Effect of parameters on Grain Orientation Behaviour In Single Point Incremental Forming

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This Thesis entitled Effect of parameters on Grain Orientation Behaviour In Single Point Incremental Forming by Nathu Lal Singroul is approved for the degree of Master of Technology from IIT Hyderabad.

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Abstract

In this work effects of different incremental forming parameters (tool diameter, incremental depth, and wall angle) on the grain orientation in the in the deformed region of formed components, in rolling and transverse direction is studied for aluminum sheet Al-5052 of thickness 0.7mm. This is done by using XRD in which brags angle(2θ) and corresponding intensity of peaks are recorded. Al-5052 is having FCC crystal lattice structure, for FCC crystal structured material maximum intensity of peaks are on the planes, {111}, {200}, {220} and plane{311}, and these planes corresponding to the brag's angles (2θ): - 38.38°, 44.56°, 64.92°, 77.99° respectively. Variations on the intensity of the peaks for the corresponding brag's angles looking for the study, i.e. by observing these variations of the intensity of the peaks on the planes, one can say that which plane have a maximum percentage of grain along a particular direction. The intensity of the peaks on the planes are corresponding to percentage of grain accumulated on that particular plane, which means, a plane having maximum intensity of peak corresponding to particular brag's angle resulting from a maximum percentage of grain accumulation on that plane. By observing these intensity peaks variations, one can say that which particular parameter has an effect on the grain orientation behaviour for Al-5052 material in the given direction. In This study tool diameter, incremental depth, and wall angle are the parameters for studied, experiments are performed in two different levels for each parameter. Full factorial method for design of experiment is used for study. The components are formed in such a way that tool movement direction and rolling direction of the sheet are parallel in one side of the deformed component and perpendicular to other side wall of the component. In that case, viz parallel to sheet rolling direction and perpendicular to sheet rolling direction. For the study small rectangular strip from both the direction is taken and experiments are performed in all the specimens.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Introduction

Sheet metal forming process uses bending, stretching, drawing or their combinations are used to produce parts for wide variety of applications. Most of the conventional metal forming processes uses special tooling for the production which leads to extra cost and lead time due to their design and manufacturing of such tooling. So the conventional processes are suitable for the mass production so the incurred cost in tooling can be compensate by large volume production. But today's scenario is not like that customer wants more variety of products with the minimum expenses so we need to produce wide variety of product with least cost for that the conventional metal forming process is not suitable as it is suitable for mass production if we produce large variety of product with conventional metal forming process we require huge tooling cost for their design and fabrication so it's not suitable. Incremental Sheet Metal Forming (ISMF) is one such technology that satisfies the requirement of customized production at low cost.

Incremental sheet metal forming produces product without using die so as regard as die less forming process which lower the cost of final product. Hence it's not using any die or special tooling so the cost incurred in their design and fabrication is eliminated which leads to huge impact on final product cost reduction. Incremental sheet metal forming process is gaining importance

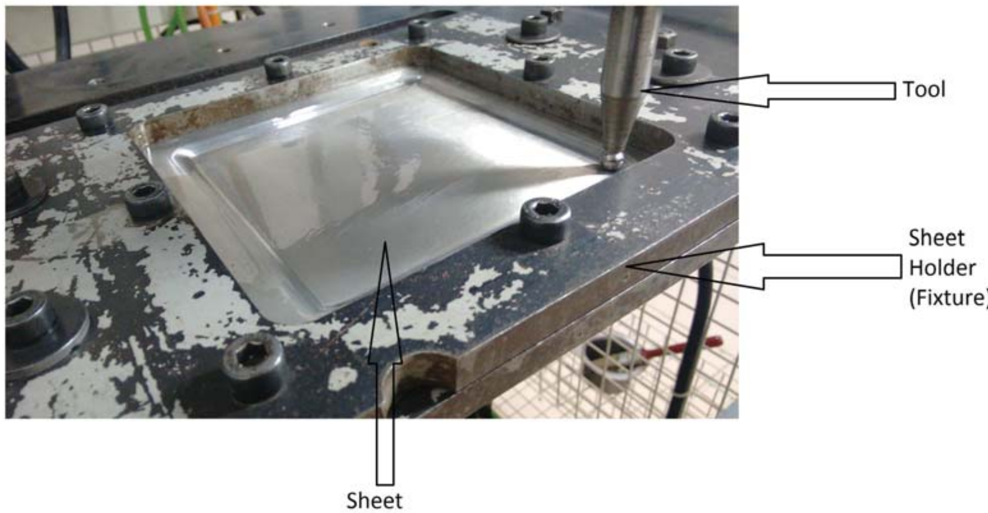


Figure 1.1: Representation of incremental forming with a single forming tool

because of its great potential to form complex three-dimensional parts without using component specific tools, unlike in conventional stamping operation. Forming products without using specific tooling is another alternative for effective and economic production of low volume and large variety of products. Hence, it offers a valid manufacturing process to match the needs of mass customization. The benefit of this process is mass customization, high formability, low cost, process flexibility as the final shape is defined by the kinematics of tool path and not by part specific dies and punches as in the case of conventional sheet metal forming processes.

In Incremental sheet metal forming process the sheet is clamped in a fixture with opening window and hemispherical ended tool is programmed to move in a pre-defined path which progressively deform the sheet and give final shape of product. The movement of the tool is defined the final shape and size of the product without using of specific tooling. Higher forming limit achieved as compared to conventional stamping process due to localized deformation. The die-less nature of ISMF provides a competitive alternative for economic and effective production of low-volume functional sheet metal parts. Figure 1.1schematically shows the basic components of incremental forming (IF) process. The process is carried out on a Computer Numerical Control (CNC) machine. Sheet is clamped about it's periphery on a fixture with an opening window and the hemispherical/spherical forming tool is moved along predefined path and progressively forms the components. As the tool moves in small step size the production cycle is comparatively large but it is suitable for small batch production.

1.2 Configurations of Incremental Sheet Metal Forming

The incremental forming process produces a product without using die, but one can use die support also based on this ISMF process is classified into two categories: with-die forming and without die forming Figure 1.2 shows schematics of different ISMF process variants. Negative die-less incremental (Fig.1.2(a)) forming also known as Single Point Incremental Forming (SPIF) is the simplest variant of incremental forming. In this variant, a single tool forms the component form one side (top) of the sheet without any support from the other side (bottom). It is fully flexible and die-less process. As the sheet is free from bottom side in SPIF.

Two Point Incremental Forming(TPIF) die support is uses and the die support can be partial or full and it can be static or dynamic based on the nature of the support ISMF has partial die support, full die support and Double sided incremental forming process. Partial die support or positive incremental forming process in which the partial die is the static support as shown in figure1.2(b), full die support as shown in Figure1.2(c) and full die can be negative or positive and the clamped sheet can move up and down. In this process die support is designed based on the final shape of the product or die is a replica of the product. All of the configurations are realized with mounting the required attachment on standard NC (numerical control) machines. Other variants of TPIF are Double side incremental forming process showed in Figure1.2(d)instead of static support one independent tool is mounted which controls independently and act as a tool for this additional controller is required to control the second tool.

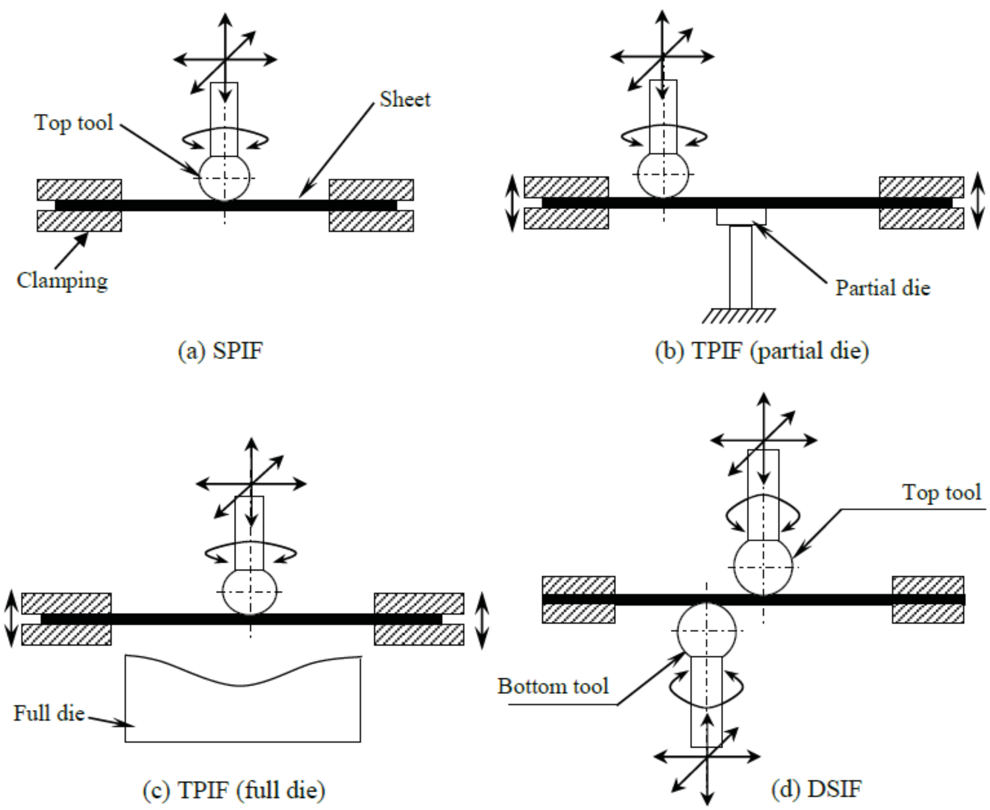


Figure 1.2: Variants of incremental sheet metal forming[13]

Chapter 2

Literature Review

2.1 Literature Review

Incremental sheet metal forming process serves the purpose of mass customization and rapid development of the industrial products with reduced cost and lead time It has the capability to form axi-symmetric and asymmetric components without using special tooling.

During ISMF material is deformed by progressively tool movement in which the tool movement is overlapped in subsequent tool path due to that strain hardening takes place of the overlapped deformation zone. This increases the equivalent strain of the material being formed in subsequent contours with an increased tendency of failure. Therefore, developing capability to form a component without fracture and good surface finish become an important requirement. This accurate prediction of formability will assist to improve surface finish and accuracy of the final product. In the conventional metal forming process the forming limit is defined where localized necking start. Formability of conventional metal forming process is represented by Forming Limit Diagram (FLD) introduced by Keeler and Backofen. FLD is a plot of major and minor principle strain for various loading condition like simple tension, biaxial, plain strain, etc. formability of ISMF is majorly govern by amount of thinning of the deformed sheet leads to fracture. Formability of ISMF is much higher than the conventional metal forming process and given by the negative slope towards minor positive

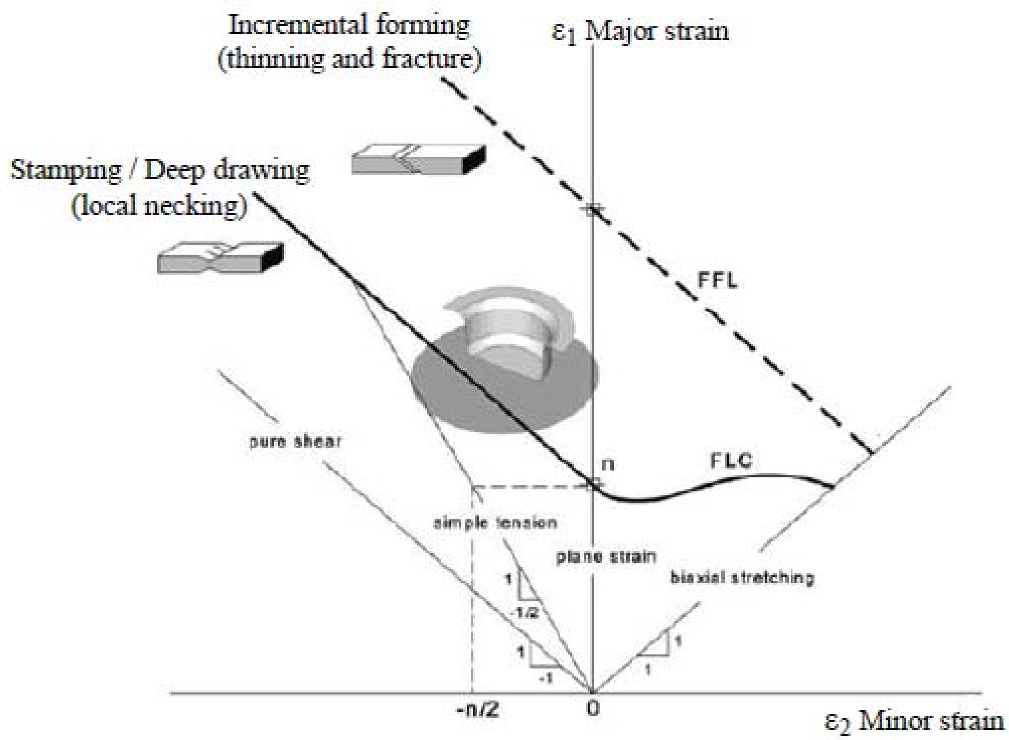


Figure 2.1: Schematic representation of forming limit of SPIF against that of stamping and deep drawing [14]

strain region. Deformed sheet thickness is predicted by sine law however, thickness measurement of a wide variety of components formed using single point incremental forming shows considerable amount of difference between predicted value by sine law and the measured value. Sine law expression for predicting thickness is derived by assuming through thickness shear, plain strain deformation only. Thickness predicted by sine law is overestimated and uses as an approx value. This is reported in many studies.[[2], [8], [9]].

Kim and Park, reported the effect of process parameters like tool type (freely rotating ball, hemispherical), tool size, feed rate, friction at tool-sheet interface on fully annealed Al 1050 sheets by conducting experiments and FEA analysis[11]. It was found that the formability is improved when a ball tool of a particular size is used with a low feed rate. As the tool size increases, the deformation zone or the contact zone increases and the level of strain decreases. As a result, the forming depth increases. They also observed influence of tool diameter on formability in rolling direction (RD)

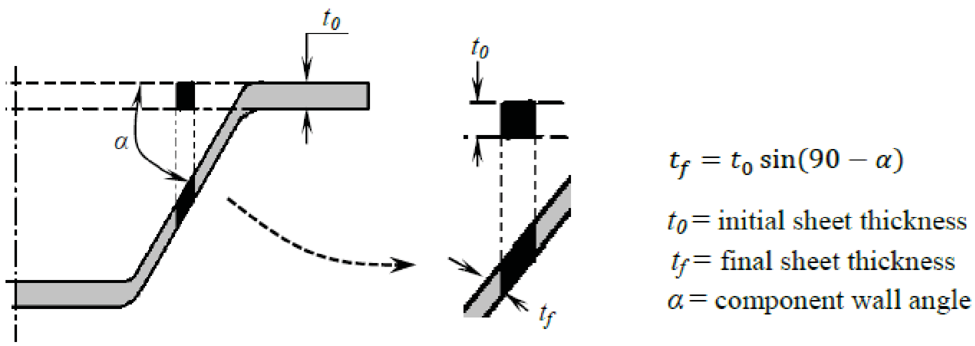
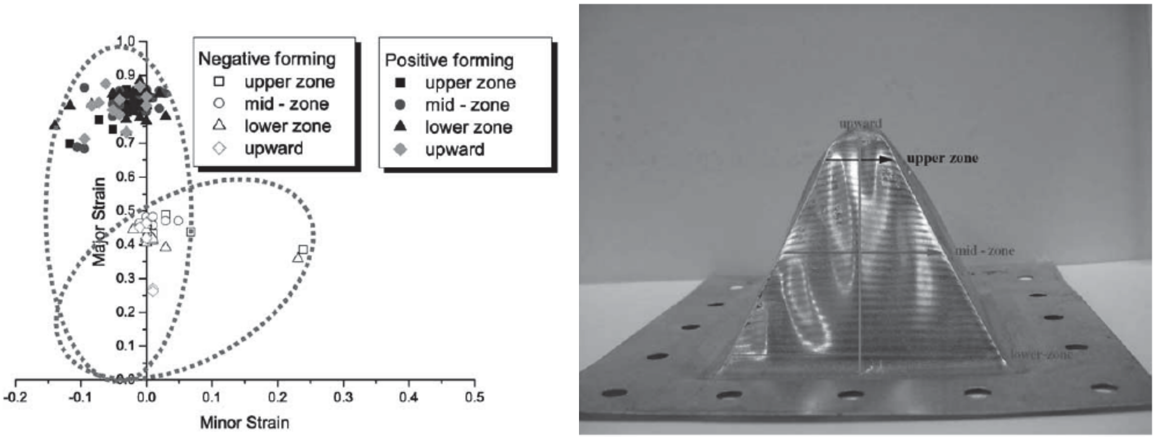


Figure 2.2: Illustration of sine law [14]

and transverse direction (TD) of sheet and found that in RD, formability decreases with increase in tool diameter and rotating tool suitable for improve formability. Friction at the tool sheet interface increases the pressure on the tool and reduces stress in the sheet that delay crack initiation which increase formability.

Park and Kim, examined the formability of annealed aluminium sheet under negative and positive incremental forming conditions[12] . The positive incremental forming method is better than conventional one because the deformation occurs in plain strain condition and the forming limit curve shows higher formability in plain strain deformation condition due to that reason positive incremental forming process is capable to form complicated shapes with sharp corners or edges because the plane-strain mode of deformation becomes quite dominant as shown in figure 2.3(a).The support column of the jig should be designed properly and is based on the complexity of the shape to be formed. In the Negative incremental forming process biaxial stretching is occurring, resulting it is difficult to form complex and sharp corner or edges, because cracks easily occurs due to biaxial mode of deformation.

Fratini, conducted experiments by forming truncated cones and pyramidal shapes to study the effect of material properties of the sheet on the formability of copper, brass, high strength steel, deep drawing quality steel (DDQ), AA 1050-O and AA 6114-T4 as sheet materials[5]. They show that the higher the strain hardening coefficient (n) greater will be the formability and relevant influence by strength coefficient (K) and percentage elongation (A). Interaction effect between strength and hardening coefficient (K-n) and hardening coefficient and percentage elongation(n-A) is high. There-



(a) (b)

Figure 2.3: (a)Strain distributions of Positive and Negative Incremental Forming (b)distribution of zones in formed components.[12]

fore formability of material, mostly depends on the hardening coefficient such observation is fully consistent with the process mechanism. It is well known fact that the strain hardening coefficient is an indirect measurement of material to undergoes thinning with no plastic collapse and process mechanism in IF is stretching and local thinning. So material having a high hardening coefficient has greater formability.

Jeswiet, covering several technical aspects in incremental forming process[10]. They summarized that the ISMF has four major parameters, namely sheet thickness, tool diameter, incremental depth, and speed of deformation. Incremental Depth has significant influence on the formability, forming force, forming time and surface roughness, surface roughness and forming forces increases when increase incremental depth, and formability and forming time decreases. Increase angular speed of tool may increase formability due to local heating of the sheet and positive reduction of friction effect at tool sheet interface. There is a negative aspect in that forming tool wear quickly and lubricant tend to burn so need to create a safety environment. Tool diameter plays significant role in IF. When the tool diameter is small the strain is concentrated in the deformation zone of the sheet under the tool and when the tool diameter is large the deformation zone is more so the strain is distributed to more area, thus deformation will take place like conventional stamping and conventional stamping has lower formability compare to ISMF process hence formability is less. The large tool diameter also increases the forming force. For Sheet thickness they propose a linear relation between sheet thickness and formability with increase sheet thickness increases formability.

Ham and Jeswiet, used fractional factorial designs of experiments for studying the effect of process variables on formability of AA 3003 sheet[6]. They reveal that the process parameter like incremental depth, tool size, spindle speed rotation and forming angle govern whether the component can be formed or not. Material thickness and tool size has a significant effect on maximum forming angle. Also observed the effect of forming tool, linear feed rate on formability it was found that slower federate increase of forming a part. Feed rate control the movement of the tool over the surface of the sheet and also heat dissipation in the sheet-tool interface when the federate is low the heat dissipation time is more so likelihood increases the forming a part. The second experiment shows that small effect of step size on the maximum forming angle and the material thickness, tool size and the interaction between material thickness and tool size have a significant effect on maximum forming angle.

Ham and Jeswiet, uses Box-Behnken Design of Experiment to study the effect of parameters ,namely material type, tool size, material thickness, step size and shape with three different level, on forming limit curve and concluded that material type has greatest effect on formability followed by geometry to be formed[7].

Jackson and Allwood, conducted experiments using copper sheets to study the deformation mechanism in SPIF and TPIF to explain the mechanism of Incremental Forming process[9]. For that they cut the sheet into two equal parts and form a rectangular grid in cross section as shown in figure2.4 and joined back and form the components by ISMF. After forming again break in two parts as previous and observed and found that an appreciable amount of through thickness shear occur in the tool movement direction and tensile stress responsible for fracture are reduced. Lines joining the corresponding points of upper and lower sheet surface remain almost normal to the surface in meridional plane this indicates that the deformation in a plane perpendicular to the tool movement direction (Meridonal Plane) is stretching and bending. In a plane parallel to the tool path significant through thickness shear is observed thus tensile stress responsible for fracture gets reduced and higher formability is observed in ISMF. The wall thickness reduction does not exactly follow the sine law

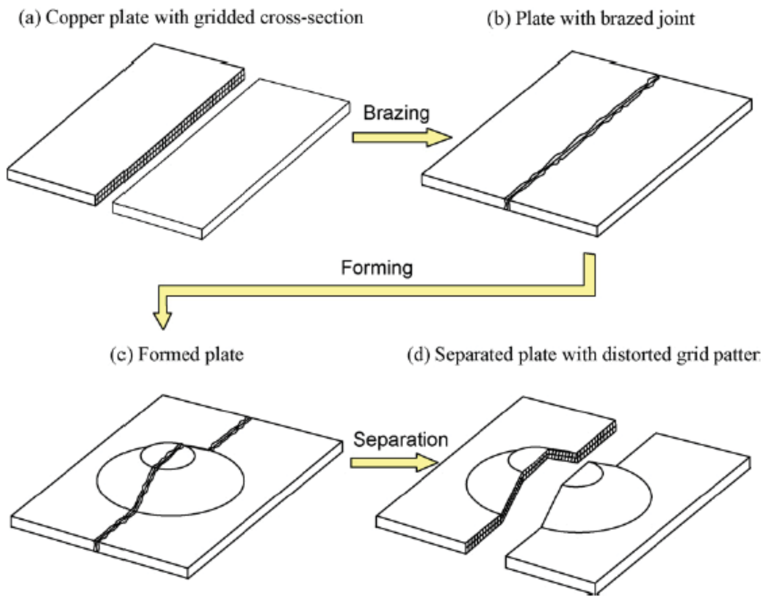


Figure 2.4: Schematic diagram of method for measuring through-thickness deformation: (a) copper plate with gridded cross-section; (b) plate with brazed joint; (c) formed plate; and (d) separated plate with distorted grid pattern [9]

due to increased stretching and shear perpendicular to the tool direction.

Duflou, improve formability performances through the dynamic heating because the limited accuracy of single point incremental forming process has identified as deficiency of the process[4]. To improve the performance, they opted a alternative approach in which the material properties of the sheet are differentiated by localized temperature variation. In this way, different zones can be created in the sheet metal part being processed. By means of a dynamic heat a ductile area with low yield strength is generated . By synchronizing the movement of the heat source over the sheet metal surface with the tool feed rate and direction, and by using appropriate cooling of the surrounding area, a temperature gradient can be assured between this area and the work-piece zone where no deformation is taking place. A favorable impact is observed on process force due to the increased temperature vicinity of the tool contact zone. This force reduction, combined with improved spring back behavior, allows to significantly reduce unwanted deformations and geometric errors, resulting in an all over improved accuracy level.

Jeswiet, measured forces in SPIF and TPIF of Al 3003-O sheets (1.21 mm thick) using

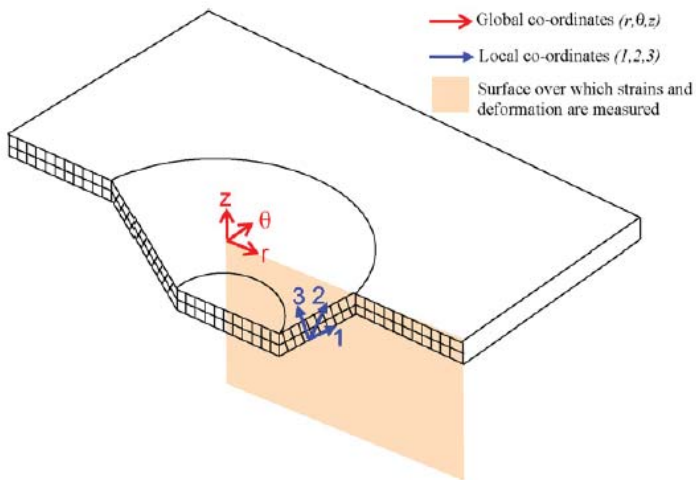


Figure 2.5: A three-dimensional representation of the global and local co-ordinate sets used to interpret strains in SPIF,TPIF and pressing [9]

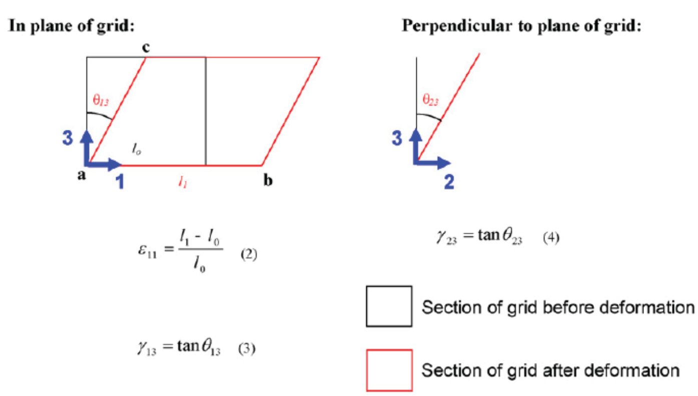


Figure 2.6: Calculation of engineering strains from deformation [9]

cantilever type force sensors[10]. They mounted the sensors on the forming tool for SPIF and on the fixed tool (static support) in TPIF to measure axial, radial and tangential forces. They observed a negative value of tangential force and explained that this unexpected behavior is either may be due to spring back that pushes the tool in the backward direction or due to electricity on forming tool. During TPIF process average and peak forces are increases when increases the wall angle. Axial force is much large as compare to tangential and radial force.

Duflou, conducted experimental study to measure forming forces in SPIF and observed same trend of peak force for components with 60 ° wall angle for different parameters(Tool size, Incremental depth etc)[3]. They concluded that the by increasing tool size, Incremental depth forming forces increases. But Incremental depth has insignificant effect on forming forces so one can use little more incremental depth to save the forming time. One can also reduce the forming time by increasing the tool size and incremental depth also resulting good surface finish in the final part but it increases the force significantly and chances of failure of components will be more for higher value of parameters and become limiting factor. Forming forces also increase with the increasing wall angle Initially it increases and deceases In case of 60 ° wall angle component, decrease in force after peak value is due to localized necking observed near the forming limit region.

Ambrogio, attempted force measurement based strategy to prevent the failure in SPIF[1]. They measured forces by mounting the fixture on top of a dynamometer to form conical component with different initial sheet thickness (AA 1050-O material) and process parameters. The measured force trend is directly influenced by the technological parameters initial sheet thickness and wall inclination angle with increase these parameters force will increase. Actually, up to the force peak, bending is the most dominating mechanism in the specimen; after the peak, the typical stretching mechanics begins and the force trend presents a more complex behaviour, due to the two different effects on the sheet, namely thinning which tends to reduce the required force and material strain-hardening which tend to increase the forming force. Three different force trends are recognizable for different parameters.

1. Stead state curve:- : Once the peak is reached, the forming force remains constant because

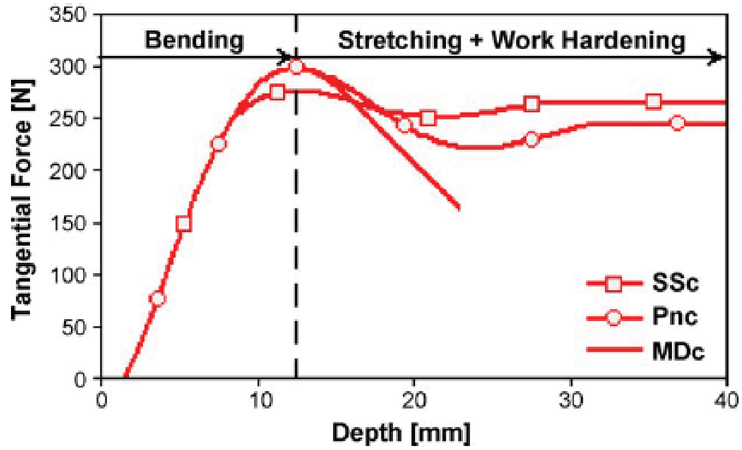


Figure 2.7: Forming force trends during SPIF of Al 1050-O sheet, conical component.[1]

the material thinning effect is immediately compensated by strain hardening. this typically happens for a small wall inclination angle.

2. Polynomial curve:- : After the peak, the curve shows a low negative gradient due to the large thinning during the former stage of stretching. This trend is typically monitored when low strength materials are worked

3. Monotonically decreasing curves:-After peak material thinning is taking and strain hardening is not able to achieve equilibrium. So the force trend is moving down. When material thinning is not compensated by strain hardening, a monotonically decreasing trend is observed leading to component failure.

According to the above considerations, it is worth pointing out that the curve gradient after the peak can be assumed as a critical indicator for the investigated process and setup a critical force gradient. Force gradient is continuously measured and compared with critical one

2.2 Scope and Objective of the work

The present work is on the effect of incremental forming parameters (Wall Angle, Tool Diameter and Incremental Depth) on the grain orientation in different planes of Aluminum sheet. Most of the works in the Incremental Forming process is carried out on formability, effect of material properties on formability[5], effect of process parameters tool type (freely rotating ball, hemispherical), tool size, feed rate, friction at tool-sheet interface on formability[11], examine which process has more formability[12]. To improve the formability and accuracy different alternative approaches or strategies are applied(Hot incremental forming)[10]. Cover most of the technical aspects in the incremental forming process, effect of forming parameters on final components, forming forces and in forming time also covers the material parameters effect on the components.

The main objective of this work is effect of parameters on the grain orientation behavior on single point incremental forming process. This is experimental study. Truncated cones are formed of Aluminum 5052 sheet with two levels of each parameter (Wall Angle, Tool Diameter and Incremental depth). The small rectangular strips from two side walls, i.e. from rolling and transverse direction, is taken out from each component for XRD measurement. By analyzing the XRD measured result one can see the variation in the grain orientation of the formed components. More variation in the grain orientation of the crystallographic planes of the sample shows the maximum effect on that sample.

2.3 Organization of Thesis

The Thesis is organised as follows. In the first chapter is introduction of the process. In second chapter literature review is presented. In the third chapter methodology is presented. In fourth chapter results and discussions for the measured samples, which are from formed components with different parameters and directions. In the fifth chapter conclusions and future scope of the work is mentioned.

Chapter 3

Methodology

Aluminium 5052 sheets having 0.7 mm thickness are used for forming components. Truncated pyramidal shaped components by different parameters ie tool diameters, incremental depth(Pitch), wall angle, are formed and side wall of the formed regions are cut for XRD Measurement. Components are formed in such a way that tool movement direction and rolling direction of the sheet is aligned on one side of the wall named as Rolling Direction(RD), and in another side wall of the sheet tool movement direction and rolling direction are perpendicular to each other named as Transverse direction(TD).For measurement small strip(sample) from the deformed region of the sheet is cut from both the wall as shown in figure 3.1 in which tool movement direction is parallel for one sample and perpendicular for other sample.

Experiments are carried out by varying each of the three parameters, namely (i) wall angle, (ii) incremental depth and (iii) tool diameter at two different level and are given in Table 3.1.

Table 3.1: Factor with their associated levels used for grain orientation study

Factors(Unit)	Level 1	Level 2
Incremental Depth(mm)	0.1	0.25
Tool Diameter(mm)	8	12.7
Wall Angle $\alpha(Degree)$	30	50

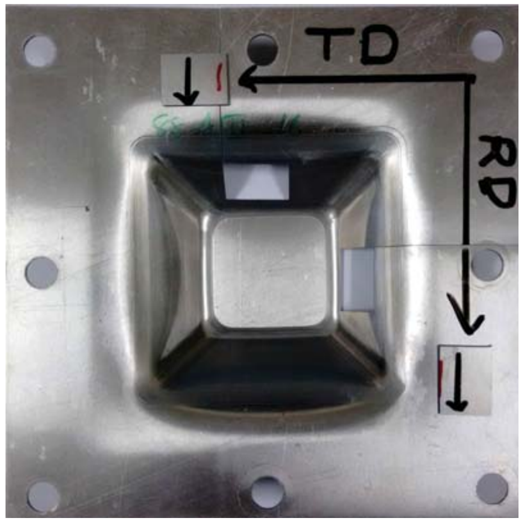


Figure 3.1: Geometry of components used for grain orientation study

A full factorial design is used and a total of 8 experiments are carried out using the spiral tool path generated for each of experiment. After forming each component, a small piece from the flat wall region in Rolling Direction(RD) and small flat piece from Transverse Direction of the deformed wall region from the component is cut and used for the XRD Measurement. XRD analyses are carried out using XRD machine (Model: MZ-III, Rich Seifert Co., Ahrensburg, Germany with control unit STEPSCAN 1000, GBC122XRD Automation). Visual XRD-Ziefert Automation Traces v6 software is used for recording and analysing data. Testing conditions used: 40 kV and 40 mA. Copper material (Cu K-alpha) is used for X-ray having wavelength of 1.541841Å, and scan rate of 3 degree/min i.e. step size 0.050 degree/sec is used.

Table 3.2: Experiment and their respective parameters

S.N.	Wall Angle $\alpha(Degree)$	Tool Diameter(mm)	Incremental Depth(mm)
Experiment1	30	8	0.1
Experiment2	30	8	0.25
Experiment3	50	8	0.1
Experiment4	50	8	0.25
Experiment5	30	12.7	0.1
Experiment6	30	12.7	0.25
Experiment7	50	12.7	0.1
Experiment8	50	12.7	0.25

Chapter 4

Result and Discussion

The grain orientation variation is studied for undeformed sheets both in rolling and transverse direction and the patterns are shown in Fig.4.1(a) and (b) respectively. For aluminium material peaks are noted at 2θ (Bragg's angle) values of 38.20°, 44.50°, 64.80° and 77.80° they correspond to diffraction from {111}, {200}, {220} and {311} planes, respectively shown in figure4.1. Table 4.1 shows the relative percentage of grains that are oriented along different planes in undeformed sheet in Rolling and Transverse Directions respectively.

Table 4.1: Percentage of Grains oriented along Different plane for undeformed sheet in Rolling and Transverse Direction

	Percentage of Grains oriented on Different plane
RD	{111}-4.39 {200}-32.07 {220}-38.92 {311}-24.62
TD	{111}-4.09 {200}-30.22 {220}-40.64 {311}-25.05

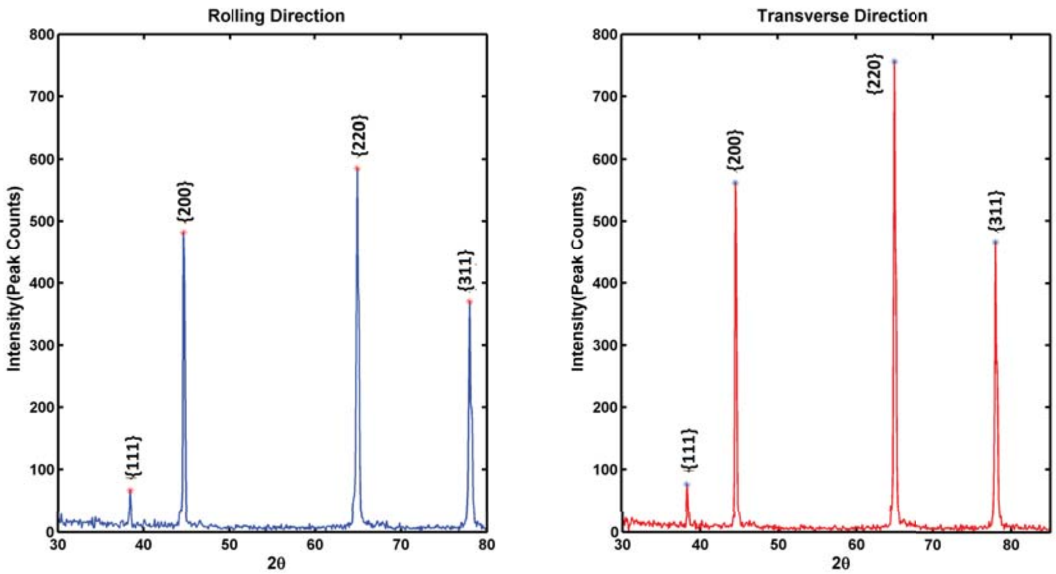


Figure 4.1: XRD pattern of base metal along(a) Rolling Direction (b) Transverse Direction

4.1 Effects in Rolling Direction

4.1.1 Effect of Wall Angle

The table4.2 shows the grain orientation percentage on different planes for the 30° of wall angle of the component. The table shows that variation in the grain orientation is insignificant among all the planes of formed components. When comparing with base metal, plane {111} have greater variation after deformation, and plane {200} has shown decreasing trend for all value of tool diameter when increases the incremental depth. Compare first two experiment which shows small variation in the grain orientation percentage in all planes, and in Plane {111} percentage of grain is increases and decreases on the rest of the planes but this variation is not much. Which means when form components with wall angle of 30° and 8mm tool diameter the incremental depth has minor effect on the grain orientation in rolling direction. But when formed with a little higher tool diameter the Planes {111} and {220} has shown comparatively more variation in grain orientation percentage, which shows incremental depth have more effect on the higher tool diameter. For 0.1mm incremental depth when increases the tool diameter from 8mm to 12.7mm refer Table4.2 variation in the grain orientation is less, and only plane {111} has shown little more variation. For 0.25mm incremental depth this variation is comparatively more on all the planes which indicate that tool diameter has more effect with 0.25mm incremental depth compared to 0.1mm incremental depth. But by looking for the above table one can say that grains are distributed in all planes and conclude that to form components of wall angle of 30° higher parameters are can be used without much disturbing the grain orientation.

Table 4.2: Grain orientation on different planes for the 30° of wall angle in rolling direction

S.No.	Incremental Depth(mm)	Tool Diameter(mm)	Percentage of Grains oriented on planes			
			{111}	{200}	{220}	{311}
1	0.1	8	26.57	32.067	27.572	13.78
2	0.25	8	30.31	31.38	25.63	12.67
3	0.1	12.7	34.46	27.57	23.71	14.24
4	0.25	12.7	20.48	22.029	37.58	19.90

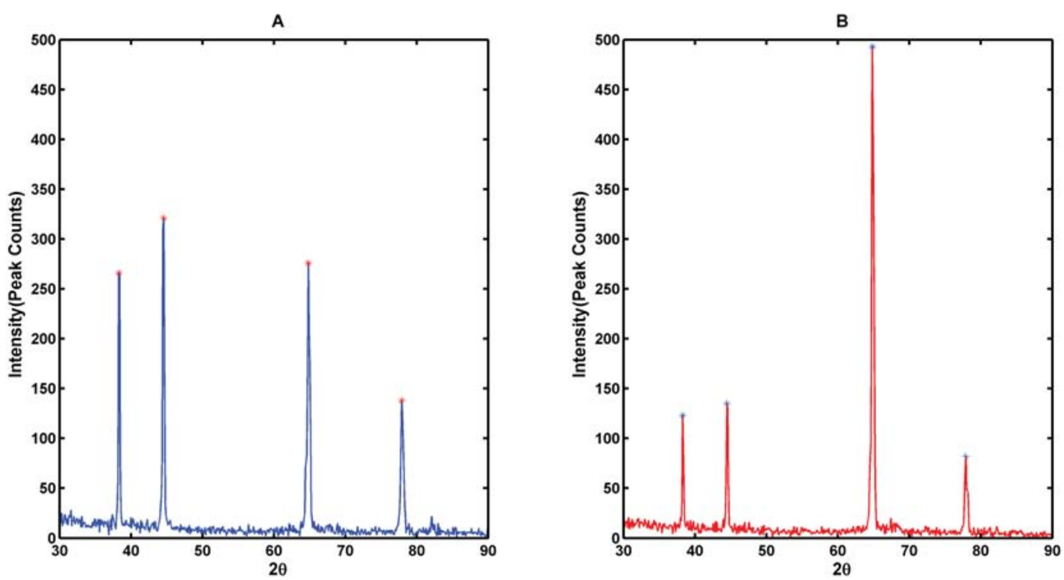


Figure 4.2: XRD pattern for 0.1mm incremental depth with 8mm tool diameter and (A)30° and (B) 50° of wall angle

The table4.3 shows the grain orientation on different planes for the 50° of component wall angle formed using different tool diameters and incremental depth. It can observe that most of the grains are oriented on {220} Plane, for all value of Incremental depth and tool diameter. The table shows that for both tool diameters when increase the incremental depth percentage of grain orientation in the {220} plane is increases and the rest of the plane has decreasing trend, but decrement in the rest of the planes are not significant. For 0.25mm incremental depth and 12.7mm tool diameter 75.48 percentages of the grains are orientated in {220} plane and on the rest of the planes have a minimum percentage of grain, which means the effect of parameters on this component is more or these parameter values has greater effect on the grain orientation nature of the formed components. When components of higher wall angle are formed more stretching and thinning will be there, and using the higher tool diameter and low incremental depth will increase the overlapping of the tool path which leads to more and more thinning and this can be correlated to increased tendency of failure. Which means The components having more grain orientated on a single plane, chances of failure will more for that component. The above table shows such type of data in which the grains are oriented on a preferred orientation in {220} plane so chances of failure of the higher degree wall angle of the components are more.

Table 4.3: Grain orientation on different planes for the 50° of wall angle in rolling direction

S.No.	Incremental Depth(mm)	Tool Diameter(mm)	Percentage of Grains oriented on planes			
			{111}	{200}	{220}	{311}
1	0.1	8	14.76	16.21	59.18	9.84
2	0.25	8	10.87	14.85	65.58	8.68
3	0.1	12.7	14.23	15.33	58.55	11.86
4	0.25	12.7	5.43	10.13	75.47	8.95

The table4.3 show that tool diameter has more effect when component formed with 0.25mm of incremental depth, and for 0.1mm incremental depth tool size has less effect. For 50° of wall angle component, whether the tool diameter is 8mm or 12.7mm or incremental depth is 0.1mm or 0.25mm the grains will be oriented in particular plane{220}. Incremental depth has more effect when component formed with 12.7mm of tool diameter shows in the figure4.7. One can better

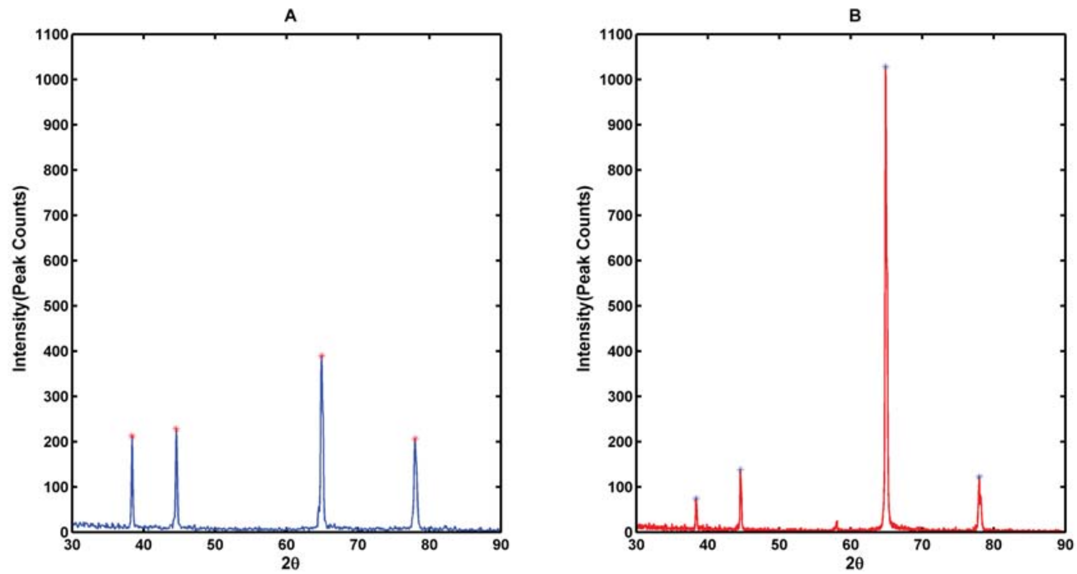
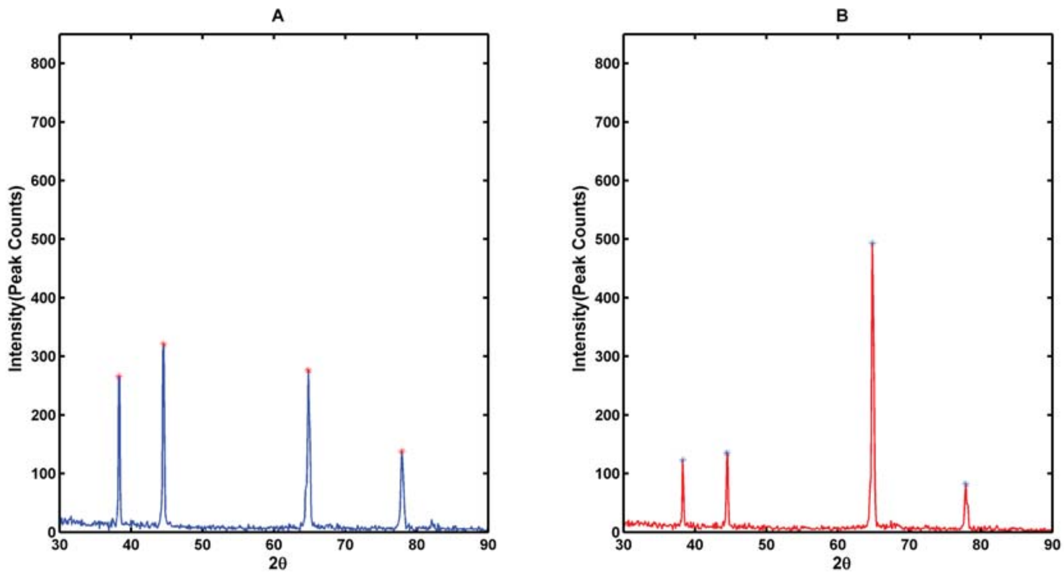


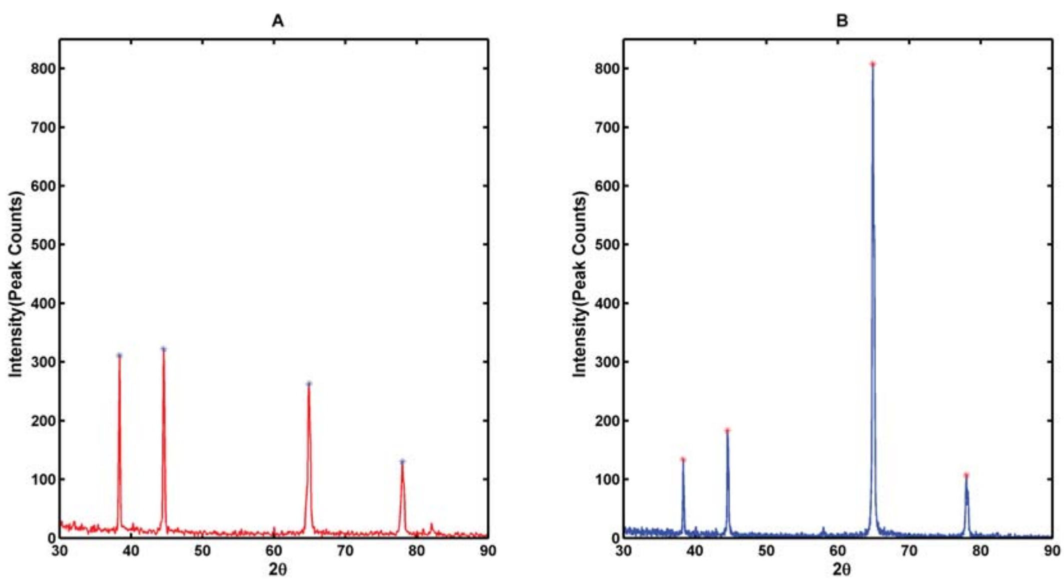
Figure 4.3: XRD pattern for 0.25mm incremental depth with 12.7mm Tool Diameter and (A) 30 ° and (B) 50 ° of wall angle

visualize the effects of wall angle through Figure4.4 In which XRD pattern for 8mm tool diameter and Incremental depth of (A) 0.1mm and (B) 0.25mm and Wall angle of (a)30 ° and (b) 50 ° is shown. By observing Figure4.4(a) In (A) variation of the peaks are insignificant among the planes, but in the Figure (B) only plane {220} shows maximum peaks, which is corresponds to the 50 ° of wall angle. Similarly by comparing Figure4.4(b) between (A) and (B) we can observe similar variation of the peaks as observed for Figure4.4(a), but Figure4.4(b)(B) has shown more fluctuation in the peaks which corresponds to the parameters 8mm tool diameter, incremental depth of 0.25mm and 50 ° of wall angle.This we can see from figure4.4.

Similarly observing the Figure4.5 we can see the variations of the intensity of the peaks on different planes for different parameters. The Figure4.5(b) (B) shows the maximum variation in the peaks in plane {220}. So when increase the wall angle from 30 ° to 50 ° the peak variation is maximum value correspond to parameters, 12.7mm tool diameter, 0.25mm of incremental depth and 50 ° of wall angle.

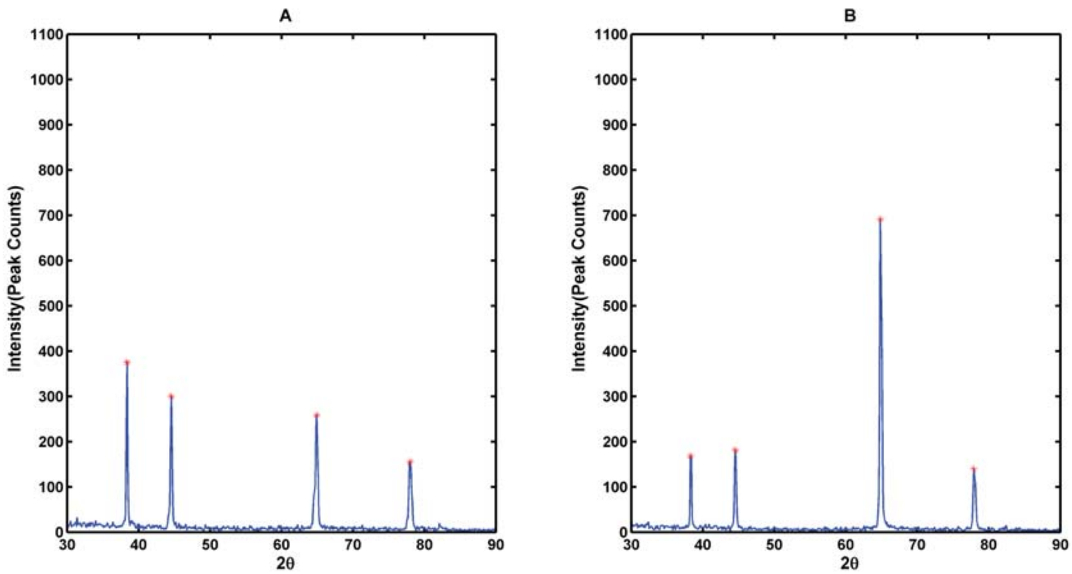


(a)

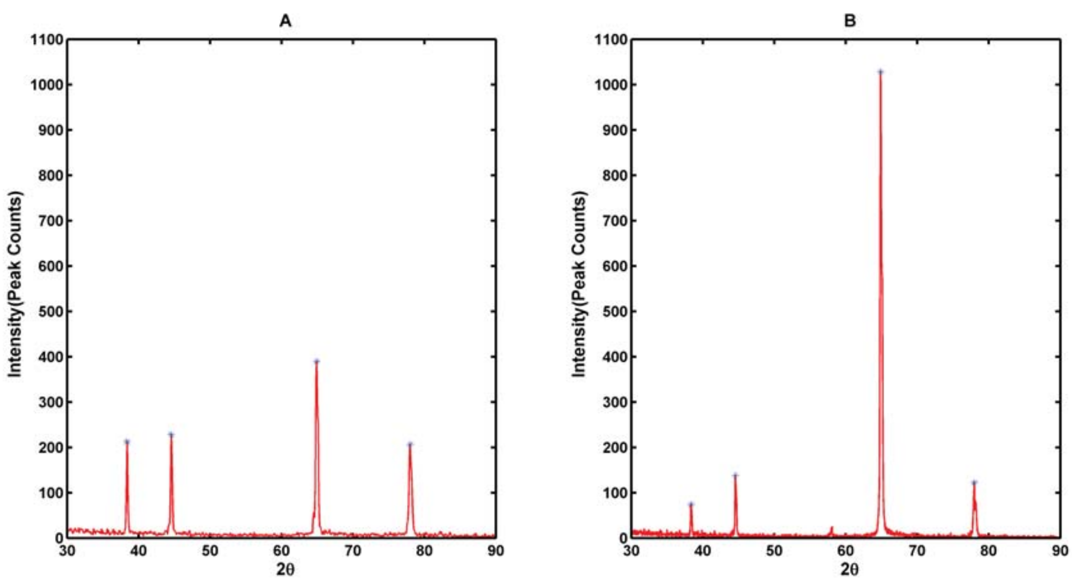


(b)

Figure 4.4: XRD pattern for 8mm tool diameter, wall angle of (A) 30 ° and (B) 50 ° and incremental depth of (a) 0.1mm and (b) 0.25mm



(a)



(b)

Figure 4.5: XRD pattern for 12mm tool diameter, wall angle of (A) 30 ° and (B) 50 ° and incremental depth of (a) 0.1mm and (b) 0.25mm

4.1.2 Effect of Incremental Depth

The table4.4 for the grain orientation on different planes for 0.1 mm incremental depth with different wall angle and tool diameter. From above table one can observe that on the planes {111}, {200} and {311} percentage of grain orientation is decreases and for {220} plane grain orientation percentage is increases, but increment of grain orientation percentage is more compare to the decrement. Comparing on experiment 1 and 3 shows that for 8mm tool diameter when increase the wall angle increment in the percentage of grain on a plane {220} has significant as compared to the variation on the rest of the planes. And for 12.7mm tool diameter, when go for higher wall angle same variations in the percentage of the grain orientation is observed as previous one. Which shows that for 0.1 Incremental Depth and 50° of wall angle, whether the tool Diameter is 8mm or 12.7mm most of the grains are oriented on {220} plane. The Component with 30° of wall angle grains are distributed more or less similar to all planes except for {311} plane, but in 50° of wall angle component having a maximum percentage of atoms on a plane {220}.

Table 4.4: Grain orientation on different planes for 0.1mm Incremental depth and different value of wall angle and tool diameter in rolling direction

S.No.	Wall Angle	Tool Diameter(mm)	Percentage of Grains oriented on planes			
			{111}	{200}	{220}	{311}
1	30	8	26.57	32.06	27.57	13.78
2	50	8	14.77	16.21	59.18	9.84
3	30	12.7	34.47	27.57	23.71	14.25
4	50	12.7	14.23	15.34	58.55	11.85

The table4.5 for the grain orientation percentage on different planes for 0.25 mm incremental depth and different wall angle and tool diameters. The above table shows similar variation in the grain orientation as shows for 0.1mm Incremental depth, i.e. increment of grain orientation percentage only on {220} plane and decrement on the rest of the planes. For 30° of wall angle grains are distributed more or less similar in all planes except for {220} plane, which is corresponds to tool diameter of 12.7mm and for 50° of wall angle, {220} plane has maximum percentage of grains.Hence for 30° of wall angle and 0.25mm incremental depth, Tool diameter has small effect on grain orientation and for the 50° of wall angle tool diameter has more effect. Variation in grain orientation on {220} plane is significant when a higher degree of wall angle component is formed irrespective of tool diameter used, whether the tool diameter size is 8mm or 12mm doesn't matter for 0.25mm incremental depth,

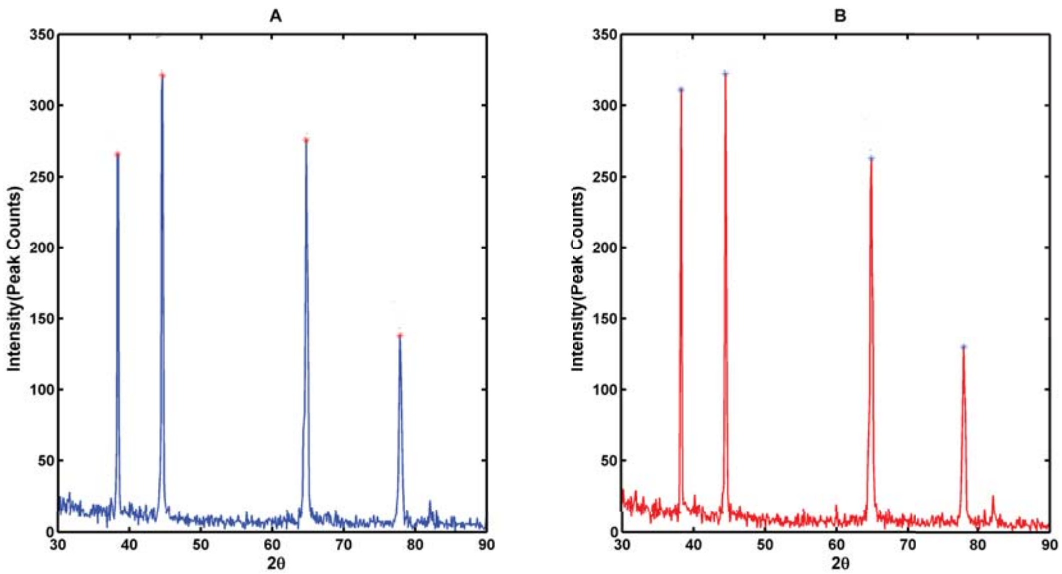


Figure 4.6: XRD pattern for 8mm tool diameter and 30° of wall angle and incremental depth of (A)0.1mm (B) 0.25mm

this nature is similar to 0.1mm incremental depth but less. So the wall angle has a significant effect on grain orientation nature.

Table 4.5: Grain orientation on different planes for 0.25mm incremental depth and different value of wall angle and tool diameter in rolling direction

S.No.	Wall Angle	Tool Diameter(mm)	Percentage of Grains oriented on planes			
			{111}	{200}	{220}	{311}
1	30	8	30.31	31.39	25.63	12.68
2	50	8	10.87	14.85	65.58	8.68
3	30	12.7	20.49	22.02	37.58	19.90
4	50	12.7	5.44	10.13	75.48	8.96

From Figure4.8 and Figure4.9 one can observe the Incremental depth effect on grain orientation. Figure4.8(a) shows very insignificant variation in the peaks where as Figure4.8(b) shows intensity of the peak is more and have significant variation in it, so for 8mm tool diameter and 50° of wall angle, incremental depth has more effect on grain orientation, and for 30° of wall angle

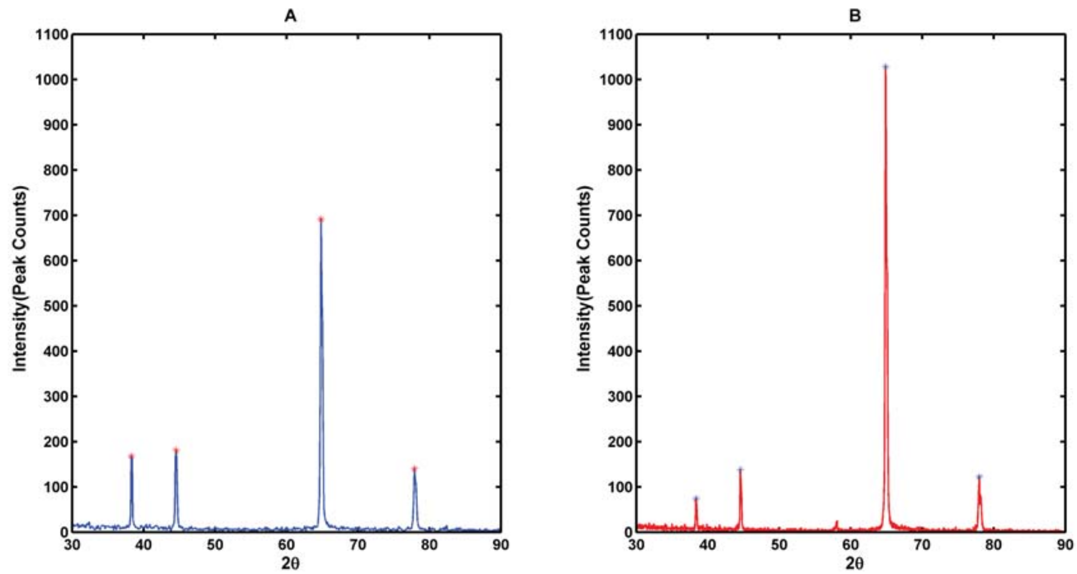
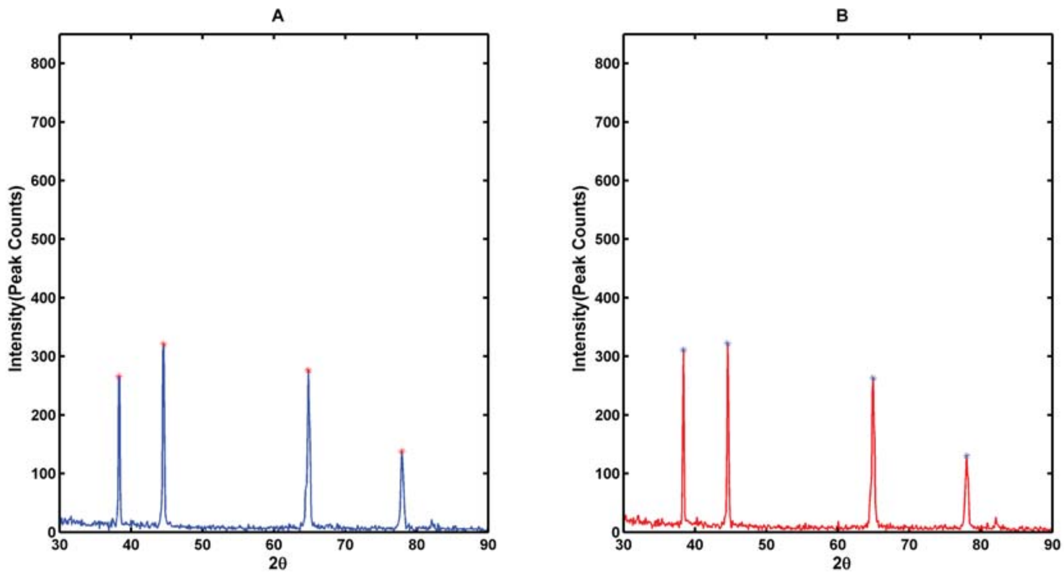
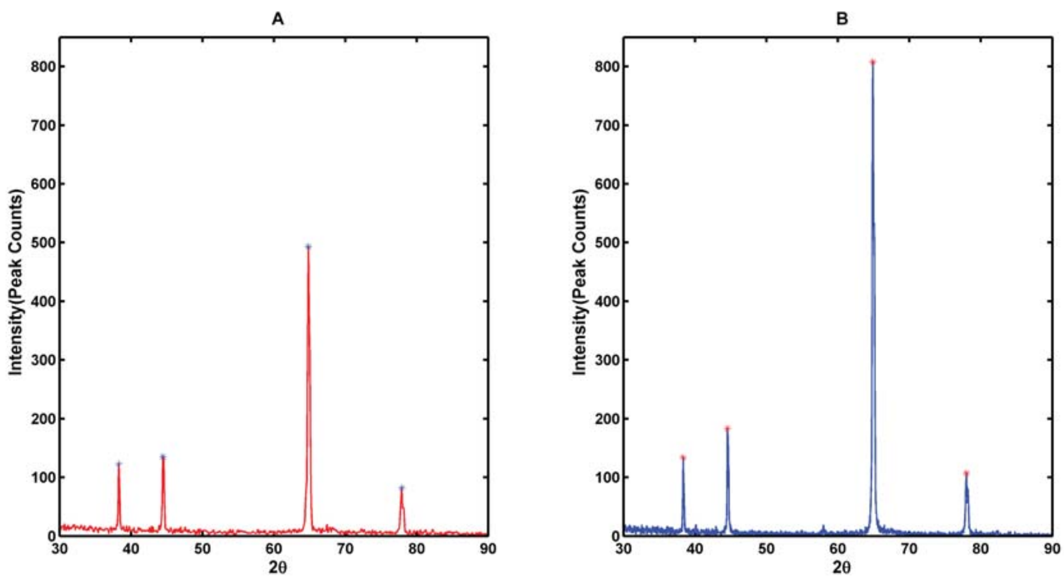


Figure 4.7: XRD pattern for 50 ° of wall angle and 12.7mm tool diameter with incremental depth of (A)0.1mm and (B)0.25mm

incremental depth has insignificant effect on grain orientation. Similarly for 12.7mm tool diameter refer Figure4.9 (a) shows some variation in the peaks between Figure (A) and Figure (B) but comparison to variation in the Figure4.9(b) it's less, so for 12.7mm Tool Diameter and 50 ° of wall angle incremental depth has effect but for 30 ° of wall angle incremental depth has insignificant effect on grain orientation.

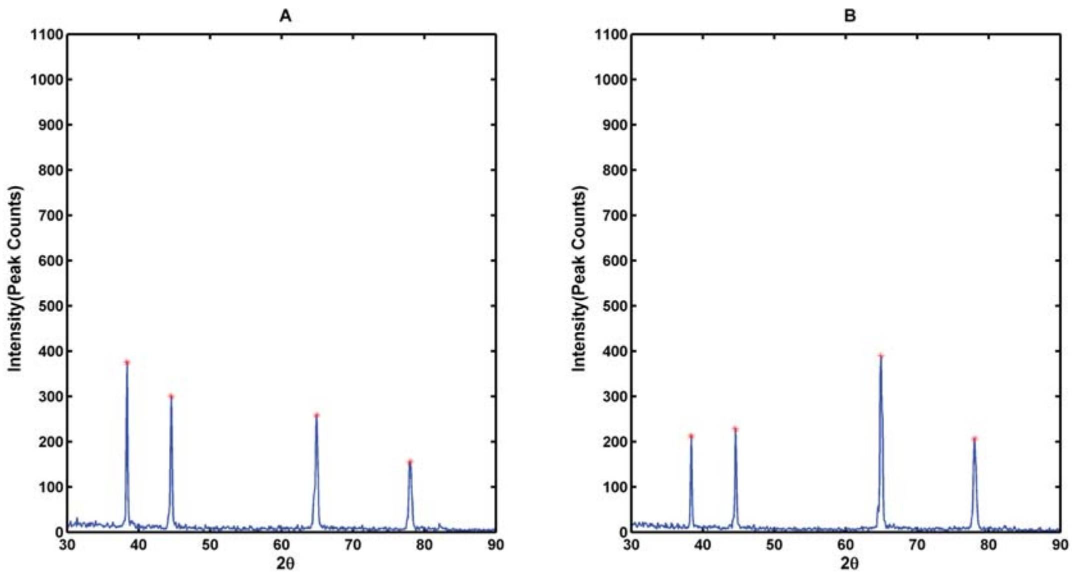


(a)

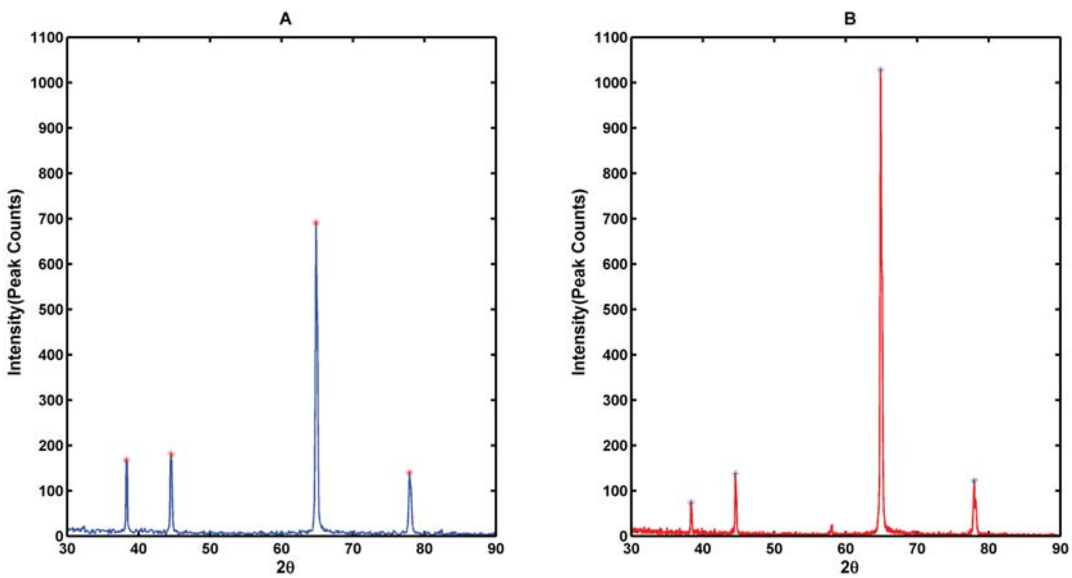


(b)

Figure 4.8: XRD pattern For 8mm tool diameter,incremental depth (A) 0.1mm and (B) 0.25mm and wall angle of (a) 30° and (b) 50°



(a)



(b)

Figure 4.9: XRD pattern for 12.7mm tool diameter,incremental depth of (A) 0.1mm and (B) 0.25mm and wall angle of (a) 30 ° and (b) 50 °

4.1.3 Effect of Tool Diameter

The table4.6 for the grain orientation on different planes for tool diameter 8mm and different value of wall angle and incremental depth. The table shows that for 30 ° and 50 ° of wall angle when increase the incremental depth the percentage of grain orientation on plane {220} is increasing and on planes {200} and {311} grain orientation is decreasing, but the decrement of grains is insignificant when compare to increment of the percentage of grains in {220} plane. For 50° of wall angle and for both incremental depth most of the grains are oriented on {220} plane only. So for 50° of wall angle tool diameter shows significant effect on grain orientation. And plane {220} has a maximum value for 50° wall angle and 0.25mm pitch. Which means component formed with 8mm tool diameter and 50° of wall angle and 0.25mm pitch have more chances of failure compared to other components listed in the table4.6.

Table 4.6: Grain orientation on different planes for 8mm tool diameter for different value of incremental depth and wall angle in rolling direction

S.No.	Wall Angle	Incremental Depth(mm)	Percentage of Grains oriented on planes			
			{111}	{200}	{220}	{311}
1	30	0.1	26.58	32.06	27.58	13.79
2	30	0.25	30.31	31.38	25.63	12.67
3	50	0.1	14.77	16.21	59.19	9.85
4	50	0.25	10.88	14.86	65.59	8.69

The table4.7 for the grain orientation on different planes for tool diameter of 12.7mm with different wall angle and incremental depth which shows that for 30° of wall angle when increase the incremental depth the variation in the grain orientation is not much,So for 30° of wall angle tool diameter has insignificant effect on grain orientation, and for the 50° of wall angle plane {220} have maximum percentage of grains and rest of the planes have very low percentage of grains. Hence, for 50° of wall angle tool diameter has a significant effect. For 50° of wall angle incremental depth has also shows effect, for 0.1mm and 0.25mm incremental depth the variation in the grain orientation is drastically changes for {220} plane which shown in Table4.7.

The Figure4.11 shows the effect of tool diameter for 30° of wall angle and for two levels of incremental depth. Figure4.11(a) shows small variation in the peak corresponding to the plane {111} and Figure4.11(b) shows comparatively more variation in the peaks which means by increasing tool

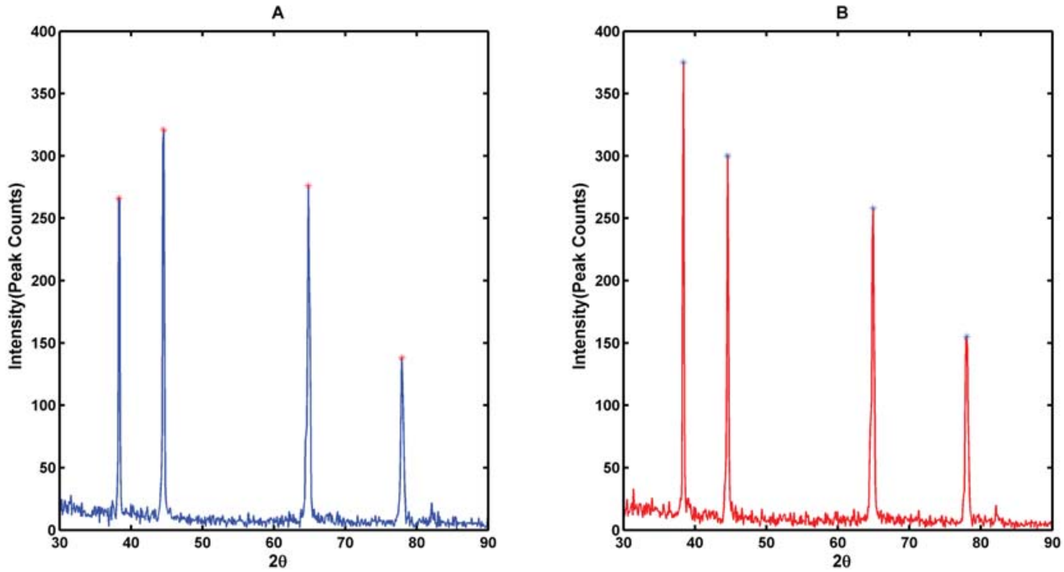
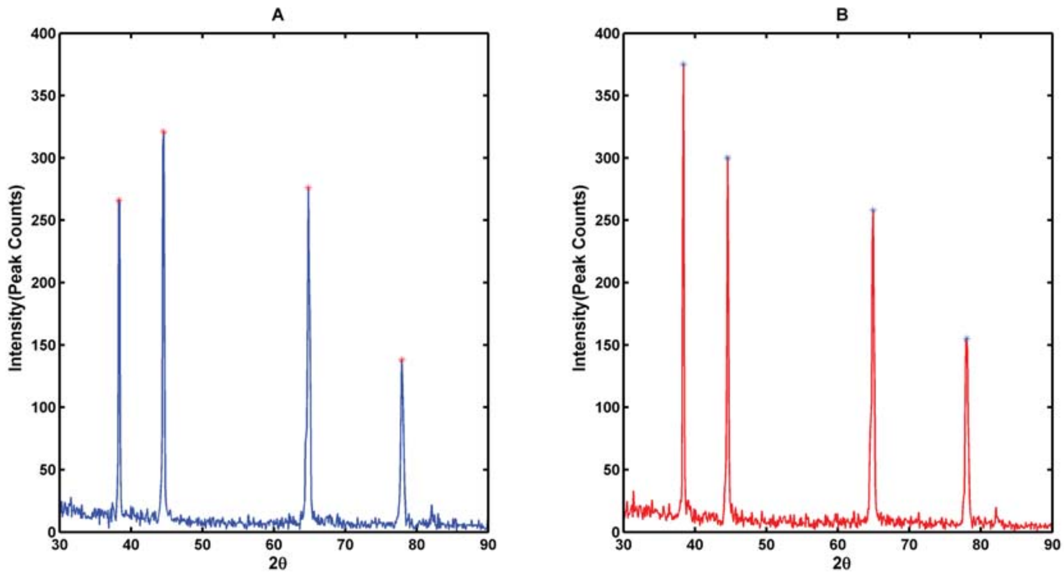


Figure 4.10: XRD pattern for 30° of wall angle and 0.1mm incremental depth with tool diameter (A)8mm and (B)12.7mm

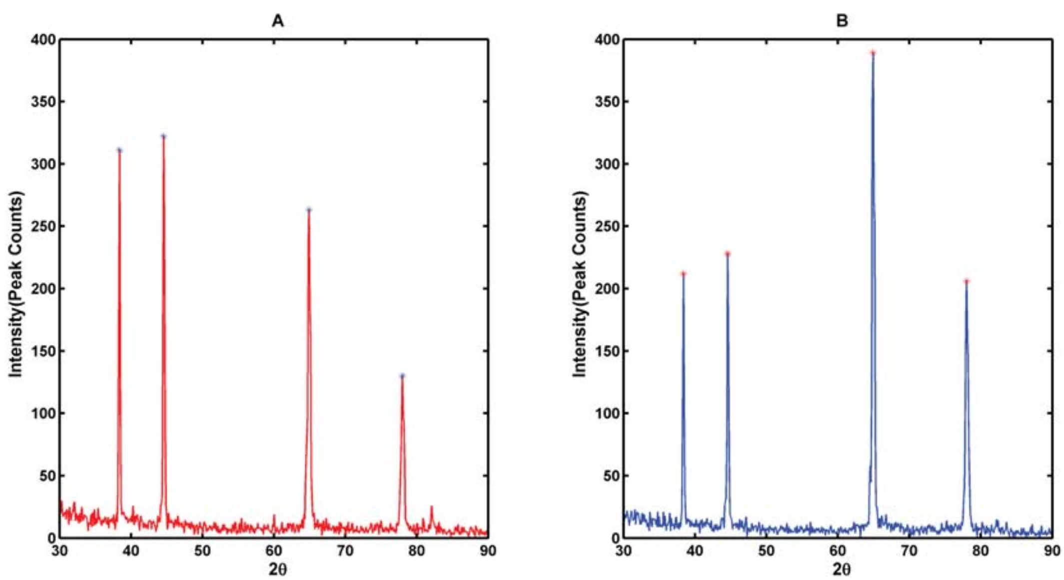
Table 4.7: Grain orientation on different planes for 12.7mm tool diameter for different value of Incremental depth and wall angle rolling direction

S.No.	Wall Angle	Pitch(mm)	Percentage of Grains oriented on planes			
			{111}	{200}	{220}	{311}
1	30	0.1	34.46	27.57	23.74	14.25
2	30	0.25	20.48	22.02	37.59	19.90
3	50	0.1	14.24	15.34	58.55	11.86
4	50	0.25	5.44	10.13	75.47	8.96

diameter and for increased incremental depth tool have more effect for 30° of wall angle. For 50° of wall angle the Figure4.12 shows the variation of the peaks. On comparing respective figures of Figure4.11 and Figure4.12 more variation can found in the Figure4.12 So for 50° of wall angle tool diameter has more effect and this effect is even more for higher forming parameters.

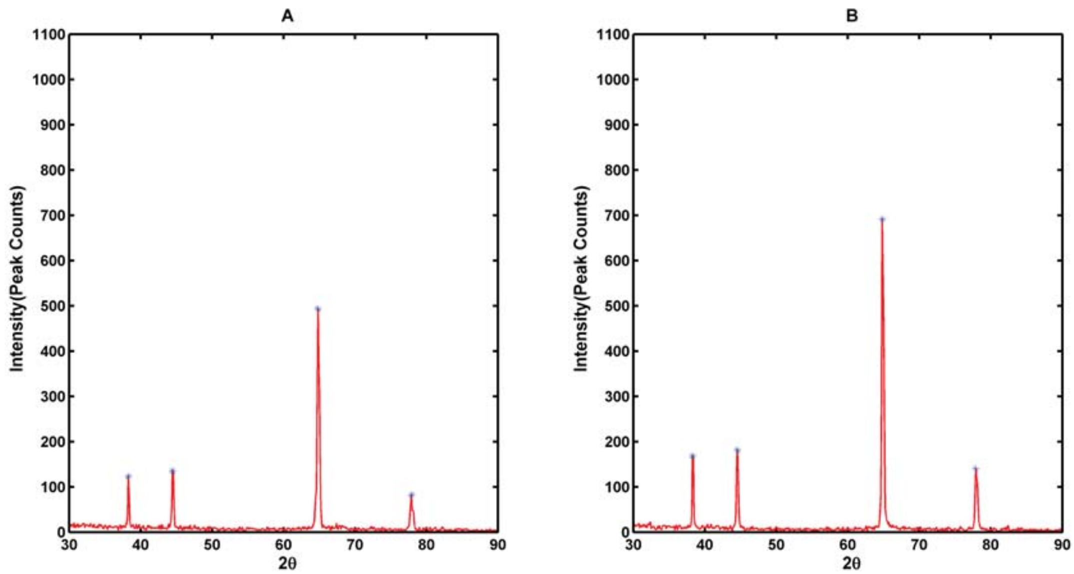


(a)

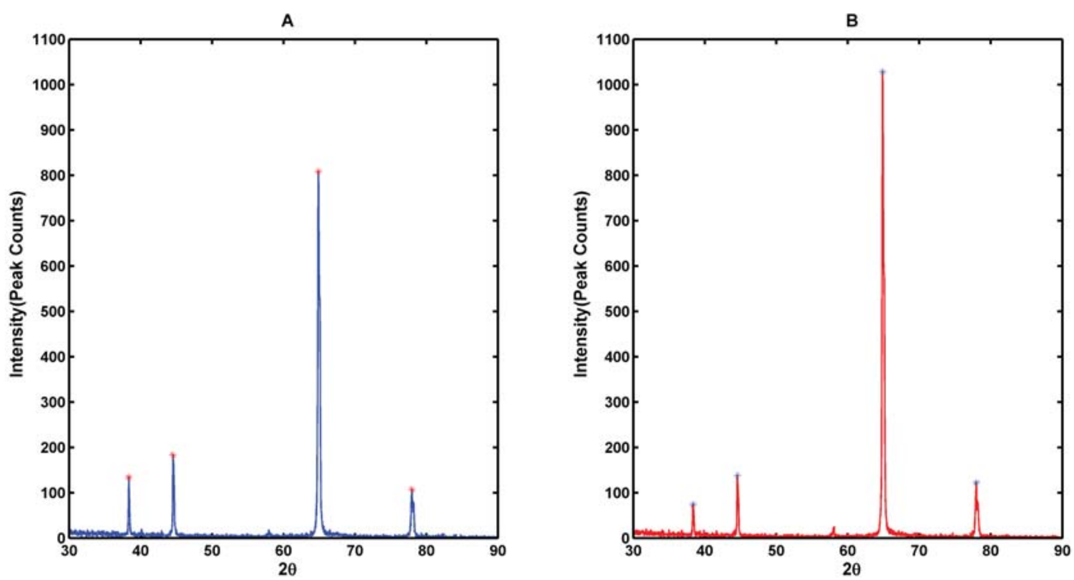


(b)

Figure 4.11: XRD pattern for 30 ° of wall angle and tool diameter of (A) 8mm and (B) 12.7mm and incremental depth of (a) 0.1mm and (b) 0.25mm



(a)



(b)

Figure 4.12: XRD pattern for 50° of wall angle and tool diameter of (A) 8mm and (B) 12.7mm and incremental depth of (a) 0.1mm and (b) 0.25mm

4.2 Effects in Transverse Direction

The table4.8 show for the grain orientation on different planes for 30° of wall angle in the Transverse Direction which shows that the plane {220} have increasing trend for all value of tool diameter when increases the incremental depth and plane {111} and plane {200 has decreasing pattern. On comparing incremental depth for 8mm tool diameter is showing that incremental depth has not much effect on grain orientation this we can observe in the first two rows of Table4.8 in which variation of the grain on the different planes is less. And for 12.7mm tool diameter when increase the incremental depth the variation of the grain orientation on different planes are more comparable to the variation in the grain orientation observed for 0.1mm incremental depth, this variation is more on plane {220} compare to the rest of the planes. So for 12.7mm diameter incremental depth has a little more effect on grain orientation when compare to 8mm tool diameter components. On comparing for the effect of tool diameter for different incremental depth, for 0.1mm incremental depth the variation in the grain orientation is very less that we can see from the above table. So for 30° of wall angle and 0.1mm incremental depth tool diameter has less effect on grain orientation nature in transverse direction. And for 0.25mm incremental depth the variation in the grain orientation is more as compare to 0.1mm incremental depth and specially on a plane {220} has a maximum increment of grains, So for 0.25mm incremental depth tool diameter has more effect on grain orientation. Effect of parameters on grain orientation for 30° of wall angle, one can say that for 8mm tool diameter incremental depth has insignificant effect. And 12.7mm tool diameter effect is more, And for 0.1mm incremental depth tool has small effect and for 0.25mm incremental depth tool has more effect.

Table 4.8: Grain orientation on different planes for the 30° of wall angle In transverse direction

S.No.	Pitch(mm)	Tool Diameter(mm)	Percentage of Grains oriented on planes			
			{111}	{200}	{220}	{311}
1	0.1	8	21.67	23.81	40.46	14.04
2	0.25	8	15.96	29.35	44.79	9.88
3	0.1	12.7	14.26	22.22	47.15	16.36
4	0.25	12.7	6.61	17.54	57.01	18.81

Table4.9 shows for the grain orientation on different planes for 50° of wall angle and for different value of incremental depth and tool diameters. Which shows the plane {220} has maximum variation in percentage of grain and has increasing trend for all value of incremental depth when increases the tool diameter from 8mm to 12.7mm and variation on the rest of the planes are

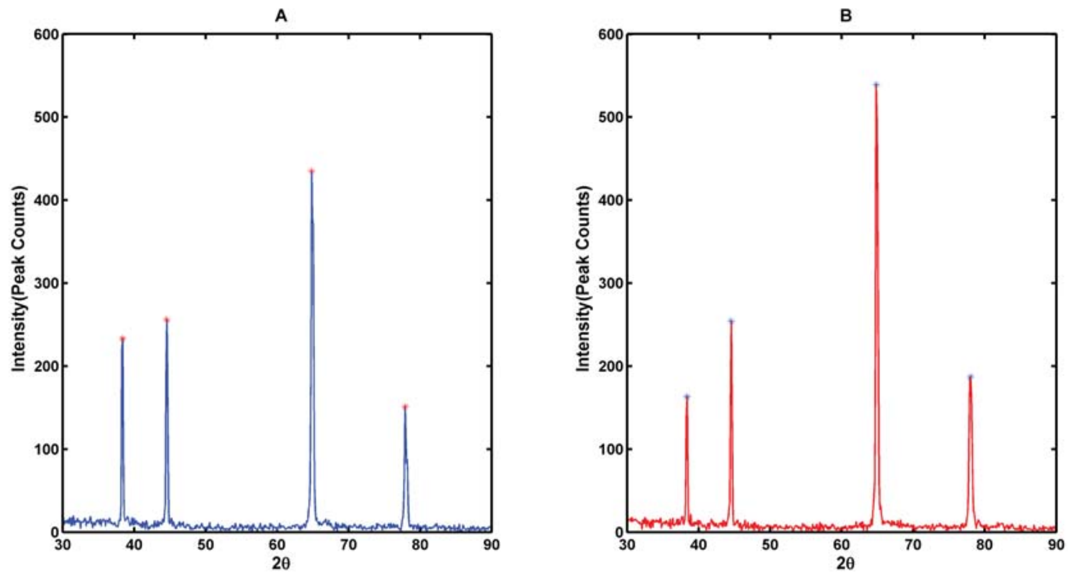


Figure 4.13: XRD pattern for 30 ° of wall angle and 0.1mm incremental depth and tool diameter of (A) 8mm (B) 12mm in transverse direction

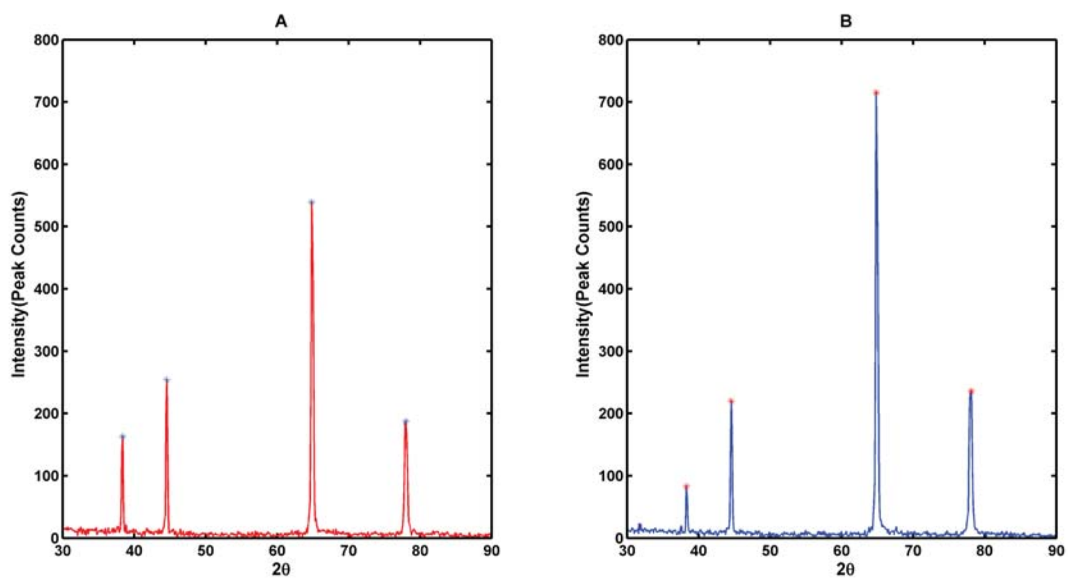


Figure 4.14: XRD pattern for wall angle of 30 ° and tool diameter of 12.7mm for incremental depth of (A)0.1mm (B) 0.25mm in transverse direction

insignificant. Observing for 50 ° of wall angle when increase the incremental depth whether the tool diameter 8mm or 12.7mm plane {220} has maximum variation in the grain orientation but for 8mm tool diameter this variation is more. When compared with 12.7mm of tool diameter from that one can say that small tool diameter with low incremental depth overlapping of tool path on a deformed region of the sheet is more. From above table can also observe the tool diameter effect on grain orientation, on comparing row one and three one can observe the variation in grain orientation in which {220} plane have maximum of grain and has maximum variation, and on comparing second and fourth row similar variation can observe as previous one, so the tool diameter has almost similar effect for 0.1mm and 0.25mm incremental depth and for 50° of wall angle in Transverse Direction. Hence the tool diameter and incremental depth have a similar effect on grain orientation for the 50° of wall angle in transverse direction. This is not the case for the rolling direction, effect of tool diameter is more for 0.25mm incremental depth or incremental depth has more effect with 12.7mm tool diameter while tool diameter and incremental depth has almost similar effect for 50° of wall angle in transverse direction and this effect is less on comparing with rolling direction that we can see on comparing the tables of grain orientation on different planes for 50° of wall angle in rolling and transverse direction. Hence for rolling direction variation in the grain orientation is more so chances of failure of the component is more in the rolling direction compared to transverse direction.

Table 4.9: Grain orientation on different planes for the 50° of wall angle in transverse direction

S.No.	Incremental Depth(mm)	Tool Diameter(mm)	Percentage of Grains oriented on planes			
			{111}	{200}	{220}	{311}
1	0.1	8	12.95	17.14	59.21	10.69
2	0.25	8	8.20	17.31	66.80	7.67
3	0.1	12.7	9.83	14.90	66.77	8.48
4	0.25	12.7	6.64	12.30	71.54	9.51

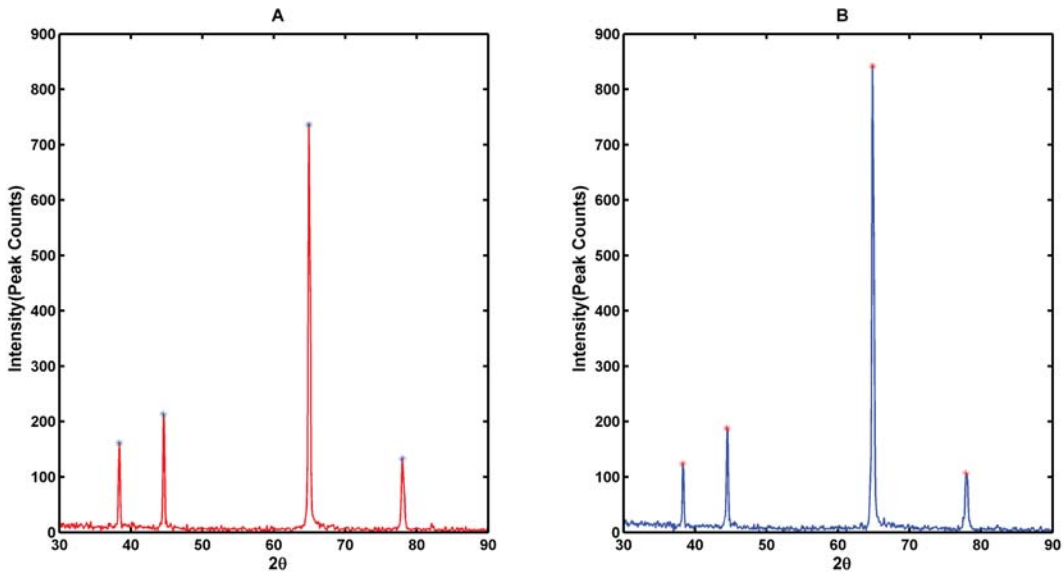


Figure 4.15: XRD pattern for 50° of wall angle and 0.1mm incremental depth for tool diameter of (A) 8mm and (B) 12.7mm in transverse direction

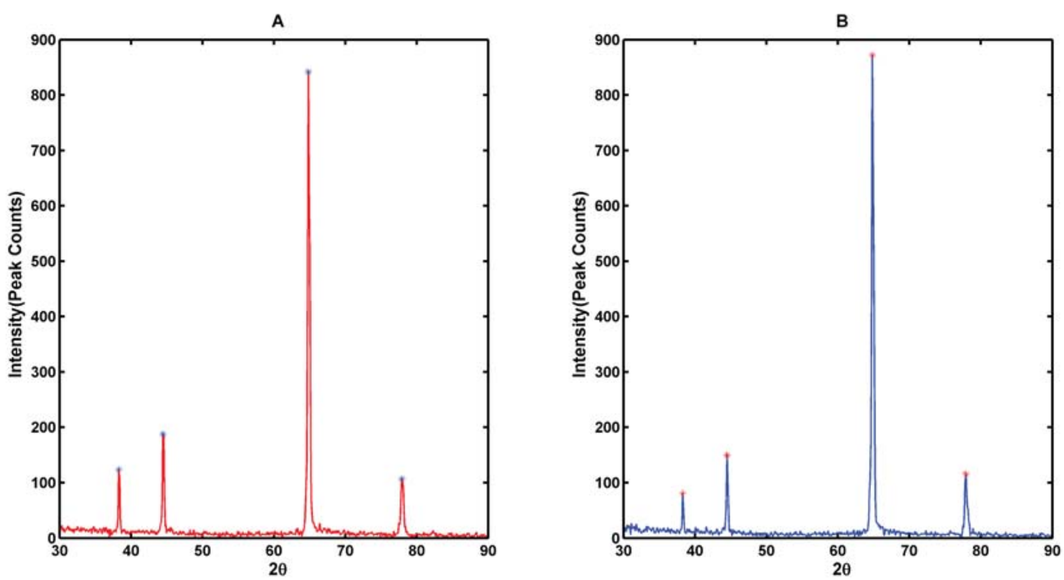
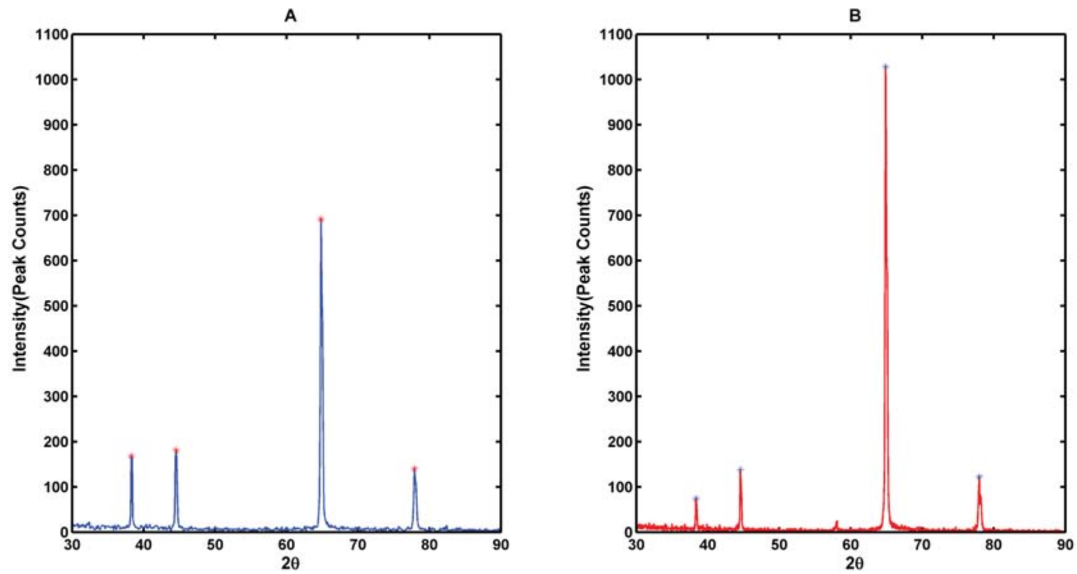


Figure 4.16: XRD pattern for 50° of wall angle and 12.7mm tool diameter for incremental depth of (A) 0.1mm and (B) 0.25mm in transverse direction

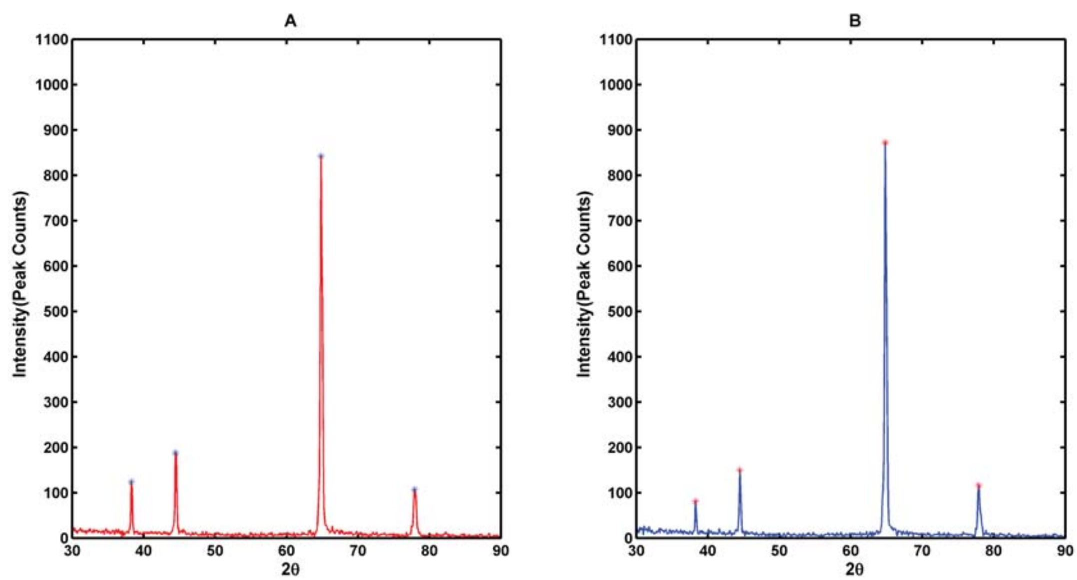
4.3 Comparison of Rolling and Transverse Direction

The figure4.17 for comparing the effect of incremental depth in both rolling and transverse direction for 50° of wall angle and 12.7mm tool diameter which shows that plane {220} have maximum percentage of grain in all the figure and variation on the plane {220} is more for the rolling direction as compare to transverse direction this is clear from the figure 4.17, variation of the intensity (peak counts) is from 691 counts to 1028 counts for rolling direction and difference of 337 counts and for transverse direction 842 to 872 counts difference of only 30 counts which showing rolling direction has more variation in the counts, so for the same parameters incremental depth has more effect on rolling direction as compare to transverse direction. The figure4.18 shows for the comparison of Tool diameter for the 50° of wall angle and 0.1mm of incremental depth which shows that {220} plane has maximum intensity of peak and variation in peaks is more for Rolling Direction that one can observe in the figure4.18, which indicate that tool diameter has greater effect in rolling direction as compare to transverse direction.It clear from the figure4.18 the peak intensity counts variation is from 493 to 691 counts and difference of 198 counts for rolling direction and for transverse direction it is from 736 to 842 counts difference of 106 counts, so Rolling Direction has more variation in the peaks. Figure4.19 shows for comparison of wall angle for 0.25mm incremental depth and 12.7mm tool diameter which shows that variation in the peaks is more in Rolling Direction as compare to Transverse Direction, from the figure4.19 it is can be see that peak counts variation is from 389 to 1028 for rolling direction difference of 639 counts and from 715 to 872 counts for transverse direction difference of 157 so the wall angle has maximum effect on the grain orientation effect in rolling direction as compare to transverse direction.

In all the figures the variations of the peaks is more in the Rolling Direction as compare to Transverse Direction when component is formed with same parameters in both direction. So the variation is more in the Rolling Direction, chances of failure of the component in the Rolling Direction is more because most of the grains are oriented along particular plane when component rolling direction and tool movement directions are same.So The effect of forming parameters are more in the Rolling Direction, that we can see on the Figures4.17,4.18,4.19 in which peaks variation is more for rolling direction in all figures.



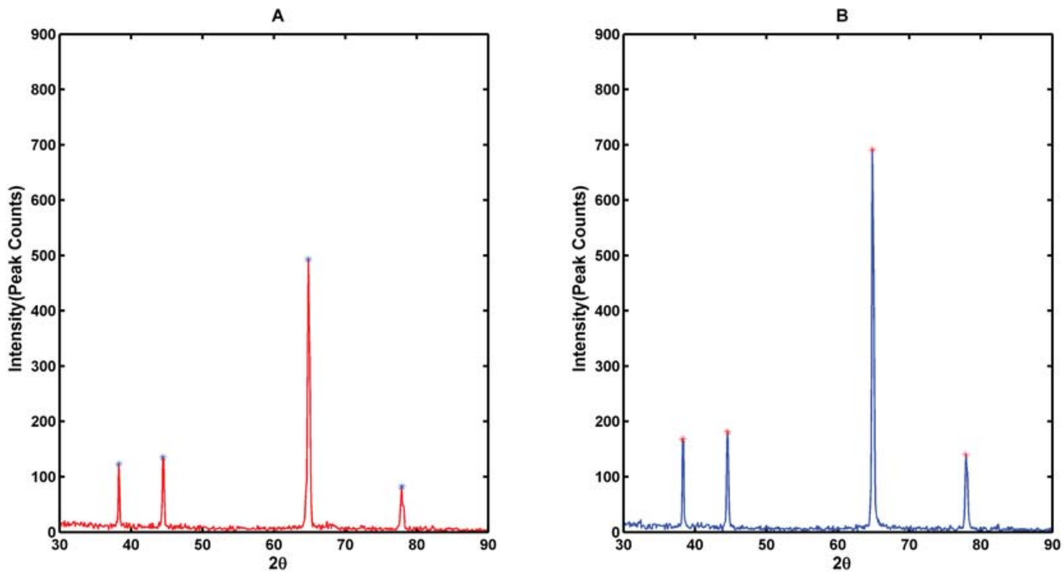
(a)



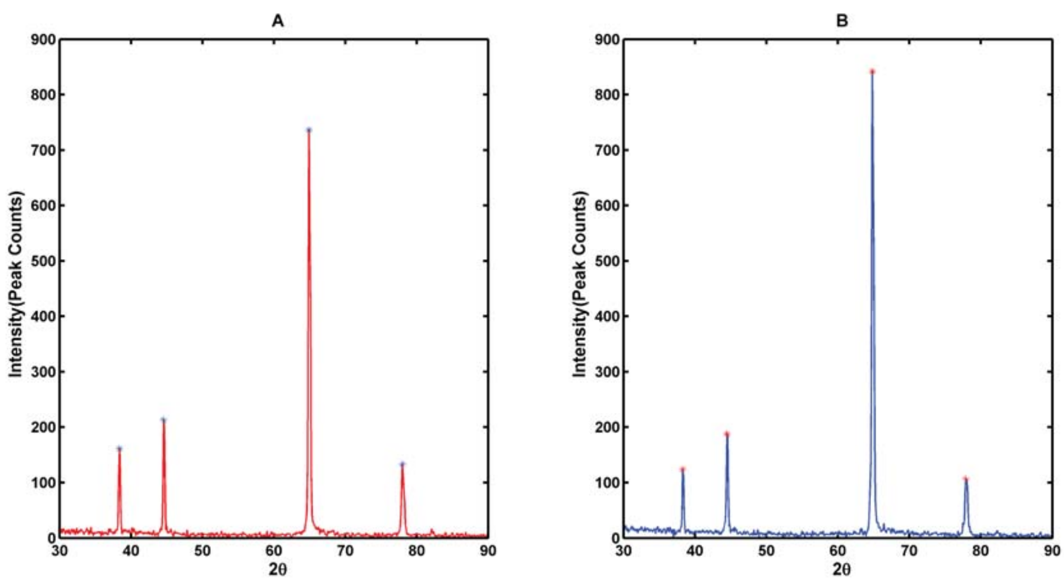
(b)

Figure 4.17: XRD pattern for 50 ° of wall angle and 12.7mm tool diameter for incremental depth of (A) 0.1mm and (B) 0.25mm in (a) rolling direction and (b) transverse direction

From Figure4.20 and Figure4.21 one can see the variation in the maximum peaks in {220} plane for 30 ° and 50 ° of wall angle and different tool diameters and incremental depth in Rolling



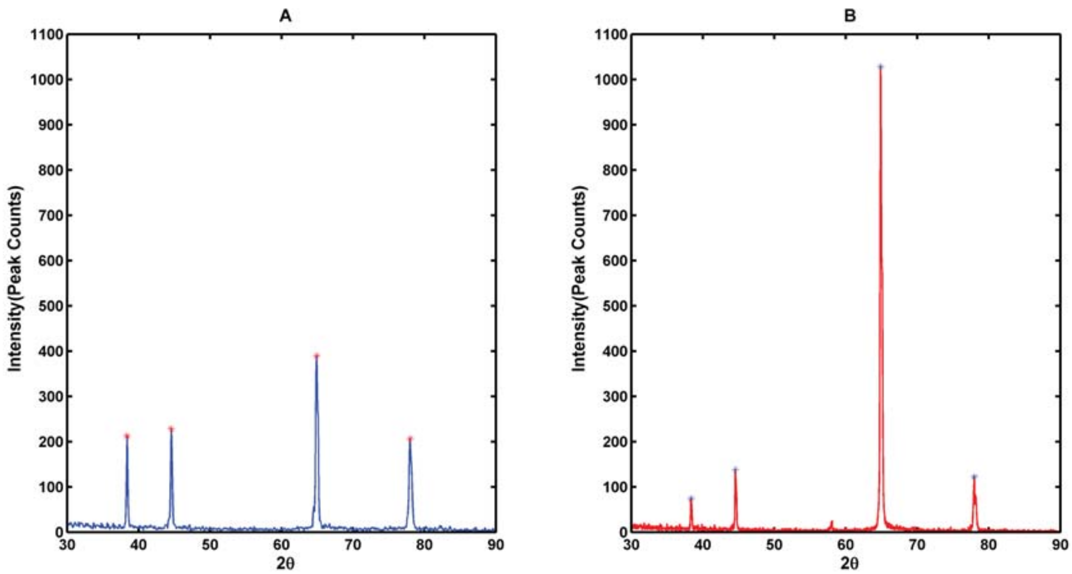
(a)



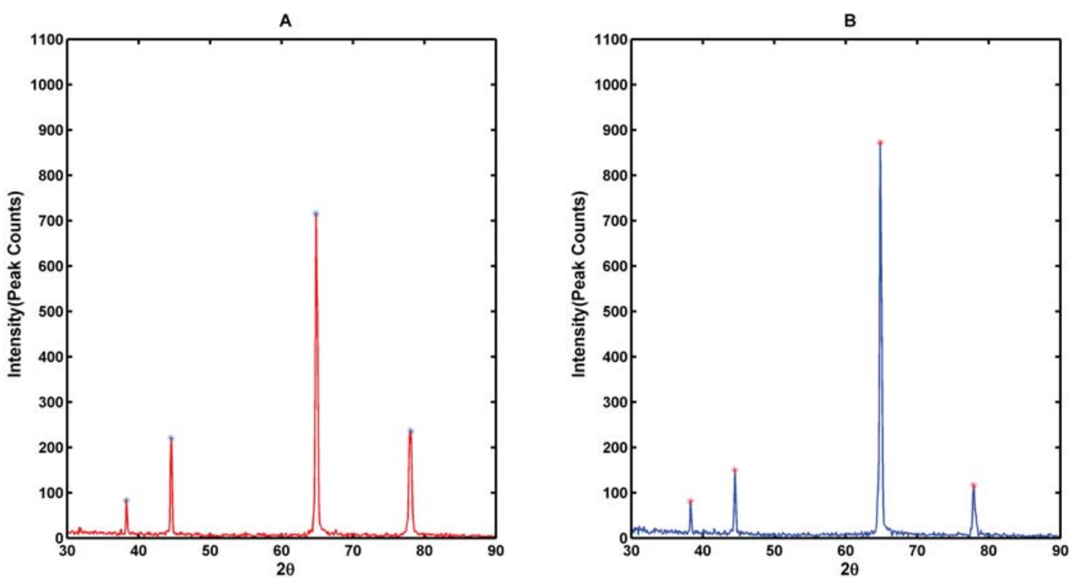
(b)

Figure 4.18: XRD pattern for 50° of wall angle and 0.1mm of incremental depth for tool diameter of (A) 8mm and (B) 12.7mm in (a) rolling direction and (b) transverse direction

and Transverse Direction, for Rolling direction the variation is more for the same parameters. Hence for the given parameters effect on the grain orientation nature of the Aluminum-5052 sheet is more



(a)



(b)

Figure 4.19: XRD pattern for 0.25mm of incremental depth and 12.7mm tool diameter for wall angle of (A) 30° and (B) 50° (a) in rolling direction and (b) transverse direction

in Rolling Direction as compared to Transverse Direction. Chances of failure of the components are more in Rolling Direction.

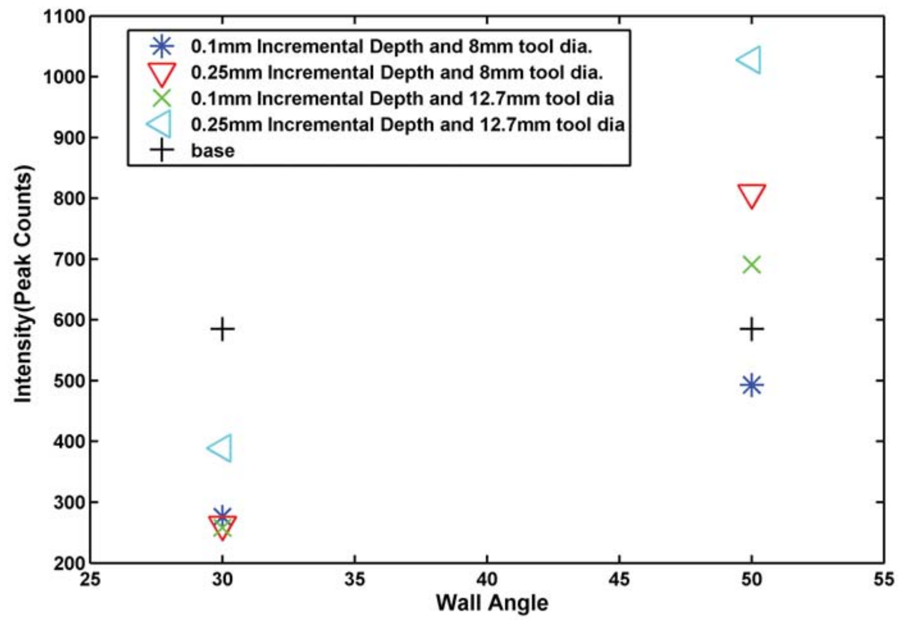


Figure 4.20: Variation of peak in {220} plane for 30 ° and 50 ° of wall angle and different parameters in rolling direction

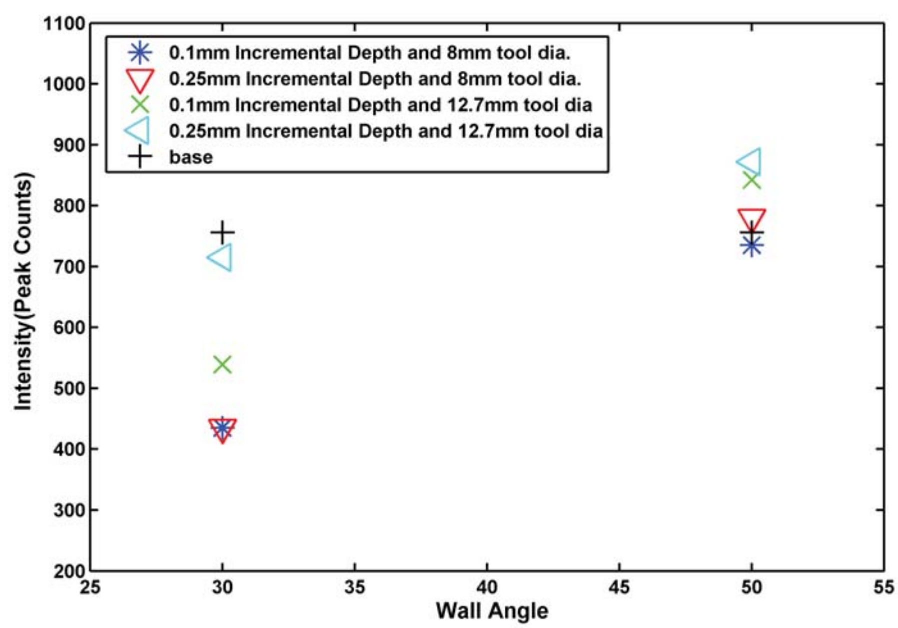


Figure 4.21: Variation of peak in {220} plane for 30 ° and 50 ° of wall angle and different parameters in transverse direction

Chapter 5

Conclusions and Future Scope

5.1 Conclusions

XRD analysis is carried out to analyze the grain orientation behavior and effect of forming process parameters during SPIF. Pyramidal components are formed in such a way that the walls of pyramid after deformations remain along rolling and transverse direction. XRD analysis of the formed components are carried out taking samples along rolling and transverse direction. Which reveal that wall angle has more effect on grain orientation nature. For small wall angle, the effect of parameters is insignificant in both rolling and transverse directions. But for the higher wall angle, both, tool diameter and incremental depth have more effect on the grain orientation for the above mentioned parameters. The variation in the grain orientation on the different planes increases with increasing the tool diameter and incremental depth and wall angle, but the wall angle has more effect than others, and tool incremental has significant effect as compared to incremental depth effect. Tool Diameter has similar effect, as wall angle, for higher tool diameter has more influence on grain at higher wall angle and higher incremental depth. For the all parameters the effect is more when the component is formed with its highest value and this effect is more in the rolling direction because the variation of the grain orientation of the planes is more in the rolling direction as compared to transverse direction. Hence the chances of failure of components in rolling direction are more as compared to transverse direction because the majority of the grain has a tendency to orient along a single plane which increases the tendency of component failure.

5.2 Future Scope

There are not many studies on the grain orientation nature of the incrementally formed components. The following points can be considered as the scope for future work.

- Strain rate effect on grain orientation for different materials.
- Effect of working condition (Temperature) on grain orientation.
- Variation in residual stress in formed component and grain orientation relation study.

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