Volume 5, Special Issue, June 2018 ISSN: 2348-8565 (Online)

International Journal of Modern Engineering and Research Technology

Website: http://www.ijmert.org Email: editor.ijmert@gmail.com

National Conference on
Advances in Mechanical Engineering and Nanotechnology (AMENT2018)
29-30 June, 2018
Organized by
Department of Mechanical Engineering, University College of Engineering (A), Osmania University, Hyderabad, TS, India

A Systematic Quantitative Review of the Effect of Process Parameters in Single Point Incremental Sheet Forming

Zeradam Yeshiwas
Department of Mechanical Engineering
University College of Engineering (A),
Osmania University
Hyderabad (T.S.) [INDIA]
Email: arakanti@gmail.com

A. Krishnaiah
Department of Mechanical Engineering
University College of Engineering (A),
Osmania University
Hyderabad (T.S.) [INDIA]

ABSTRACT

Single point incremental sheet forming [SPIF] is an emerging sheet metal forming process suited for small volume and prototyping. Several academic researchers and experts in the metal forming industry have investigated the process in the past decade. However, further studies are essential on the formability, *accuracy, surface finish, and process mechanics to develop the process into an industrialized sheet forming process. This study gives a comprehensive literature review of the effect of process parameters i.e. tool diameter, step size, feed rate, and material thickness on the formability, surface quality, and accuracy. A systematic quantitative literature review has conducted to assess the effect of the aforementioned process parameters, from 45 journal articles and 2 conference proceedings. The study also examines uniformity between conclusions made on the effect of process parameters; distinguish what technique has used i.e. Simulation or Simulation with the Experimental. Besides this, the most investigated sheet material has distinguished. The study also included the quota of assessments towards formability,* surface *finish, and dimensional accuracy. After the assessment has made, analysis of the reviews made on the effect of the process parameters has conducted and the research gaps have outlined to provide highlights for future research idea.*

Keywords: *Accuracy, Formability, SPIF, Surface Finish, Systematic quantitative review*

I. INTRODUCTION

Single point incremental sheet forming is an emerging process for manufacturing sheet metal parts and it is well suited for small batch production or prototyping. In SPIF sheet is formed into the desired final part by a series of small incremental deformations until the part fully formed.

The deformation is commonly accomplished by using a spherical tipped forming tool attached to a tool holding devices that follow the contour created from the CAM package (Figure 1.1). The operation is performed either by using a machine specifically designed for the process, a three-axis CNC mill or industrial robots.

SPIF has a number of merits, some of them include there is no need of supporting dies; no need for positive or negative molds. It can be executed in a conventional CNC machine and the forces required for deformation is small when compared to the conventional sheet forming. However, the process is not fully industrialized, it needs further investigations.

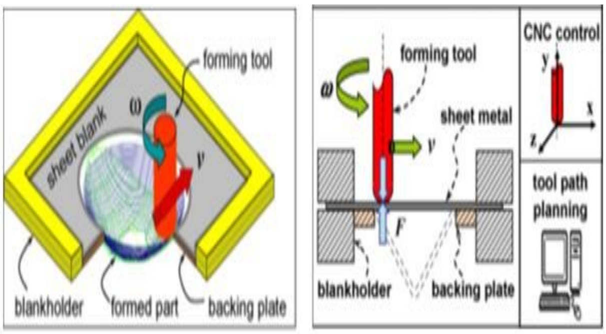

Figure 1.1 Single point incremental sheet forming and basic elements[1]

The primary objective of the review is to assess what the literature reports about the effects of process parameters on formability, surface finish, and dimensional accuracy. Besides, assessing consistency between conclusions, distinguish the types of investigations used, identify the most investigated material, to assess whether the investigations towards formability, surface quality, and dimensional accuracy were conducted proportionally. Finally to find out the research gaps.

II. Methods

A systematic quantitative literature review is mainly employed for the assessment. The merits and other details of this literature review method are described in Pickering and Byrne [2].

In this review, original research articles and conference proceedings were only considered. a total of 45 journal articles and 2 conference proceedings([3] and [4]) published from 2005 to 2017. In addition, two-point incremental forming and heat-assisted SPIF were not considered. The research articles and conference proceedings are collected mainly from database searches. In this review, the most commonly used academic search engine is Google Scholar and the most used databases searched is science direct.

2.1 Effect of process parameters on formability

Base on the assessments carried out, formability can be evaluated by using three distinct approaches. The first one is by finding the maximum forming angle, the second one is by considering the maximum formability depth achieved and the third one is by considering the maximum thickness reduction achieved without failure.

Effect of step depth on Formability

To find out what the pieces of literature reports about the effect of step depth on the formability in SPIF, a total of 18 studies were taken. Of these, 12 studies found the formability to increase with the lower value of step depth. 5 papers conclude formability increases with the higher value of step depth and 1 paper conclude step depth doesn't have a considerable impact on formability. The results are illustrated in

Figure 1.2 and details are presented in Table 1.1.

From the Table 1.1, only 4 of the investigations have conducted by combining simulation with experimental methods of investigation furthermore 18 papers have investigated by using experimental investigation technique. Besides this, aluminum alloys have used in most of the investigations.

Chezhian 2010 [20] Steel 0.3, 0.4,0.5 Experimental Step depth does not have much impact on formability.

Effect material thickness on Formability

This review has conducted to examine the effect of material thickness on formability in SPIF. The evaluation has taken from 15 papers. Of these 15 papers, 14 of the papers concluded that increase material thickness is compulsory to increase formability. Besides this 1 paper concludes that decrease material thickness to increase formability. The pie chart in Figure 1.3 presents the details on the effect of material thickness on formability. From the Table 1.2, most of the studies have conducted by applying experimental investigations technique. In this investigation aluminum alloy is the most studied material.

Table 1.1 Effect of step depth on Formability

Authors	Materials Investigated	Step Depth (mm)	Investigation Type	Effect of step depth
Conte 2017 [5]	Composite	1,2	Experimental	Formability increases with the
Davarpanah 2015 [6]	Polymer	0.2,0.4,0.6,0.8,1.0,1.4,	Experimental	higher value of step depth
		1.8	Experimental	
Pandivelan 2015 [7]	Aluminum	0.15,0.2,0.25,0.3,0.35	Experimental	
Bagudanch 2015 [8]	Polymer	0.2, 0.5	Experimental	
Zhang2016 [9]	Polymer	0.5, 1.0		
Shanmuganatan 2013	Aluminum	0.2, 0.4, 0.6, 0.8, 1	Simulation & Experimental	Formability increases with the
Song 2017 [11]	Aluminum	0.16,0.18	Simulation & Experimental	
Golabi 2014 [12	Steel	1,1.5,2	Simulation & Experimental	
Kurra 2017 [13	Steel	0.7, 1.1, 1.5	Simulation & Experimental	
Ham 2006 [14]	Aluminum	0.05, 0.12, 0.25	Experimental	
Le 2008 [15]	Polymer	0.2, 1	Experimental	
Hussain 2008 [16]	Titanium	0.2, 0.75, 1.3	Experimental	
Bhattacharya 2011 [17]	Aluminum	0.2,0.5,0.6,0.8,1	Experimental	
Bosetti 2010 [3]	Aluminum	0.3,0.8	Experimental	
Huang 2008 [4]	Aluminum	0.5,1,1.5,2,2.5,3,3.5,4	Experimental	
Ham 2007 [18]	Aluminum	0.05,0.12, 0.25	Experimental	
Oleksik 2014 [19]	Aluminum	0.25, 0.5,1	Experimental	

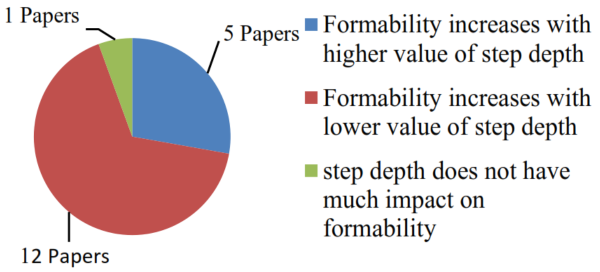

Figure 1.2 Effect of step depth

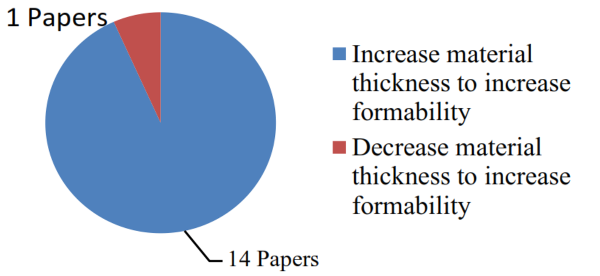

Figure 1.3 Effect of material thickness

Effect of Tool diameter on formability

To assess what the pieces of literature say about the effect of tool diameter on the formability in SPIF, 23 papers has taken. The results of the assessment are present in figure 1.4 and the detail is in table 1.3.

The details in table 1.3 reported that from the total of 23 studies, 5 of the studies have conducted by combining simulation with experimental technique and 18 studies have conducted by using an experimental study. From the review, most of the studies have conducted on aluminum alloys.

Effect of Feed rate on formability

Assessment of the available literature to review the effect of step depth on the

Table 1.2 Effect of Material Thickness on Formability

Authors	Materials Investi-gated	Material thickness (mm)	Investigation Type	Effect of material thickness
Franzen 2009 [21]	Polymers	2,3	Experimental	Increase material thickness to increase
Shanmuganatan2013[10]	Aluminum	1,1.25	Simulation & Experimental	formability
Golabi 2014 [12]	Steel	0.5,0.7	Simulation & Experimental	
Jeswiet 2005 [22]	Aluminum	1.21, 1.02	Experimental	
Ham 2006 [14]	Aluminum	0.81, 1.2, 2.1	Experimental	
Manco 2010 [23]	Aluminum	1, 2	Experimental	
Silva 2010 [24]	Polymer	2,3	Experimental	
Marques 2012 [25]	Polymer	2,3	Experimental	
Bhattacharya 2011 [17]	Aluminum	0.28,0.49,0.71	Experimental	
Gulati 2016 [26]	Aluminum	0.55, 1.09,1.67	Experimental	
Bagudanch 2015 [8]	Polymer	1.5, 2.0	Experimental	
Chezhian 2010 [20]	Steel	0.4,0.6,0.8	Experimental	
Huang 2008 [4]	Aluminum	0.2,0.4,0.6,0.8,1,1.2	Experimental	
Tisza 2012[27]	Aluminum	0.6, 1.0, 1.5	Experimental	
Zhang2016 [9]	Polymer	1.5, 2	Experimental	thickness to increase form-ability

formability in SPIF shows four different conclusions made by the researchers (Figure 1.5). Table 1.4 describes the studies that have conducted to investigate the effect of feed rate.

Table 1.4 the details in which, 4 of the investigations have conducted by combining simulation with experimental technique while 10 of the investigations has conducted by using an experimental investigation.

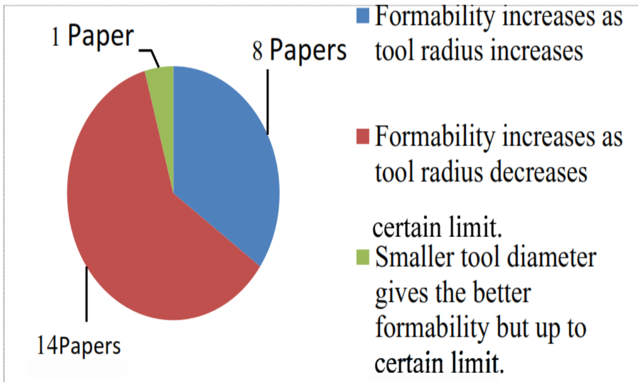

Figure 1.4 Effect of tool diameters

Table 1.3 Effect of Tool diameter on formability

Authors	Materials Investigated	Tool diameter (mm)	Investigation Type	Effect of Tool diameter
Le 2008 [15]	Polymer	6,12	Experimental	Formability increases as
Ziran 2010 [28]	Aluminum	4,6,10	Experimental	tool radius increases
Silva 2010 [24]	Polymer	10,15	Experimental	
Bagudanch 2015 [8]	Polymer	6,10	Experimental	
Zhang 2016 [9]	Polymer	10,12	Experimental	
Majagi 2015 [29]	Aluminum	6,8,10	Experimental	
Golabi 2014 [12]	Steel	6,10,14	Simulation & Experimental	
Li 2014 [30]	Aluminum	30,25.4,20,10	Simulation & Experimental	
Ham 2006 [14]	Aluminum	4.76,12.7	Experimental	Formability increases as
Franzen 2009 [21]	Polymer	10,15	Experimental	tool radius decreases
Marques 2012 [25]	Polymer	8,10,12	Experimental	
Hussain 2008 [16]	Titanium	8,12,16	Experimental	
Durante 2011 [31]	Aluminum	5,10,15	Experimental	
Malwad 2014 [32]	Aluminum	6,12	Experimental	
Huang 2008 [4]	Aluminum	4, 6, 8, 10, 12, 14	Experimental	
Ham 2007 [18]	Aluminum	4.76, 6.35, 9.52	Experimental	
Bhattacharya 2011 [17]	Aluminum	4, 6, 8	Experimental	
Gulati 2016 [26]	Aluminum	8, 12	Experimental	
Oleksik 2014 [19]	Aluminum	6, 8, 10	Experimental	
Shanmuganatan 2013 [10]	Aluminum	2.5, 5, 10	Simulation & Experimental	
Kurra 2017 [13]	Steel	6, 10, 14	Simulation & Experimental	
Naga 2014 [33]	Aluminum	8, 10, 12	Simulation & Experimental	
Malwad 2014 [32]	Aluminum	6, 12	Experimental	Formability increases as tool radius decreases But up to certain limit.

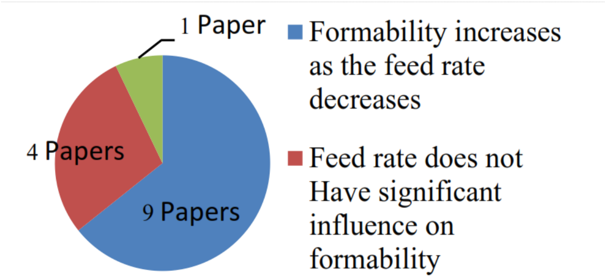

Figure 1.5 Effect of Feed Rate

Effect of Parameter interactions on Formability

A few numbers of researchers have studied the effect of parametric interactions on the formability in SPIF. The conclusions that have gathered from these few studies showed, all the studies have conducted by using an experimental technique. Besides, the investigations [37], [3], [4] and [14] use an aluminum sheet for the conduct of the investigation while [15], uses polymer sheet for the conduct of the investigation. The conclusions made by the researchers are detailed in Table 1.5.

Le 2008 [15] Formability increase; when Large tool radius with a small step size; Small step size with a small

feed rate ; A large tool with a small feed rate

Bosetti 2010 [3] Step-down, feed rate interactions do not influence formability

Huang 2008 [4] Formability will decrease with the decrease of (to/Rtool) ratio and ($\Delta z/R_{tool}$) ratio; or The formability increases with the decrease of (R_{tool}/t_o) ratio and ($\Delta z/t_o$) ratio;

Ham 2006 [14] Small tool size and thickest material increase formability

Note: Original sheet thickness (t_o); Step depth (Δz); Tool Radius (R_{tool})

Table 1.4 Effect of Feed rate on formability

Authors	Materials Investi-gated	Feed Rate (mm/min)	Investigation Type	Effect of Feed rate
Rattanachan 2009 [34]	Steel	300, 3000	Experimental	Formability increases as
Le 2008 [15]	Polymer	1000,3000	Experimental	the feed rate decreases.
Hussain 2008 [16]	Titanium	1200,2600, 4000	Experimental	
Ham 2006 [14]	Aluminum	1270, 2540	Experimental	
Gulati 2016 [26]	Aluminum	1000, 2000, 2500	Experimental	
Zhang2016 [9]	Polymer	100,500	Experimental	
Radu 2011 [35]	Steel	1500,3000	Simulation & Experimental	
Naga 2014 [33]	Aluminum	100,300,500	Simulation & Experimental	
Kurra 2017 [13]	Steel	750, 1500, 2250	Simulation & Experimental	
Golabi 2014 [12]	Steel	600,1200	Simulation & Experimental	Feed rate does not
Bhattacharya 2011 [17]	Aluminum	40,60,80	Experimental	Have significant influ-ence
Uheida 2017 [36]	Titanium	1200,2000,4000	Experimental	on formability
Bosetti 2010 [3]	Aluminum	1000,1500	Experimental	
Bagudanch 2015 [8]	Polymer	1500,3000	Experimental	High feed rate increases formability

2.2 Effect of Process Parameters on Dimensional Accuracy

Dimensional accuracy is of vital importance in any manufacturing process. All manufacturing processes have different allowable dimensional tolerances. SPIF cannot be marketed as a viable forming method unless information like dimensional accuracy has been determined. The dimensional accuracy study is important for determining how accurate SPIF is; this could lead to an understanding of possible applications for SPIF[40].

Effect of step depth on accuracy

Effect of step depth on accuracy has tested by considering two investigations that have satisfied the criteria to review its effect on accuracy. The final conclusions in both studies were accuracy increases with a decrease in step size. In both studies, aluminum alloy is the material used for the study. The first investigation [10], has conducted by using both simulation and experimental techniques. The variations of step depth used in the first investigation are 0.2, 0.4, 0.6, 0.8 and 1mm. An experimental investigation technique has used for the conduct of the second investigation [38]. Besides, the step depth variation used in the second study is 0.1, 0.6, 1.1, 0.1, 0.2, 0.3, 0.4, 0.5, 0.7 and 1.0mm.

Effect of Material thickness on accuracy

From the survey made only 1 study has found in which that concludes material thickness influences the accuracy of the parts formed by the single point incremental sheet forming. The researcher has confirmed accuracy increases whenever the sheet thickness increased [21]. Polymer sheets with 2 and 3mm thickness have used in the investigation. The method the researchers used for the conduct of the investigation was experimental.

Effect of Tool Diameter on Accuracy

From the assessment carried out on the effect of tool diameter on the accuracy, 1 study has found in which that concludes tool diameter influences the accuracy. The researcher has concluded that accuracy increases with a decrease in tool radius. Simulation with the experimental investigation has used for the conduct of the study [35]. Steel sheet material has used for the investigation. Besides, 6 and 10mm diameter forming tool has used for the investigation.

Table 1.5 Effect of Parameter interactions on Formability

Authors	Effect of Parameter interactions
Hussain 2010 [37]	Formability increases; when Higher step size with higher tool radius is used. Formability decreases; when Small step size with higher tool radius or Large step size with a small tool radius is used
Le 2008 [15]	Formability increase; when Large tool radius with a small step size; Small step size with a small feed rate ; A large tool with a small feed rate
Bosetti 2010 [3]	Step-down, feed rate interactions do not influence formability
Huang 2008 [4]	Formability will decrease with the decrease of (t_0/R_{tool}) ratio and ($\Delta z/R_{tool}$) ratio; or The formability increases with the decrease of (R_{tool}/t_0) ratio and ($\Delta z/t_0$) ratio;
Ham 2006 [14]	Small tool size and thickest material increase formability

Note: Original sheet thickness (t_0); Step depth (Δz); Tool Radius (R_{tool})

Effect of Feed rate on Accuracy

From the investigation carried out on the effect of feed rate on accuracy, two studies have found in which that concludes feed rate affects the accuracy ([35], [39]). The first conclusion is that accuracy increases with the decrease in feed rate [35] and the other conclusion is that an increase in feed rate improves accuracy [39]. The first investigation uses steel material and the feed rate used is 1500 and 3000mm/min. Besides, this study uses simulation and experimental investigation techniques. The second investigation uses polymer sheet and the feed rate used is 1200, 1400 and 1600mm/min. The investigation technique used in this study is experimental.

Effect of Parameter interactions on accuracy

From the review made on incremental sheet forming only one paper has found in which that concludes parameter interactions influence the accuracy [41]. An experimental technique has used for the investigation and the material used for the conduct of the investigation is Aluminum. The first conclusion of the researcher is accuracy increases with the interaction of minimum vertical step size with maximum; sheet thickness, tool diameter, and feed

Table 1.6 Effect of Step Depth on Surface Roughness

Authors	Step Depth (mm)	Effect of Step Depth
Radu 2011 [35]	0.05,0.5	With smaller vertical step
Shanmuganatan 2013 [10]	0.2, 0.4, 0.6, 0.8, 1	depth better surface finish achieved.
Golabi 2014 [12]	1,1.5,2	
Cerro 2006 [43]	0.5,1	
Mulay 2015 [44]	0.25, 0.5	
Malwad 2014 [32]	0.2,0.5	
Echrif 2014 [45]	0.25, 0.6, 1, 1.25	
Hamilton 2010 [46]	0.10,0.25, 0.40	
Mulay 2017 [47]	0.2, 0.4,0.6	
Gulati 2016 [26]	0.5, 1, 1.5	
Hussain 2008 [16]	0.2,0.75,1.3	
Malwad 2014 [32]	0.2,0.5	
Chezhian 2010 [20]	0.3,0.4 0.5	
Lu 2014 [38]	0.1, 0.6, 1.1,0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 1.0	
Lasonon 2013 [48]	0.381,0.762	
Cavaler 2010 [49]	0.4,0.6,0.8	Better surface finish
Bosetti 2010 [3]	0.3,0.8	achieved with an increase of
Shah 2016 [50]	0.2, 0.5, 1	the vertical depth
Bhattacharya 2011 [17]	0.2,0.5,0.6,0.8,1	Surface roughness increases up to a certain angle and then decreases.

rate. The second conclusion of the researcher is accuracy increases with the interaction of maximum sheet thickness with; maximum tool diameter and Minimum feed rate. The third conclusion of the researcher is that accuracy increases with the interaction of maximum tool diameter with maximum feed rate and minimum spindle speed.

III. Surface Roughness Summery of Papers

Surfaces are commercially and technologically important for a number of reasons. The first one is Aesthetic reasons, Secondly, Surfaces affect safety. Thirdly, Friction and wear depend on surface characteristics. Fourthly, Surfaces affect mechanical and physical properties; Fifthly, Assembly of parts is affected by their surfaces; the last one is, smooth surfaces make better electrical contacts [42].

Effect of step depth on Surface Roughness

The assessments on the pieces of literature to review the effect of step depth on the surface roughness in SPIF shows three different conclusions that have made by the researchers. Figure 1.6 described the conclusions and Table 1.6 present the details. Steel sheet has used in 4 of the investigations including [35], [12], [20], [49] and aluminum has used for the conduct of the study in all the rest of 15 investigations. Besides this simulation and experimental investigations have used in the studies [35], [10], [12] and [43]. While the rest of the investigations have conducted using experimental investigation.

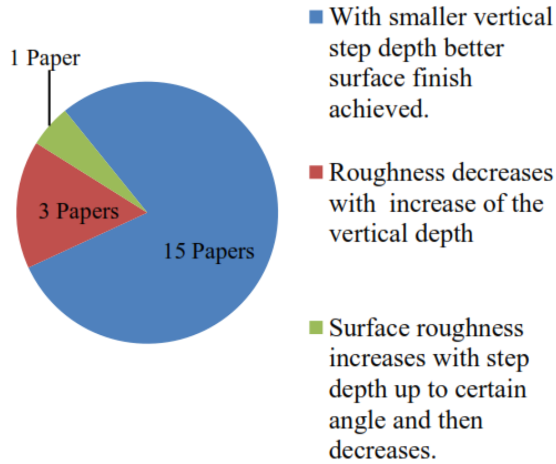

Figure 1.6 Effect of step depth

Effect of Material thickness on Surface Roughness

Based on the reviews made, two studies have investigated the effect of material thickness on the surface roughness of the part produced by the SPIF ([26] [20]). The first investigation concluded that increasing material thickness leads to the rough surface of the formed part [26]. Aluminum alloy has used for the conduct of the study and the material thickness variations used in this investigation is 0.55, 1.09 and 1.67mm. The second investigation [20], concluded Increasing sheet thickness leads to the better surface finish. The material thickness variations used in this investigation are 0.4, 0.6, and 0.8mm. Both of the investigations have used an experimental method for the conduct of the investigation.

Effect of Tool diameter on Surface Roughness

The assessments on the pieces of literature to review the effect of tool diameter on the surface roughness in SPIF show two different conclusions that have made by the researchers. Figure 1.7 display the results and table 1.7 describes the details.

Table 1.7 depicts the details of the tool diameter used and the conclusions made on the effect of tool diameter on the surface roughness. Aluminum alloy is the materials used in 5 of the investigations [10], [17], [45], [47] and [26]. Steel material has used for the conduct of 2 of the investigation [35], [49] and further 2 of the investigations used polymer sheet [9], [21]. Besides this, two of the studies [10] and [35] used both simulation and experimental methods. While the experimental method has used in the rest of the investigations.

Effect of Feed rate on surface roughness

To review the effect of feed rate on the surface finish, 7 studies have analyzed. 3 of the papers conclude feed rate does not have a significant influence on surface finish. Figure 1.8 illustrates the result of the review. The details of the conclusions on the effect of feed rate have illustrated in table 1.8. Aluminum alloy is the materials used in 6 of the investigations and steel material has used in 1 of the investigation. One study [35], used both simulation and experimental methods for the study. The

Table 1.7 Effect of Tool Diameter on Surface Roughness

Authors	Tool diameter (mm)	Effect of Tool diameter
Shanmuganatan 2013 [10]	2.5, 5, 10	Increasing tool diameter enhance the
Radu 2011 [35]	6,10	surface finishing
Bhattacharya 2011 [17]	4,6,8	
Cavaler 2010 [49]	16,20	
Echrif 2014 [45]	5,10,20,30	
Mulay 2017 [47]	8,10,12	
Gulati 2016 [26]	8,12	
Zhang 2016 [9]	10,12	
Franzen 2009 [21]	10,15	Decreasing tool diameter enhance the surface finishing

Table 1.8 Effect of Feed on Surface Roughness

Authors	Feed rate(mm/min)	Effect of Feed rate
Mulay 2015 [44]	500,800,1200	Does not have a significant
Bosetti 2010 [3]	1000,1500	Effect on surface finish.
Shah 2016 [50]	500,800,1200	
Radu 2011 [35]	1500,3000	Increase feed rate leads to a
Lasonon 2013 [48]	317.5, 635,1270	better surface finish
Mulay 2017 [47]	600, 1400, 2200	Decrease feed rate leads to a better surface finish
Gulati 2016 [26]	1000, 2000, 2500	

material used in this investigation is steel. Experimental method has used in the investigations [44], [3], [50], [48], [47] and [26]. The material used for the conduct of the investigations in these 6 studies is Aluminum.

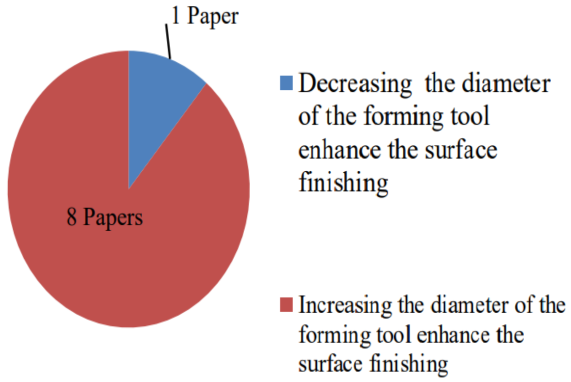

Figure 1.7 Effect of Tool diameters

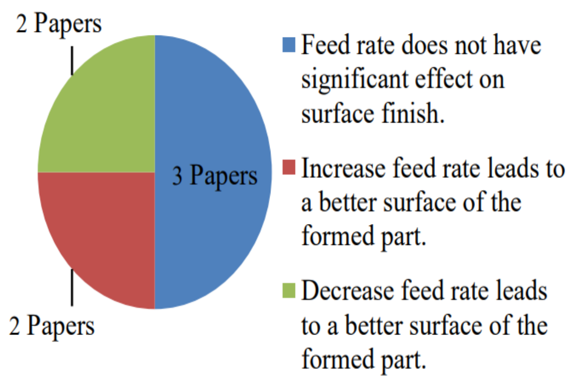

Figure 1.8 Effect of Feed rate

Effect of parametric interaction on surface roughness

Effect of parameter interactions on surface roughness has reviewed by considering the 2 Studies [51, 29]. The material used in the first case is Steel. Based on the conclusion made, increasing feed rate and step depth decreased roughness and also large tool radius and higher step depth improve roughness [51]. An aluminum sheet material has used in the second investigation. The researcher has concluded, an increase in vertical step with the larger size of tool diameter decreases the surface roughness [29]. The experimental study is the technique used in both of the investigations.

IV. Conclusions and Research Gap

The intention of the review in this literature has outlined in the introduction part of this unit. In this section, the conclusions and research gaps are described based on the aims of the review. In the first part of this section, the summary of a quantitative review of the sheet material used; the methods used for the investigation; the most investigated quality of the part (formability, accuracy, and surface finish) by single point incremental forming is identified. In the second part of this section, the research gaps based on the quantitative reviews are highlights for future studies.

Formed Sheet

Aluminum is the most studied material from the reviews carried out on the effect of process parameters on formability, surface roughness and accuracy in the single point incremental sheet forming process. From 47 papers, 29 of the studies have conducted on Aluminum Alloys. The investigations further comprise the polymer, steel, titanium and composite sheet materials. Figure 1.9 illustrates details of how many times the materials used in the investigations.

The same survey result has been noted by Echrif and Hrairi [52] in 2011. It is noticed that only certain sheet metal types are used in the forming processes such as aluminum, titanium, magnesium, polymer, and copper. It is observed that aluminum alloy was more studied, and that is because aluminum sheets have better formability when compared to other sheet metals.

Types of Investigations

In this literature survey, the investigations that have been conducted to examine the formability, surface finish and accuracy of the parts made by the single point incremental sheet forming have considered. Form 47 papers 39 papers were conducted on the experimental investigations whereas 8 of the investigations have conducted by simulation with the experimental technique. The details of how many papers relied on experimental or simulation with the experimental technique are described in figure 1.10.

Based on the investigations as depicted in figure 1.10, the experimental approach has used in most the studies. While simulation combined with the experimental approach is an emerging technique in the study of the single point incremental sheet forming process.

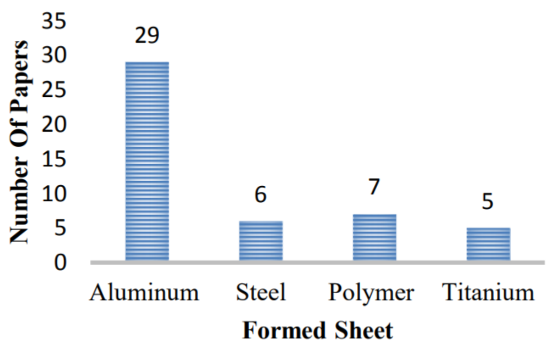

Figure 1.9 Formed sheet distributions

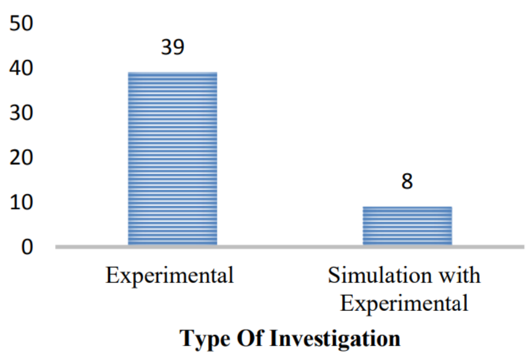

Figure 1.10 Investigations techniques used

Consistency of results

The reviews conducted to investigate the effect of process parameters on formability has used to decide on the consistency of the studies. The formability has chosen because it has extensively investigated when compared from accuracy and surface finish studies.

From the reviews, highest consistency or agreement between the researchers (More than 90%) has observed on the effect of material thickness on the formability, which is when the thickness of the material increases the formability of the part made by the single point incremental sheet forming also increase. The other evaluations on the effect of feed rate, the effect of tool diameter, the effect of step depth do not show excellent consistency since the maximum consistency is below 70% (figure 1.11).

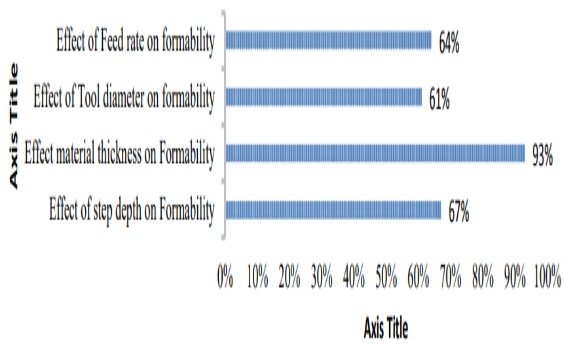

Figure 1.11 Consistency on the evaluations made

Most studied quality

Investigations on formability, surface roughness, and accuracy in the single point incremental forming further assessed by considering the 45 journal articles and 2 conference proceeding. The details of the quantitative data on the studies made to investigate the most investigated quality of accuracy, surface roughness, and formability have illustrated in figure 1.12.

From figure 1.12, most of the investigations have conducted to study the formability in the single point incremental sheet forming process and also less research interest has given to the accuracy of the single point incremental sheet forming process.

Studies on effect Parametric Interactions

In this literature study, the effect of a particular process parameter in the formability, surface finish and accuracy of the parts produced by the single point incremental sheet forming is introduced. However, 6 authors have pointed out the effect of parametric interactions on the formability, surface finish and accuracy of the parts formed by the single point incremental sheet forming. Form 48 studies 6 studies investigated the effect of parametric interactions as depicted in figure 1.13.

From figure 1.13, a majority of the investigations have been a relay on the investigation of the effect of particular process parameters on the formability, surface finish and accuracy of the parts formed by single point incremental sheet forming. From figure 1.13, we further understand that fewer research concerns have given to investigate the effect of parametric interactions on SPIF.

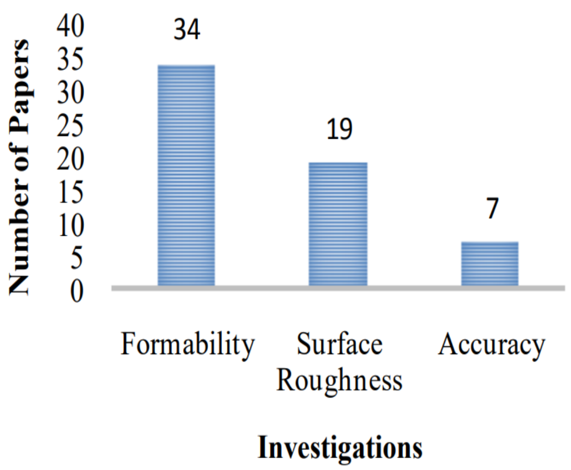

Figure 1.12 Most studied quality

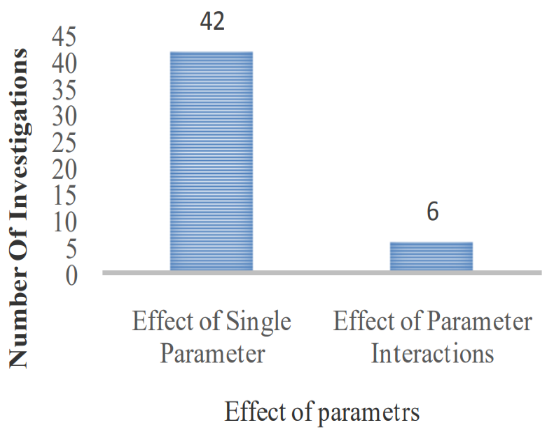

Figure 1.13 Studies on effect Parametric Interactions

V. Research Gap

- The following major research gaps have observed after carry out the systematic quantitative literature review taken from 45 journal articles and 2 conference proceedings.
- Most the studies on the single point incremental sheet forming are dealt with the formability studies. From the review, accuracy and surface finish studies need more concern.
- There is no consistency in the results of the effect of process parameters on the formability limit, accuracy and surface finish. As a result of this, investigate the effect of process parameters on the formability limit, surface roughness and accuracy of a specific material are significant.
- Aluminum is the most studied material in SPIF. However, a wide range of materials other than aluminum needs to examine.
- From the evaluations on the consistency in section 1.5.3 is clear that working on optimization techniques is required to get optimum process parameters for better formability, accuracy and surface roughness of the parts that will be produced by using SPIF.

- Most of the investigations are experimental investigations. So simulation with experimental studies should be considered.
- Most of the investigations on the effect of process parameters has not studied the effect of parametric interactions on the formability, surface roughness, and accuracy. Rather, the studies concerned with making the other parameters constant and varying the required parameter. Hence, the effect of parameter interactions needs more consideration.

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