the test specimen both lead to an increase in springback. A tool was chosen for testing that would maximize the heating effects of the spindle rotation. In order to achieve this, a long tool was constructed. This allowed the heat generated from frictional forces to remain largely in the tool tip, rather than being sunk away from the tip by the tool holder, as seen when using a short tool. Author has conducted the necessary experiment and proven that springback is not responsible from spindle speed or feed rate rather if the step size is increased the springback effect can be reduced.

Daniel Afonso et al., 2017 [16] and his team has explored the possibility of implementing ISF in tunnel type parts formation. They have desired the process to increase the flexibility of the formed components in shape of tunnel and also reducing the need of post processing operations and also reduce material waste. Researcher has got the vision of implementing ISF in forming tunneling parts from the fact that forming usually produces container like products. Experiments are performed by forming a straight tunnel with a frustum geometry. A 2mm thick aluminum sheet is used with a 10mm spherical tip tool and a feed rate of 1500mm/min. Researcher has performed each test until the failure point. The results of the experiments show a reduced forming limit and a low accuracy as the tunnel shape is complex to form, but still concludes that forming a sheet into tunnel type parts is possible through SPIF process.

Tyler J Grimm et al., 2017 [17] has focused on reducing forming operation by providing a unique tool geometry designed by the researchers which suggests tool to form the sheet material in multiple directions. The work done by the researcher indicates that a more complex tool tip can give more formability, better surface finish and reduced spring back effect. As the tool is of complex geometry the spindle is rotated at around 300-6000RPM. The researcher has taken the advantage of such high spindle speed as this much speed creates more friction between the tool tip and sheet metal and thus heat is generated on the sheet surface. The complex tool geometry was observed to form a reactive shape formation as the tool created a rotational impression on the sheet while forming it in desired shape. The idea of such a complicated tool tip seemed very promising at first but after the experiment conducted by the researcher it was clear that a tool geometry like this cannot be commercially or industrially used.



**Figure 5 Innovative tool design [17]**

Hardik S Beravala et al., 2015 [18] has made SPIF on material AL 19000 aluminum alloy the main area of research here. Researcher has developed their own setup design and fabrication of sheet metal holding fixture and ISF tool. They have developed a fixture to hold 150mm×150mm size of sheet metal. The tool designed by the researcher is very commonly used (i.e. hemispherical) and the material used here is stainless steel 304 and the tool tip diameter is 14mm. A 0.9mm thick aluminum alloy AL 19000 sheet is used. The

desired shape selected here is a combination of square and spherical shapes. Various dimensional errors, surface roughness, and thickness distribution is measured and analyzed on the formed component for selective machine parameters.

D.S. Malvad et al., 2014 [19] has performed experiments on AA8011 to analyze effect of wall angle and tool diameter on formed product. All the parts are formed into cone shape with a diameter of around 95mm and the researcher has designed multi-angled tests to evaluate maximum forming angles and depth for the respective material. In this experiment it is found that tool size affects not only formability but also the surface finish of the formed product.

Cawley. B. et al., 2013 [20] has done a good work in examining the tool mostly used in incremental sheet metal forming process. The objective of this research is much more similar to this research and is mainly focused on tool geometries like hemispherical, flat-bottomed and parabolic tool geometries. Aluminum (AL 3003) of sheet thickness of approximately 1.6mm is taken into experimentation for all the tool geometries and a conical frustum is desired shape in this operation to determine the failure points of all the tools and to compare them in the post-experiment analysis. The variable wall angle conical frustum test is performed by the researcher to determine the maximum wall angle as the sheet gets thinner with the progressing experiment and until the part is formed and fractured. Some minor errors like starting point of the tool on the work piece is also taken into consideration and in addition to forming limits recorded, several other phenomena are also

observed which are related to tool shape in any way possible.

M. Tisza. 2012. [21] has proposed an overview over the basic idea of incremental sheet forming. The elaborative classification of ISF on the basis of forming method, part geometry, forming path and tool path geometry, applied tools, etc. The most usual classification is given on the basis of forming method and according to it ISF can be distinguished as single point, two point or hybrid process. He states the single point incremental forming is one of the most researched upon and used method among all the various classified approaches because SPIF can be done without any die and using a single tool as shown in figure above. The research also touches some aspects on the formability issues highlighting the forming limit diagrams regarding different materials which claims that FLD plays an important role in ISF operations. Some basic details regarding ISF has been the area of focus in research paper.

V. Franzen et al., 2008 [22] have focused forming specifically SPIF in manufacturing polymer sheets. It was a basic idea to perform SPIF on polymer sheets and thus many different polymer materials like polyoxymethylene (POM), polyethylene (PE), polyamide (PA), polyvinyl chloride (PVC), polycarbonate (PC). Thickness of all the different materials is 2-3mm. The main motto behind these experiments is said here to eliminate the fact that sheet thickness plays a vital role in forming process. Alongside sheet thickness diameter of single point forming tool and feed rate are worked upon as well considering ISF on polymer sheets a better chance compared to metals. Even when polymers are used in ISF uneven surface defect as

wrinkles are observed where maximum force is applied (i.e. maximum change in formation).

Amit Kumar Gupta et al., 2006 [23] has come up with an idea of galvanizing the steel sheets before performing any forming operation on it and thus different levels (thickness) of zinc layers' form on it. The researcher considers multiple sheets of different galvanized layers on it and an uncoated sheet for reference. There are many observations one can make from the researcher's experiment like: as the coating thickness increases the strain limits also increases, in short the formability has no dramatic change regardless the coating on it but some materials like stainless steel and aluminum show good and higher formability ranges on FLD but do not stand up to the mark in actual experiment.

Vincent J. Vohnout et al., 2005 [24] focuses mainly on the increment of formability of metal sheets by using high velocity deformation and in the process a chance to observe a decrease in distortion in forming operation conducted. The material he chose is steel and he made the plate electromagnetic by applying eddy's current rule and then with high velocity struck it on the die expecting greater impact on the desired shape of the finished formed product, but instead the high velocity (around 220m/s) was too much impact force for the material and the result was cracks and distortions in the sheet. The experiment shows that the velocity of the tool impact on the work piece has no relation to the surface finish desired from the idea instead tool geometry plays a much bigger role in the process whether we struck it with force or not is secondary.

M. Kleiner et al., 2003. [25] have given much importance to manufacturing light weight components by metal forming. The area of focus here is in automobile and aerospace sectors as both of them require light weight components to be manufactured. The researcher has emphasized the fact that in case the acceleration is needed to be increased the mass of the components need to be light weight and ISF focuses on producing exactly those components. He has come across some major issues like when we use high strength low ductile materials (which are generally used in automobiles) the material distribution problem was common in forming operation in it and to overcome these problems the researcher proposed some points to focus and improve like: forming at elevated temperature, ISF, superplastic forming, thixoforming. His experiment focuses on bumper beam of the car of material stainless steel AISI301. He has also implemented stainless steel in fuel tank's material instead of plastic and has achieved great results by reducing the tank wall thickness. He has tried aluminum for fuel tank material but while forming the strain increases in the thinner faces of the wall and cracks develop easily in the wall surface. Comparing both the materials stainless steel has good benefits when placed it for fuel tank material applications.

#### LITERATURE REVIEW FINDINGS

1. Incremental sheet forming has provided a great number of industrial applications such as automobile industry, aerospace industry, biomedical industry, etc.
2. Materials like aluminium alloys, steel and stainless steel alloys, copper alloys, polymers, etc. have caught attention for a lot of researchers.
3. Despite multiple tool geometries like spherical, flat-bottomed, parabolic, etc. available in ISF field, commercial use is maximized by spherical tool geometry because it can perform really good in several complex shapes easily.
4. Optimization for other tool geometries has lacked in research throughout the ISF sector.
5. Sheet thickness which plays an important role in formability of the material has not been that much worked upon in metals other than aluminium alloys.

#### CONCLUSION

Incremental sheet forming has been around for decades now and is still evolving with new and new techniques being implemented in it all the time. Researchers have explored most of the corners in ISF regarding tool geometries, sheet material and thickness, tool material, tool geometry and its tool path, forming forces, formability of the material, etc. ISF is constantly finding its way to contributing in different fields of industries constantly but still some errors are faced by researchers till now like springback effect, uneven thickness distribution, energy consumption, complexity of shape requirement, etc. These are the problems detected while we have almost explored everything about ISF, which means that a new process is well established now the thing that is left for researchers to do in ISF is optimize this process in errors like springback effect, surface roughness, variability in sheet metal thickness etc. This can lead to great future work for researchers.

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