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# EFFECT OF PROCESS PARAMETERS DURING HOT INCREMENTAL SHEET FORMING ON HARD TO FORM MATERIALS: A REVIEW

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***Abstract*** **:** Incremental sheet forming is a new production technique, where a piece of sheet is shaped through a series of small incremental localized deformations. Single point incremental forming (SPIF) has better formability limits than different sheet metal forming approaches such as stamping, drawing, etc. Traditional forming processes need expensive die. This increases the cost of the product so it can be eliminated by the use of single point incremental. The researcher develops new Hot single point incremental forming. by this method materials that have poor ductility at room temperature are also formable. Additional heat increases the formability of the material and gives us better accuracy and required geometry. this paper aims to review the paper related to Hot single point incremental forming and give overall knowledge about the Hot SPIF and its types.
**Keywords:** Single point incremental forming, Hot forming, formability, CNC machine, process parameter

## I. INTRODUCTION

A sheet metal component, often made by the form and dimensions of the component, is formed using dies and punching. This typical approach is suitable for mass production because a large number of products share the cost of dies and punches.[1]

Incremental sheet forming is a process in which the deformation is done in steps. When the single point tool is used in the incremental forming process that's called single point incremental forming.

The technique of conversion of a flat sheet of metal into a contoured final geometry using one deformation point is a single point incremental forming (SPIF). It makes it possible to shape a sheet metal in three dimensions without a high-cost die. This property of die-less formation can lower the costs of small lots and prototypes drastically.[2]

Using a Numerical Control (NC) machine and a part program, incremental forming is a die-less sheet metal forming method.[3] The cumulative impact of the local deformations generated on sheet metal leads to the desired final shape.[3] SPIF provides higher process flexibility and substantial potential to reduce costs for die fabrication in prototypes and low volume production since the tooling is different from traditional forming.[3]When compared to standard sheet metal forming, the incremental forming technique provides a higher formability limit.[3]

Computer numerical control machines are used for the SPIF. The CAD model of the required part geometry is prepared and according to it, the part program is obtained. That part program is fed into the CNC machine and the tool is moved according to the part program. We get the required geometry at the end.

Different parameters related to Single point incremental forming is spindle speed, sheet thickness, tool size, tool shape, type of lubricant, working temperature, step size, etc. which affect the different way in the process.

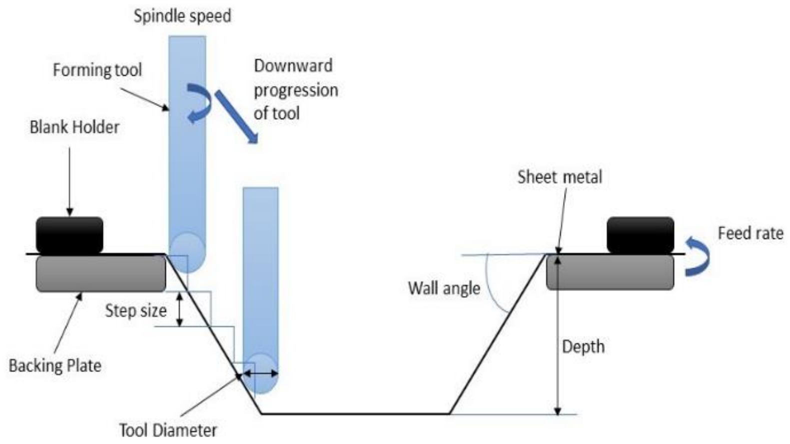
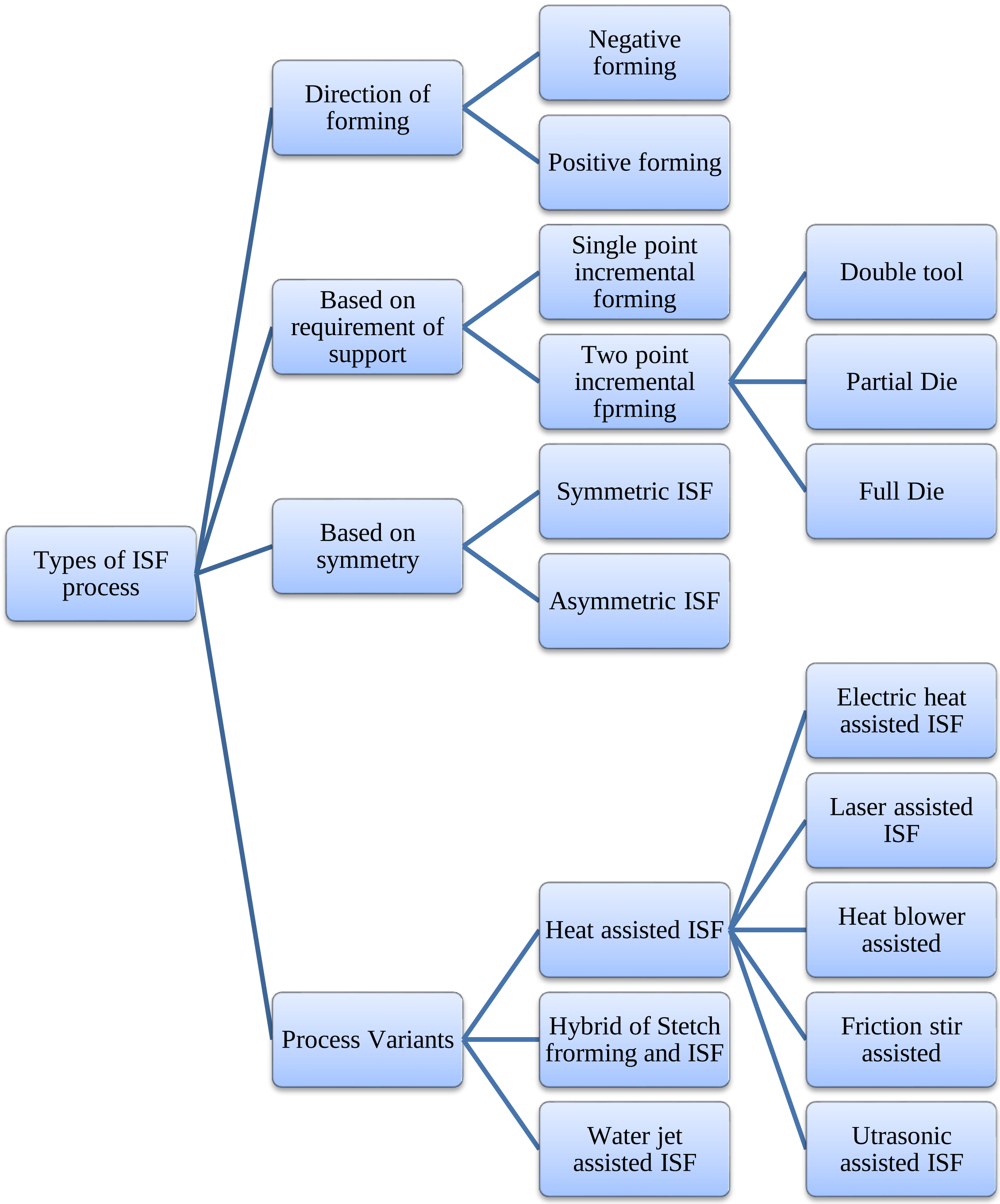



Fig 1. Principle of single point incremental forming

**Types of incremental sheet forming** [4]

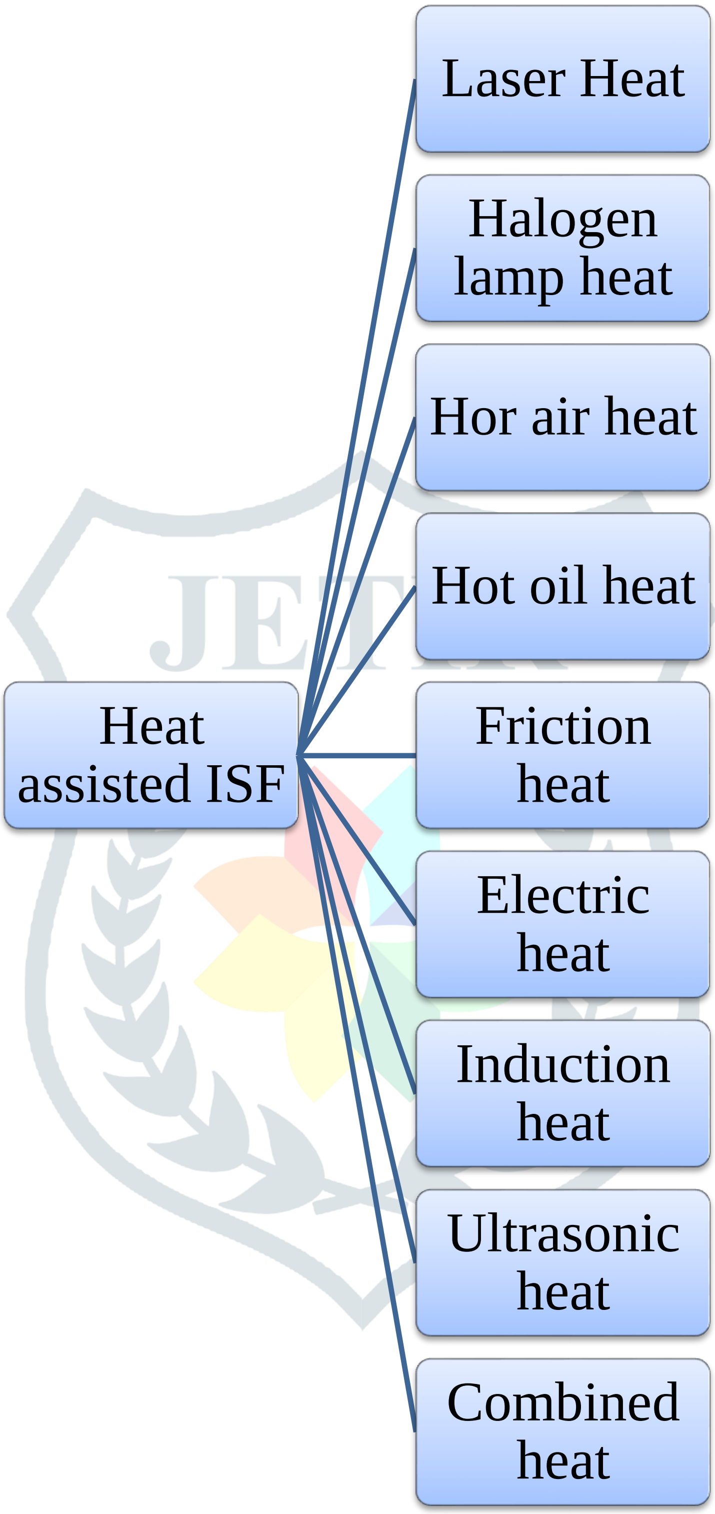



In this paper, we focus on the Heat assisted ISF. Heat assisted incremental forming process is an incremental sheet metal forming method in which heat is involved.

Heat Assisted ISF can increase processing formability and reduce spring back as well as the force forming when processing hard-to-form materials compared with Conventional ISF performed at room temperatures.[5]

Different types of heat-assisted Incremental sheet forming According to the source of heating is given below.

**Types of heat-assisted incremental sheet forming according to the source of heating**



1. In a laser heating system laser beam is used to heat the sheet. It has certain advantages like controlled heat and concentration of heat at a particular small place.

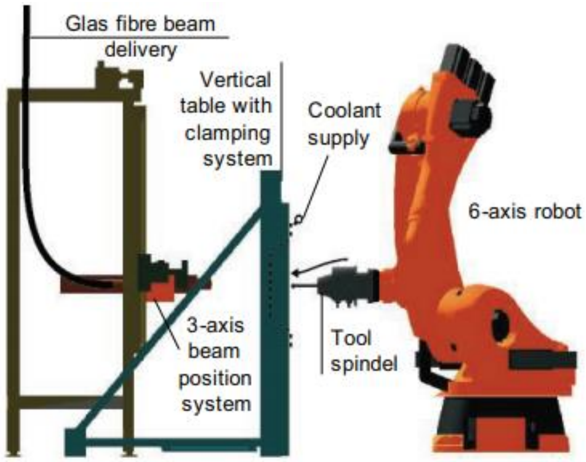



Fig 2 SPIF with Laser heating[6]

2. In the halogen lamp heat system, the halogen lamp is used to heat the sheet.

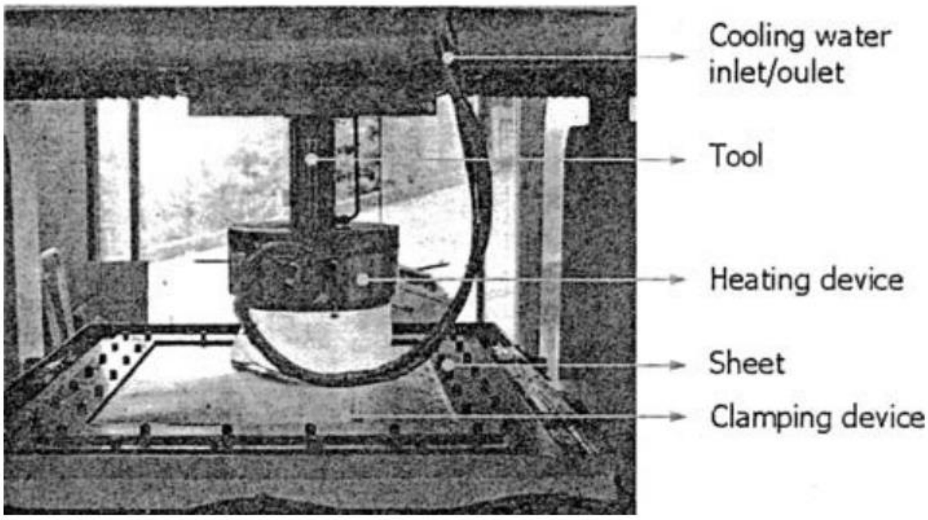



Fig 3 SPIF with halogen lamp heating[7]

3. In a hot air heat system, a hot air blower is used which gives uniform heating of sheet.

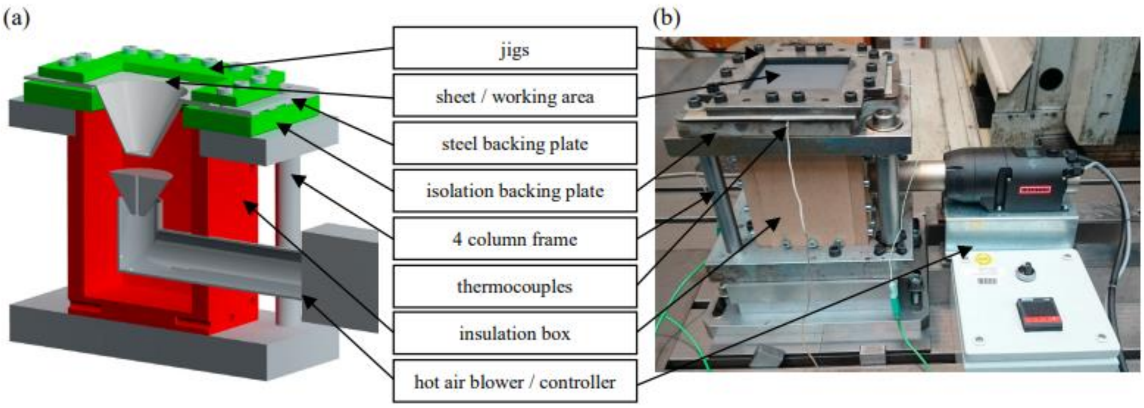



Fig 4 SPIF with Hot air blower[8]

4. In hot oil heating, the heat is applied using hot oil.

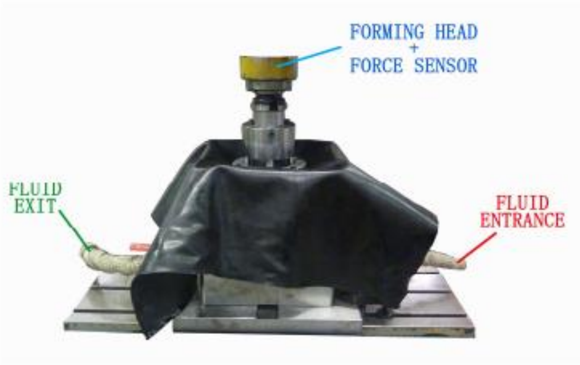



Fig 5 SPIF with Hot oil[9]

5. In frictional heating, heat is generated due to friction between the sheet and the tool. That heat helps in forming process.

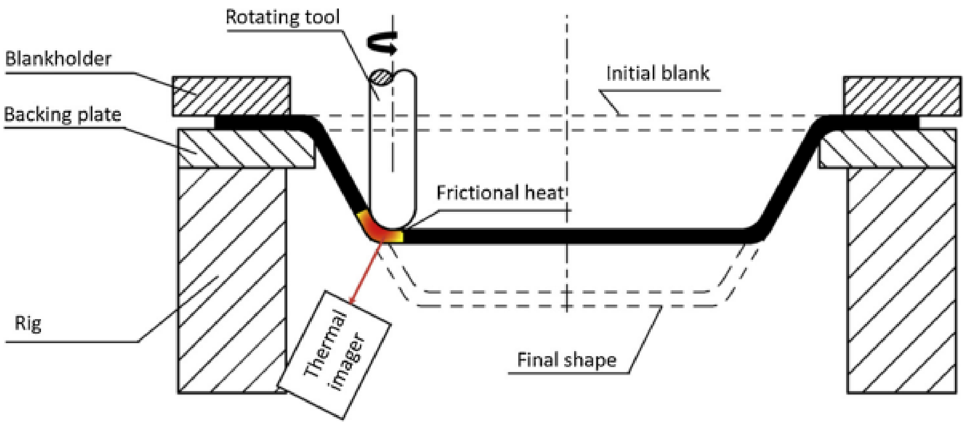



Fig 6 SPIF with frictional heating[10]

6. In electric heating, the heat is generated due to incorporating electricity in metal sheets and tools. Which helps during the deformation of the metal.

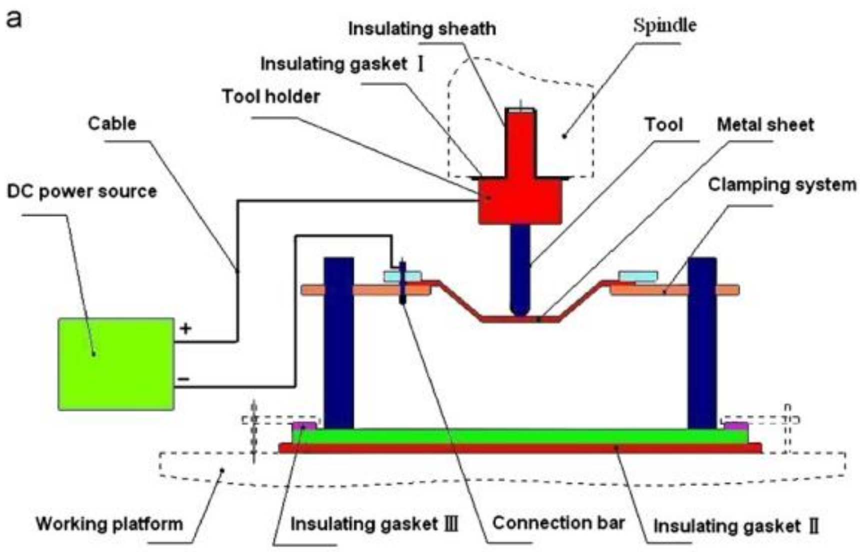



Fig 7 SPIF with electric heating[11]

7. An induction heating setup uses an arm consisting of two sliding devices and a sliding jig. With two rings the arm attaches the induction ma to the head of the ring. These rings however are firmly attached to the spindle of the CNC milling machine. It is connected to the inductor head and the pull distance is adjusted to match the sheet and the inductor. In addition, the slid jig slides over the sliding devices horizontally and vertically, so the tool and the inductor both meet at one point. The holder arm of the inductor heats the plate locally in the contact area between the device and the sheet, while the forming takes place within the device.[12]

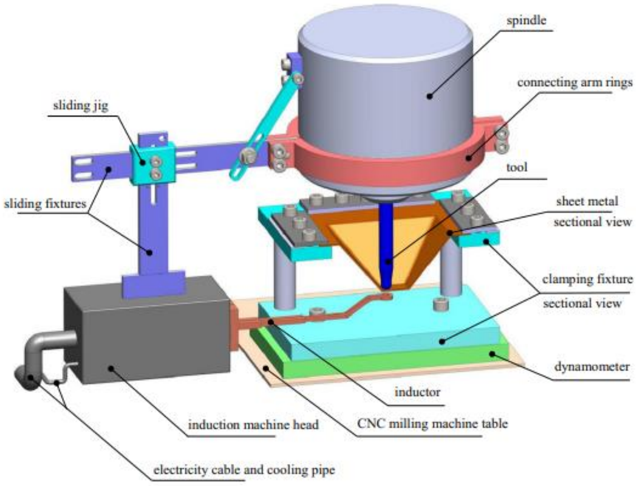



Fig 8 SPIF with induction heating[12]

8. In ultrasonic heating ultrasonic vibration is used to heat the specimen. It consisting two parts, first that consists of an ultrasonic generator and the second is SPIF set up, both are connected.[13]Fig 9 SPIF with Ultrasonic heating[13]

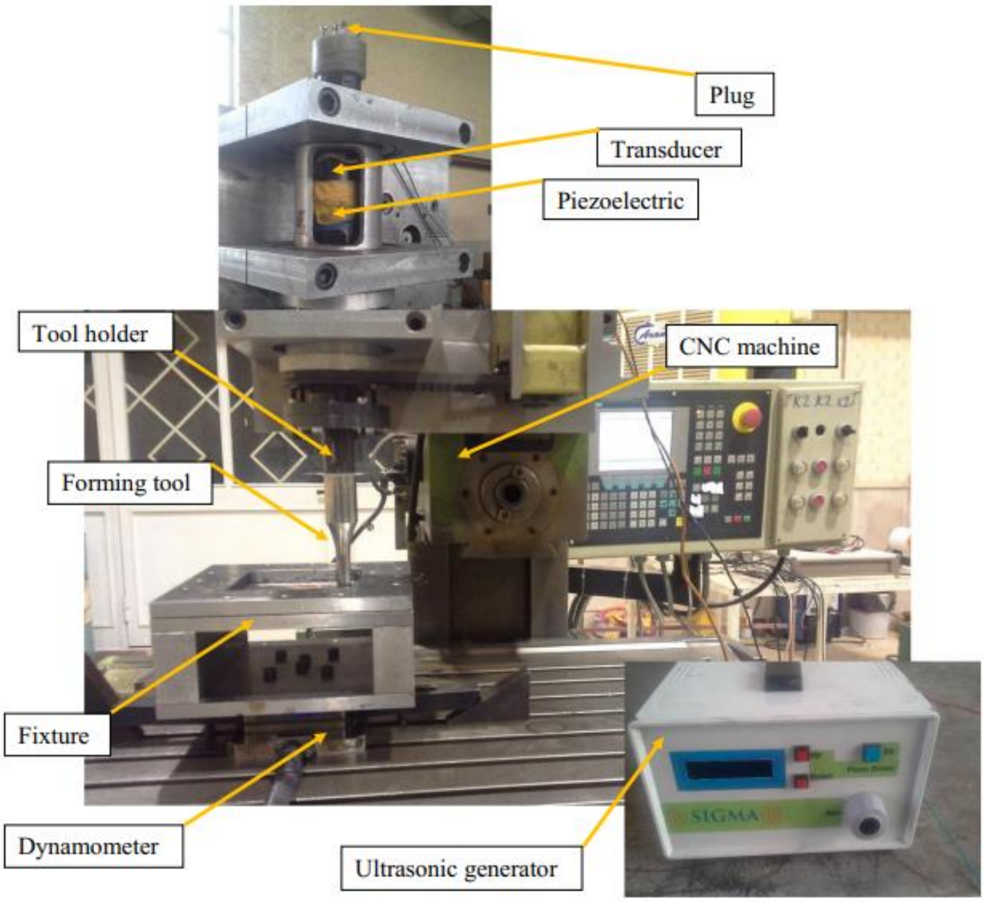



Fig 9 SPIF with ultrasonic heating[13]

## II. EFFECT OF PROCESS PARAMETER DURING INCREMENTAL SHEET FORMING

### 1. Temperature and Current

The temperature is the most affected parameter in our study. The temperature increase can soften the material and increase the formability of the material. It also affects the surface finish and microstructure. It reduces forming force. In electric heating, the temperature is the function of the current density, so many researchers specify the current instead of the temperature.

**Table 1 Effect of Temperature on hot SPIF**

| Author | Material | Method of heating | Temperature | Result |
|---|---|---|---|---|
| David Adams and Jack Jeswiet[14] | 6061-T6 Al | Electric heating DC supply (0-5 V, 0-900 A) | Not indicated ( n. i) | As the current density increases temperature increases.<br>As the current density increases wall angle, surface roughness, increase.<br>No need for the dressing of the tool between tests. |
| S. W. Kim et al.[7] | Mg alloy (AZ31) | halogen lamp | 100, 200, 250, 300℃ | As the temperature increase formability of material increase which increase the fracture height tendency. |
| J.R. Duflou et al.[6] | 65Cr2, TiAl6V4 | laser supported heating | 20- 350℃ | As the temperature increases the wall angle increase.<br>At room temperature maximum achieved angle is 30 degrees and as temperature increases maximum achieved wall angle is 57degree.<br>As the temperature increases forming force reduces. |
| G. Ambrogio et al.[15] | Mg alloy (AZ31) | Heater band | 200, 250, 300℃ | Formability increases with increase temperature. maximum formability occurs at 250℃.<br>Forming force decrease with increase temperature.<br>Wall inclination angle increase with the increase in temperature. |
| G. Ambrogio et al.[16] | AA2024-T3, AZ31B-O, Ti6Al4V (grade 5) | Electric heating DC supply | n.i | As the temperatures increase wall angle and forming height increase. |
| Wenke Bao et al.[17] | AZ31B alloy | electro pulse-assisted heating | n.i | With electro-pulse-assisted heating, the formability of material is increased.<br>The forming limit in EAIF is up to 72° when the RMS current density is 107.8 A/mm2.<br>Fine grains are obtained and the material is enhanced by plasticity. |
| Guoqiang Fan et al.[18] | Ti-6Al-4V | Electric heating | Up to 980℃ | As the current increase temperature increase.Analysis of microhardness reveals that electric hot incremental forming is an improved technique. The hardness will initially rise and then reduce as the temperature increases. The tensile strength reduces as the temperature rises. |
| Christian S. Magnus[19] | Ti6Al4V | joule heating | 750 ◦C | In Ti6Al 4V, as compared with forming at room temperature, the ISF with regional Joule heating of the forming zone has substantial benefits. The result is reduced forming force, reduced subsequent deformation, reduced spring back, and enhanced formability of already formed regions. |
| Giuseppina Ambrogio et al.[20] | Ti-6Al-4V | induction heating | 600, 700 °C | The non-magnetic material Ti-6Al-4V may be thermally deformed by inductive heating, with and without cryogenic cooling, as the |

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| | | | | sheet temperature increases. By beginning from cryogenic temperatures, the induction coil may achieve the desired temperature at the investigated punch velocities |
| Le Van Sy et al.[21] | AZ31 | direct heating | 25, 150,250℃ | The formability of AZ31 is influenced mostly by temperature. It contributes to 73.22% of all formability impacts. At 250℃ maximum formability, high geometric accuracy, and surface quality were achieved. |
| Le Van Sy et al[21] | AA5055 | direct heating | 25, 200, 300℃ | Temperature influence 73.1% on formability. The maximum wall angle achieved at hot SPIF is 85̊. |
| Guoqiang Fan et al.[22] | Ti-6Al-4V | electric heating | 200- 630℃ | The titanium sheet Ti-6Al-4V may be made with a more accurate shape and somewhat oxidized by electric heat incremental forming in a temperature range between 500 and 600°C. In the temperature range, the maximum draw angle was 72°. |
| Y.H. Ji et al.[23] | AZ31 | hot air blower | 20, 100, 150, 200, 250℃ | Formability of AZ31 increases with temperature. With different temperature different wall angle is designed. |
| Amar Al-Obaidi et al.[24] | DP 980 dual-phase steel | induction heating | 836℃ | Formability, maximum wall angle, and the crack-free result obtained with temperature rise.it also reduces forming force. |
| Y. H. JI et al.[23] | AZ31 | hot air blower | 20, 100, 150, 200, 250℃ | At temperature 150°C the value of $\varepsilon_{major}$ in deformation of plain strain stretching and axisymmetric stretching were found to be 0.55 and 0.27. As formability increases, small grain sizes are obtained. |
| L. Galdos et al.[25] | magnesium alloy | hot fluid heating | 150, 200, 250 °C | When formed in incremental stress circumstances, the formability of magnesium alloys is increased at warm temperatures. As with uniaxial tensile conditions, optimum formability is achieved at 250°C. When forming at 250°C, you get a complete recrystallized microstructure. |
| Manel Sbayti et al.[26] | Ti-6Al-4V | frictional heating | 20, 400, 500, 600℃ | Homogeneous thickness distribution is achieved at high temperatures. Spring back effect decreased with temperature increase and geometry accuracy improved temperature more than 400°C. |
| Andre Leonhardt et al.[8] | AZ31 | hot air heating | 650 °C | At temperature 300 °C the maximum wall angle is achieved with a pronounced orange peel effect. Forming force in the Z-direction decrease with an increase in temperature. |
| Sandino Torres et al.[27] | Biodegradable composite with Solanyl C1201 thermoplastic | Hot fluid heating | 80, 90 °C | 80 °C temperature gives greater formability. |
| Saeid Amini et al.[28] | annealed AA1050 sheet | ultrasonic heating | n. i | Forming force decrease up to 36% and formability increase at the maximum value of 48%. Spring back effect if reduced. |
| P. A.P. Pacheco et al.6[29] | AA1050 | electric hot | Preheat- 200̊C Working temperature - 400̊C- 500̊C | As the temperature increases the effort decrease but greater concentration on cooling and geometric accuracy is reduced. preheating showed a good solution to improve the geometric accuracy of the EHISF process. |
| Zhiyuan Yang et al.[30] | polyether-ether-ketone (PEEK) | thermal radiant panel | 70, 100, 150 °C | At constant step size as temperature increases force, twist angle decrease. |

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| | | | | Formability increases with increase temperature from room temperature to 150°C. |
| R. Mohanraj et al.[31] | titanium grade 2 | electric heating | 100, 200, 300 °C | Optimum formability was obtained at 300°C.<br>The minimum geometric deviation at 300°C is 1.52% and the maximum thickness reduction is 37.90%. |
| Khanh Dien et al.[32] | titanium | n.i | 480, 600℃ | In any case the higher temperature, the lower spring back of the Titanium sheet. Hot SPIF increases the accuracy of the vertical dimension of the product. |
| Mostafa Vahdani et al.[33] | Ti-6Al-4V, AA6061, DC01 | electric heating | 450, 300 A | The optimum parameter obtains at 450A for titanium and 300A for AA6061 and DC01. |

Temperature is the most influencing parameter for SPIF that improves the formability and reduces forming force. Xiaofan Shi et al. investigate with material low carbon steel DC04 with electric heating at 300 and 400 A DC and feed rate 1000 and 2000 mm/min and obtain that a counter tool route, a high current value, and a fast forming speed will cause a discharge phenomenon that will destroy the components; however, a helical tool path can prevent this, Although a low current value and fast forming speed can prevent discharge between the tool and the blank, this reduces the process' efficiency and precision.[34]

**2. Step depth**

Step depth is the vertical distance between two successive couture. When the tool completes the one revaluation of couture it travels vertically down and starts other couture, that distance is called step depth. It is a very important parameter for single point incremental forming. part surface finishes, formability, and forming force if affected by the step depth in spif.

**Table 2 Effect of step depth on hot SPIF**

| Author | Material | Method of heating | Step size (mm) | Result |
|---|---|---|---|---|
| S. W. Kim et al.[7] | Mg alloy (AZ31) | halogen lamp | 0.2,3 | As the step size decrease, fracture height tendency increases. The fracture occurred at 50 mm height. |
| G. Ambrogio et al.[15] | Mg alloy (AZ31) | Heater band | 0.30, 0.65, 1.00 | As the step size increases nominal force increases. |
| Ambrogio Giuseppina et al.[35] | AA5754, Ti6Al4V | Frictional heating | 0.1, 0.3, 0.5 | As the step size increases temperature decrease for both materials. |
| G. Palumbo et al.[36] | Ti6Al4V | electric static heating | 0.5 – 1.0 | Step size changes have a negligible effect on parameters. |
| M. Honarpisheh et al.[37] | Ti-6Al-4V | electric heating | 0.1,0.3, 0.5 | As the step size increases current density, heat generation, and formability decrease. |
| S. Amini Najafabady et al.[38] | Ti-6Al-4V | electric heating | 0.1, 0.3 | Surface roughness increase as the step size increase. |
| E. H. Uheida et al.[39] | pure titanium | frictional heating | 0.35- 0.8 | Forming force and the temperature increase with an increased step size. |
| Jin Wang et al.[40] | AZ31B Mg alloy | frictional stir | 0.2, 0.4, 0.6 | Step size significantly influences the temperature.<br>High values of step size lead to high temperature. |
| Le Van Sy et al.[21] | AZ31 | direct heating | 0.1 , 0.5 | For the wall angle and surface roughness, the contribution of step size is 9.33% and 63.6%. The depth step mainly affects the axial deforming force and roughness of the surface. Raising the surface quality depth step is a good solution for AZ31 sheets. |
| Le Van Sy et al.[21] | AA5055 | direct heating | 0.1, 0.5,1 | For wall angle and surface roughness, the contribution of step size is 18.43% and 4.21%. |

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| Guoqiang Fan et al.[41] | AZ31 | Electric heating | 0.2, 0.3, 0.4 | Formability increase4 with a smaller step size. As the step size increase that decreases the current density, heat generation, and formability. |
| Sandino Torres et al.[27] | Biodegradable composite with Solanyl C1201 thermoplastic | Hot fluid heating | 0.2, 0.4 | Step size 0. 4 give greater formability. |
| M. R. Sakhtemanian et al.[42] | TC4 Ti alloy | ultrasonic vibration | 0.1,0.2, 0.3 | Z = 0.1, and the largest reduction in friction coefficient, equivalent to 37%, was attained by the use of ultrasound vibration.<br>As the step size increase, the ferrite grain is broken into smaller grain sizes. |
| Zhiyuan Yang et al.[30] | polyether-ether-ketone (PEEK) | thermal radiant panel | 0.4 , 0.8, 1.2 | The force and twisting angle increase at a constant temperature as the step size increases. |
| R. Mohanraj et al.[31] | titanium grade 2 | electric heating | 0.1, 0.2, 0.3 | Optimum formability noted at 0.1 mm step size.<br>At 0.1 mm step size, the minimum geometric deviation is 1.52% and thickness reduction is 37. 90%. |
| Khanh Dien LE et al.[32] | titanium | n.i | 0.3 , 0.6 | step depth Vz seems invariable to the spring back, the step depth Vz is not also a robust parameter. |
| Mostafa Vahdani et al.[33] | Ti-6Al-4V, AA6061,DC01 | electric heating | 0.3, 0.2 | The optimum parameter for maximum formability is 0.3mm for titanium and 0.2 for aluminum and DC01 steel. |
| P. A. Grun et al.[43] | Ti6Al4V | friction stir | 0.35, 0.5,0.65 ,0.8 | Formability improved and wear is reduced at 0.5 mm step size. |
| Chang Hou et al.[44] | Jute Fabric Reinforced Poly(lactic acid) Biocomposites | thermal radiation plate | 0.5, 1.8 | The surface quality of the produced composite pieces was significantly influenced by the step size. A variable step-size would improve surface quality while also reducing forming time. |

Step size is the most influencing parameter for Spif . from the literature it was found that an increase in step size decreases the surface roughness and the smaller the step size that's improves surface quality, formability, and accuracy that is beneficial to us. The above table is the literature on the combined effect of step size and heating.

### 3. Sheet Thickness

Sheet thickness is a very important parameter in forming process. Different application needs different sheet thickness. The selection of sheet thickness affects the strength, surface finish, the force required for deformation, and formability.

**Table 3 Effect of Sheet thickness on hot SPIF**

| Author | Material | Method of heating | Sheet thickness (mm) | Result |
|---|---|---|---|---|
| Masato Okada et al.[45] | carbon fiber reinforced thermoplastic | optical heating by a halogen lamp | 0.5, 1.0, 1.5 | Forming limit increase with the increase in tool diameter.it reaches 10 mm when punch diameter is 5 mm and thickness 1.5 mm<br>Temperature decreases with an increase in the distance of halogen lamp and sheet thickness. |
| S. Amini Najafabady et al.[38] | Ti-6Al-4V | electric heating | 0.4, 0.51, 0.62, 1.05 | As the sheet thickness increases, the roughness on the outside of the piece reduces significantly. |
| Jin Wang et al.[40] | AZ31B Mg alloy | frictional stir | 1, 1.5 | Sheet thickness has a significant influence on temperature. |
| Chang Hou et al.[44] | Jute Fabric Reinforced | thermal radiation plate | 0.9, 1.5 | The forming depth limit was influenced by the thickness of the composite sheet. |

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|---|---|---|---|---|
| | Poly(lactic acid) Biocomposites | | | |

From the literature, it was found that thickness influence the surface roughness, as thickness increase surface roughness increase. With a combination of heating, the thickness distribution and more forming depth are achieved compared to room temperature.

## 4. Spindle speed

Spindle speed is the rotation of the spindle per unit time. It is measured in revaluation per minute (RPM). In spif some researcher works with high-speed rotation and some work with low-speed rotation and some work without rotation. It also affects the formability, temperature surface finish, etc.

**Table 4 Effect of Spindle speed on hot SPIF**

| Author | Material | Method of heating | Spindle speed | Result |
|---|---|---|---|---|
| G. Palumbo et al.[36] | Ti6Al4V | electric static heating | 800-1600 rpm | In testing with S = 1600 RPM, a greater level of major strain was achieved without any significant changes in the thickness reductions concerning the test with S = 800 RPM. |
| Jin Wang et al.[40] | AZ31B Mg alloy | frictional stir | 3000, 4000, 5000 rpm | Spindle speed significantly influences the temperature.<br>A higher value of spindle speed leads to a high temperature. |
| P. A. Grun[43] | Ti6Al4V | friction stir | 500, 2000, 3500 rpm | Formability improved and wear is reduced at 2000 rpm and the 1500 rpm heating effect enhance formability with less defect. |

Spindle speed is needed to increase the heating effect between the tool and sheet. friction between the tool and sheet generates heat and that helps to form. but with a combination of external heating, some researchers work with or without spindle speed. effect of the combination of spindle speed and heating describes in the above table.

## 5. Tool diameter

Tool diameter is the most affected parameter in single point incremental forming. It affects the forming force, surface finish, and formability. the selection of tool diameter directly affects the surface finish.

**Table 5 Effect of Tool diameter on hot SPIF**

| Author | Material | Method of heating | Tool diameter | Result |
|---|---|---|---|---|
| G. Ambrogio et al.[15] | Mg alloy (AZ31) | Heater band | 12, 15, 18 | Tool diameter has a nominal effect, which is negligible<br>. |
| Ambrogio Giuseppina et al.[35] | AA5754 ,Ti6Al4V | frictional heating | 12, 15, 18 | As the tool diameter increase temperature increase. |
| Masato Okada et al.[45] | carbon fiber reinforced thermoplastic | optical heating by a halogen lamp | 1, 3, 5 | Forming limit increase with the increase in tool diameter.it reaches 10 mm when the punch diameter is 5 mm.<br>forming height increased when the punch radius decreased |
| M. Honarpisheh et al.[37] | Ti-6Al-4V | Electric heating | 8,12 | As the tool diameter increases temperature and formability decrease. |
| Jin Wang et al.[40] | AZ31B Mg alloy | frictional stir | 8, 10, 12 | Tool diameter has an insignificant influence. |
| Guoqiang Fan et al.[41] | AZ31 | Electric heating | 6, 8, 12 | As the tool diameter increases wall angle decrease. With a very small size tool (6 mm) the process cannot be done. Small size tool leads to concentration of heat at the small region with the reason for burn out. |
| Manel Sbayti et al.<br>[26] | Ti-6Al-4V | frictional heating | 6, 8, 10 | By FE model noted that the smaller the tool size higher the temperature. |

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|---|---|---|---|---|
| P. A. P. Pacheco et al.[29] | AA1050 | electric hot | 8, 12 | Geometric accuracy reduces with an increase in tool diameter, it also increases heat transfer. |
| Khanh Dien LE et al.[32] | titanium | n.i | 6, 12 | The smaller the tool diameter the smaller the spring back which means the higher the accuracy. |

Tool diameter is the most affected parameter in SPIF. As the smaller tool diameter surface quality, formability, geometric accuracy is improved. It reduces spring back also. From above literature describe that a smaller tool diameter gives better results.

## 6. Feed rate

Feed rate is the movement or advancement of the tool concerning the workpiece. The unit of feed rate is millimeters per revolution. The feed rate affects the surface finish and heat generated during forming.

**Table 6 Effect of Feed rate on hot SPIF**

| Author | Material | Method of heating | Feed rate (mm/min) | Result |
|---|---|---|---|---|
| Ambrogio Giuseppina et al.[35] | AA5754 ,Ti6Al4V | frictional heating | 5, 50, 500 | As the feed rate increases temperature increases. it also affects the microstructure of the material. |
| Guoqiang Fan et al.[18] | Ti-6Al-4V | Electric heating | 200- 1400 | As the feed rate increases temperature decreases.<br>If the current is increased, a higher feed rate can be adopted |
| Jin Wang et al.[40] | AZ31B Mg alloy | frictional stir | 200, 400, 600 | Feed rate significantly influences the temperature.<br>Feed rate has negative effects on temperature. |
| Le Van Sy et al.[21] | AZ31 | direct heating | 33.33, 100 | Feed rate contributes for wall angle and surface roughness is 6.6 % and 11.18%.<br>Increasing feed rate improves surface quality. |
| Le Van Sy et al.[21] | AA5055 | direct heating | 33.33, 100 | For wall angle and surface roughness, the contribution of feed rate is 18.43% and 4.21%. |
| Guoqiang Fan et al.[41] | AZ31 | Electric heating | 700, 1000, 1300, 1600 | Unfavorable to formability is too low or too high feed rates. Except the damaged part accomplished at 700 mm/min feeding rates. At a velocity of 1000mm/min, the maximum formability (64.31) is obtained. |
| M. R. Sakhtemanian et al.[42] | TC4 Ti alloy | Ultrasonic vibration | 400, 700, 1000 | The difference in the coefficient of friction was reduced between the two modes by increasing the vertical feed rate and was equivalent to 24% for $\bar{z}$ = 0.3.<br>As the feed rate increase with ultrasonic the smaller grain size is obtained. |
| Khanh Dien LE et al.[32] | titanium | n. i | 500, 1500 | The higher the feed rate of the tool, the smaller of spring back of the Titanium sheet, High feed rate could increase the accuracy of the product. |
| Mostafa Vahdani et al.[33] | Ti-6Al-4V, AA6061,DC01 | electric heating | 900, 400 | Optimum parameter for maximum formability at 900 mm/min. |
| P. A. Grun at al.[43] | Ti6Al4V | friction stir | 600, 1050, 1500 | Formability improved and wear is reduced at 1050 mm/min.<br>The highest temperature 212° C measured at 1200mm/min. |

## 7. Wall angle

Wall angle is the angle between the forming geometry wall and horizontal base. The wall angle is the most affected parameter in SPIF. It affects the sheet thickness, tool shape, step size, etc.

**Table 7 Effect of Wall angle on hot SPIF**

| Author | Material | Method of heating | Wall angle | Result |
|---|---|---|---|---|
| S. W. Kim et al.[7] | Mg alloy (AZ31) | halogen lamp | 45̊, 40̊, 35̊, 30̊ | As the wall angle decreases the formability of the material increase. A lower wall angle gives a better result. Wall angle 30 degrees give defect-free component. |
| G. Ambrogio et al.[15] | Mg alloy (AZ31) | Heater band | 20˚- 65˚ | As the temperature increases the wall angle increase. |
| Ambrogio Giuseppina et al.[35] | AA5754 ,Ti6Al4V | frictional heating | 25˚, 30˚, 35˚ | As the wall angle increases the temperature increase. |
| G. Ambrogio et al.[16] | AA2024-T3, AZ31B-O, Ti6Al4V (grade 5) | Electric heating DC supply | 20̊- 40̊ | As the wall angle increases the surface roughness and forming height increase. |
| M. Honarpisheh et al.[37] | Ti-6Al-4V | electric heating | 45˚, 56˚, 64˚ | As the wall angle increase formability decreases. At 45-degree defect-free specimen obtained, as the wall angle increase, the crack is produced. |
| Jin Wang et al.[40] | AZ31B Mg alloy | frictional stir | 30˚, 40˚, 50˚ | Wall angles have an insignificant influence. A higher value of wall angle leads to high temperature. |
| Sandino Torres et al.[27] | biodegradable composite with Solanyl C1201 thermoplastic | Hot fluid heating | 45˚, 60˚ | wall angle 45˚gives greater formability. |
| R. Mohanraj et al.[31] | titanium grade 2 | electric heating | 30˚, 40˚, 50˚ | Optimum formability noted at 50˚ wall angle. At 50˚ wall angle, the minimum geometric deviation is 1.52%and thickness reduction is 37.90%. |

**8. Lubricant**

Lubricant is a substant that reduces the friction and heat between two contacting surfaces. In our case, it uses for the reduce the friction between workpiece and tool. It gives a better surface finish.

**Table 8 Effect of Lubricant on hot SPIF**

| Author | Material | Method of heating | Lubricant | Result |
|---|---|---|---|---|
| Qinglai Zhanga et al.[46] | Mg alloy AZ31 | electric hot method | $MoS_2$, graphite, $K_2Ti_4O_9$ + graphite | $K_2Ti_4O_9$ has a coefficient of friction of about 0.1 which satisfied the friction and lubrication condition of warm incremental forming. $MoS_2$ coated ceramic lubricating gives the coefficient of friction is about 0.07 which gives an excellent surface finish. |
| S. Amini Najafabady et al.[38] | Ti-6Al-4V | electric heating | $MoS_2$ powder | In the procedure, the average roughness of the lubricated surface is 64% less than that of the produced surface without the use of lubricants. |
| Guoqiang Fan et al.[22] | Ti-6Al-4V | electric heating | MoS2, graphite, boron nitride spray | Self-lubricating Ni disulfide composite metal matrix is suited for high temperature electric hot incremental forming with the optimal thickness of 20 µm for a 1.0 mm thick titanium sheet of |

| | | | | |
|---|---|---|---|---|
| | | | | Ti-6Al-4V. The film can prevent oxidation as well. |
| Saeid Amini et al.[28] | annealed AA1050 sheet | ultrasonic heating | n. i | The greatest results from the perspective of forming force, formability, and spring back are shown by a combination of ultrasonic vibrations with appropriate lubrication. |
| Swarit Anand Singh et al.[47] | Aluminum alloy | halogen lamp | silicone oil+ lithium base grease+graphite powder,silicone oil+lithium base grease+ MoS2 powder , silicone oil+ petroleum jelly + Wax granules , Castrol EPL 2 grease,Machine | Because the Molybdenum disulfide (MoS2) blended lubricant remains in between the interface of tooltip and sheet throughout the process, it was determined to be the most suited lubricant for ET-IF applications on Aluminum alloy. |

## 9. Tool material

Swarit Anand Singh et al. investigate for most suitable tool material for hot spif. They use different tool materials high-speed steel, stainless steel, and tool steel with the different lubricants hated by halogen lamps at temperature range 130 ºC to 180 ºC ant it concludes that tool steel is the most appropriate and recommended material for hot SPIF.[47]

## 10. Other literature

Amar AL-Obaidi et al. did SPIF with hot air blower on material glass- fiber -reinforced polymer (PA6GF47) which inserted between two Teflon layers and two dummy metal sheets, and conclude that Teflon layer improve draw-in with hot blower heating and wall angle more than 50° lead s wrinkling, folding, internal cracks and voids and heating also improve formability.[48]

Badreddine Saidi et al work on the integration of a reverse engineering method into the heated incremental forming process to manufacture a customized skull prosthetic should be the key contribution of this experimental effort. To offer a consistent and steady distribution of heating during the warm forming of titanium alloy Ti-6Al-4V skull prosthesis, a new incremental forming technique based on the usage of heat cartridges has been created. During the procedure, the incremental machine was fitted with equipment that measured effort and temperature. Heating increased titanium formability while reducing thickness reduction, as various authors had previously reported. The advantages of this heating system are numerous.[49]

Giuseppina Ambrogio et al. experiment on the PMMA sheers with glass transition and perform SPIF at 114 °C temperature and concluded that by keeping the forming temperature in a sufficient range throughout the process, hot ISF of polymers with a glass transition temperature greater than the ambient temperature is possible. The optimal approach for gradually shaping these thermoplastics, according to the analysis of the experimental plan, is to heat the material from an external source to the appropriate forming temperature. Furthermore, the benefits of the process resulting from double-sided sheet heating must be proven, particularly if thicker plastic sheets must be generated by ISF.[50]

## III. CONCLUSION

The foundations and modeling approach of heat-assisted ISF methods have been thoroughly examined in this work. The formability and geometric accuracy of many hard-to-deform materials at ambient temperatures might be enhanced at increased temperatures by incorporating new physical heat-generated techniques into the conventional ISF process. According to current research, laser heat, friction heat, electric heat, and induction heat can raise temperatures exceeding 600 °C, allowing these technologies to be used to treat extremely hard-to -form materials like Ti alloys and high-strength steels. Other sources of heating, such as halogen lamp heat, hot air heat, oil heat, and combined heat, normally produce temperatures below 400 °C. Materials like magnesium and aluminum alloys might be manufactured successfully in this circumstance. The effect of process parameter from the above literature is concluded below :

- Temperature is the most affected parameter for the heat-assisted single point incremental forming. The temperature increases the formability, forming depth and reduces forming force.
- Step size is the most influencing parameter for SPIF. here combination of heating with parameters gives better results. step size affects the formability, forming force, surface roughness. as the step size decrease increase the formability and surface roughness increase and reduce the force. A lower step size gives better results.
- Spindle speed directly influences the temperature. spindle speed affects the surface quality. High spindle speed is not needed with external heating.
- Sheet thickness affects the surface roughness, forming depth, and temperature. As the sheet thickness increases the roughness increase.
- Tool diameter significantly affects the surface quality, temperature, forming limit, geometric accuracy, spring back, etc. As the tool diameter increases the forming height, forming limit, spring back, and temperature increase as well as decrease the formability, wall angle. smaller tool concentrate the temperature and leads to burnout.
- Feed rate affects the temperature, geometric accuracy, spring back, etc. feed rate has a negative effect on the temperature. A higher feed rate gives lower spring back and better accuracy of the part.

- Wall angle is affected by the temperature and formability. Higher wall angle on=btain at higher temperature and as the wall angle increase formability decrease. best results obtained at 45˚.
- Lubricant is used to reduce the friction between the tool and sheet. in this study, the different researchers use different lubricant but $MoS_2$ powder with grease give the best result.

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