The Effect of Tool Path Strategy on Twist Behavior In Single Point Incremental Sheet Metal Forming

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ABSTRACT:
In Incremental sheet metal forming process, one important step is to produce tool path, an accurate tool path is one of the main challenge of incremental sheet metal forming process. Various factors should be considered prior to generation of the tool path i.e. mechanical properties of sheet metal, the holding mechanism, tool speed, feed rate and tool size. In this work investigation studies have been carried out to find the different tool path strategies to control the twist effect in the final product manufactured by single point incremental sheet metal forming (SPIF), an adaptive tool path strategy was proposed and examined for several Aluminum conical models. The comparison of the proposed tool path with the conventional iso planar and helical tool paths shows that there is no effect of twisting in the final model when using adaptive tool path, while the twisting effect are clearly observed and measured in the final product when using both iso planar and helical tool path When forming 80 and 110mm depth conical cup.
The time of forming has been measured and its observed that in adaptive tool path the time of forming is less than 8.7 %from the helical tool path when forming conical cup with 50mm depth and less than of 8.91% when forming conical cup with 110mm depth.

Keywords: Single Point Incremental Forming (SPIF), Tool path Strategy, Twisting, forming time.

تأثير مسار العدة على سلوك الالتواء في التشكيل النقطي التزايدي للصفائح المعدنية

الخلاصة :
يعتبر استنتاج وتوليد مسار العدة في عملية التشكيل التزايدي خطوة مهمة يجب اخذها بنظر الاعتبار ويعتبر مسار العدة الامثل هو من التحديات التي تواجه هذا النوع من عمليات التشكيل حيث يجب مراعاة عدة عوامل مثل الخواص الميكانيكية للصفائح المعدنية المراد تشكيلها، طريقة تثبيت الشريحة المعدنية، سرعة دوران العدة ومعدل التغذية وحجم العدة (القطر،الطول) لتحديد نوع مسار العدة الملائم للتشكيل.
تم في هذا البحث دراسة تاثير نوع مسار العدة على خاصية الالتواء الحاصلة بالمنتج بعد التشكيل وتطوير مسار عدة للحد من ظاهرة الالتواء ومقارنة مسار العدة المطور مع عدد من مسارات العدة الشائعة الاستخدام في تشكيل عدد من النماذج المختلفة. تبين النتائج المستحصلة من خلال هذا البحث بان الطريقة المطورة حدت بشكل كبير من ظاهرة الالتواء حيث لم يظهر اي التواء في تشكيل النماذج بعمق 50ملم في حين كانت نسبة الالتواء بسيطة جدا مقارنة مع المسارات الاخرى عند تشكيل النماذج للاعماق 80 و110ملم على التوالي. ومن ناحية اخرى فان زمن التشكيل باستخدام مسار العدة الطبقي اقل من زمن التشكيل عند استخدام مسار عدة الحلزوني وبنسبة مئوية تراوحت 8.7% عند تشكيل جزء مخروطي بعمق 50ملم الى8.91 % عند تشكيل جزء مخروطي بعمق 110ملم.

الكلمات الرئيسية: التشكيل النقطي التزايدي، تتراجية سار العدة، الالتواء، زمن التشكيل.

INTRODUCTION:

The Singe Point Incremental Forming (SPIF) is a new forming process used in sheet metal forming. Different steps of this process are shown in figure (1) (Rattanachan K. (2009)). Incremental displacements of the tool in various directions allow to form the sheet in order to provide the required shape. The main advantages of SPIF are best formability of sheets - reducing costs when prototypes or batches have to be manufactured while the drawbacks manufacture's times longer sometimes poor geometry's respect and surface aspect. (Syed Asad Raza(2009)).

Tool path

Due to the elastic-plastic properties of the sheet metal, the tool path of a given shape will vary from the final shape as shown in Figure (2). This is obvious at the beginning of the process where there is evidence of both elastic and plastic deformation. The final shape of the formed part has been found to be dependent upon a number of factors including the tool-path, the material properties of the sheet metal, the tool material, tool speed and the tool feed rates. (Durante(2009)).

TOOL PATH STRATEGIES:

For positive geometry, the tool deform the sheet starting from the centre and moving towards the boundary, whereas for concave object geometry, both outer-to-inner and inner-to-outer paths can be used.
There are two main tool path strategies used in ISPF which are:(S. Dejardin(2010)).

1- Iso-planar tool path
2- Helical tool path

In Iso-planar tool path the tool deform the sheet metals from the center and moving towards the boundary then it progress to the final depth of forming in circular movement with out changing the feed direction , as illustrated in Figure (3).(Wang Ha(2001)).
In helical tool path strategy, the tool progressively deforms the blank with a Spiral movement from the top going towards the maximum depth (direct forming, figure(4)).(Hu Zhu(2011)).
The twist effect can be clearly observed in the final product when using the above toolpath strategies, and to improve this an-adaptive tool path strategy have been developed for selected case studies.
In this work, an adaptive solution (to overcomes the twist effect) was proposed and tested, where the tool is progressively moved downwards up to the bottom of the object but it progress in circular movement and the feed direction was changed for each successive layer. An example of tool path generated is shown to figure (5).

CAD MODEL: (PROFILE-LAGRANGE+ TOOL PATH)

Starting from the CAD model of the symmetric object, the object profiles has been generated using one-dimension(1-D) Lagrange interpolation technique shown in figure (6), then the tool path was generated by dividing the total depth of the object to suitable number of layers to generate an acceptable side step towered the final depth of the forming.

The conical shape profile have been generated using 1-D Lagrange technique than the intermediate nodes have been generate to guide along toolpath. The 1-D Lagrange equation can be written as illustrated in equation (1&2).

$$f_n(x) = \sum_{i=0}^{n} L_i(x) f(x_i) \qquad (1)$$

Where n in $f_n(x)$ stands for the n^{th} order polynomial that approximates the function $y = f(x)$ given at $n+1$ data points as $(x_0, y_0),(x_1, y_1),......,(x_{n-1}, y_{n-1}),(x_n, y_n)$, and

$$L_i(x) = \prod_{\substack{j=0 \\ j\neq i}}^{n} \frac{x - x_j}{x_i - x_j} \qquad (2)$$

$L_i(x)$ is a weighting function that includes a product of $n-1$ terms with terms of $j=i$ omitted.(Tahseen (2011)).

An integration of tool path definition was created by Matlab and developed then the data have been transferred via "Ethernet" to the C-Tek vertical milling machine to control the tool.

EXPERIMENTAL WORK:

The material used to investigate the effects of the tool path is 1mm thick Aluminum alloy (Al 1050) for several models to determine the effect of the tool path on the twisting occurs in the final product. The properties and chemical composition of Al 1050 are as follows:-

- Ultimate strength (100- 110 MPa)
- yield strength (70 MPa).
- Total elongation during tensile test when using 70 mm initial gauge length is around 3-5%.

Forming limit diagram(FLD) shown in figure (7).

The technique utilized for obtaining the FLD involved electrochemical etching of a grid of circles with 2 mm initial diameter on the surface of the sheets before forming and measuring the major and minor axis of the ellipses that result from the plastic deformation of the circles during the formability tests. The values of strain were computed from (refer to the detail in figure (7)), where the symbol (R) represents the original radius of the circle and the symbols (a) and (b) denote the major and minor axis of the ellipse.(Maria(2011)).

$$\varepsilon_1 = \ln(\frac{a}{2R}) \qquad (3)$$

$$\varepsilon_2 = \ln(\frac{b}{2R}) \qquad (4)$$

The resulting FLD is plotted in figure (7) and was constructed by taking the principal strains (ε1, ε2) at failure from grid-elements placed just outside the neck (that is, adjacent to the region of intense localization) since they represent the condition of the uniformly thinned sheet just before necking occurs.

The intersection of the FLC with the major strain axis is found to occur at ε1=0.07 in fair agreement with the value of the strain hardening exponent of the stress–strain curve obtained by means of tensile tests,

$$\sigma = 140\varepsilon^{0.041} MPa \qquad (5)$$

MACHINE SET-UP:

The experimental work was implemented at university of technology using CNC milling machine (figure (8)), using machine speed 100 rpm and feed rate 750mm/min.

TOOL GEOMETRY:

The main tool geometries that used in SPIF are:-

1. Ball end tool.
2. Hemispherical tool.
3. Flat with round tool.

In this work we used a Ball end tool with diameter 12mm and length100mm, material of this tool is tool steel (X210) has HRC 58 (figure (9)), which is used in all the experimental to neglect the effect of the tool geometry on the twist behavior.

RESULTS AND DISCUSSION:

Nine conical shapes have been implemented (3x3). Test the effect of the tool path strategy on the twist behavior, 50 mm depth conical cup have been found with:

- Isoplaner
- Helical
- Adaptive

The same procedure has been repeated to form conical shapes with final depth of 80mm and 120mm as shown in figure (10).

The effect of the three tool path strategy on twisting was plotted in the figures (11, 12&13) as a relationship between twist angle value and forming depth.

The actual time of forming for the conical shapes of the three tool path strategies has been measured and plotted as a relation between forming depth and forming time as shown in figure (14).

CONCLUSIONS:

In this work, Al 1050 sheet were incremental sormed under different tool path strategies and their effects stradies, the following conclusions were drawn from the study:

1. there is no twisting in the final conical cup when using the adaptive tool path strategy while the twist effect can be observed for the same model when using both isoplaner and helical tool path.
2. as the following depth increased the twisting angle is increased, but still that the adaptive tool path strategy has the lowest effect on twisting.
3. both isoplaner and adaptive toolpaths strategy has the same forming time for the same model while the helical tool path has longest forming time that's mean the proposed adaptive tool path strategies has lowest effect on twisting and decrease the time of forming of 8.7% for all the models comparing with the helical strategy.

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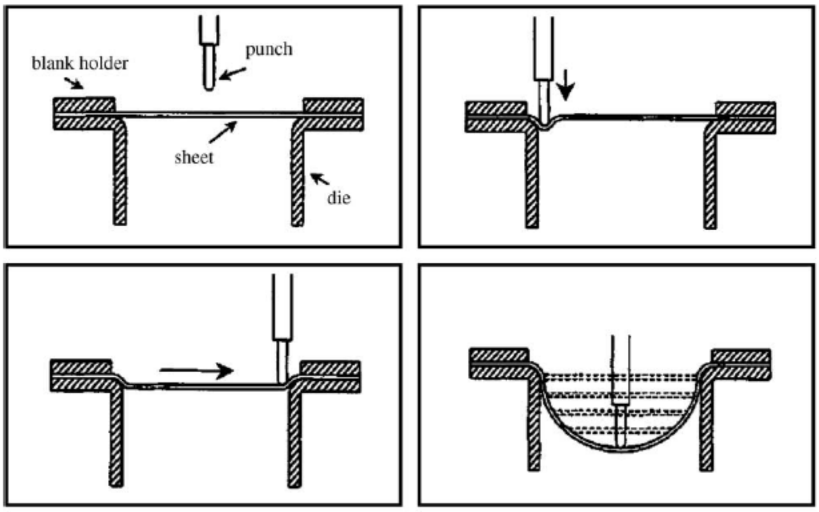


Figure (1) Principle of SPIF (Rattanachan K.2009).

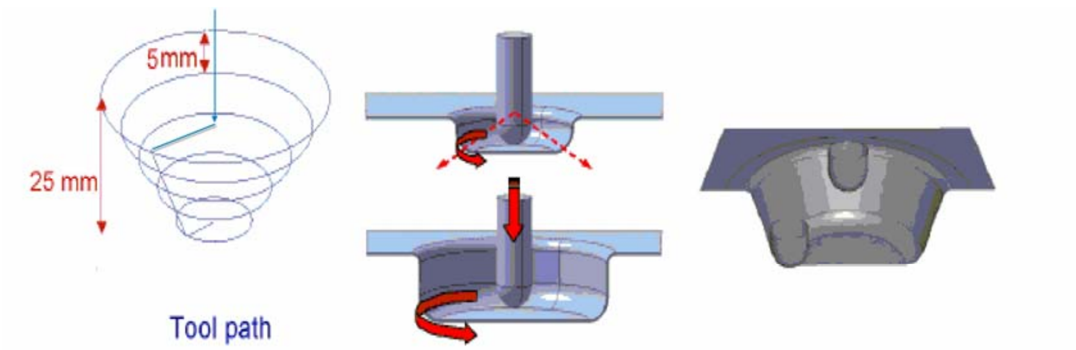


Figure (2) Tool path of forming process (Durante M.2009).

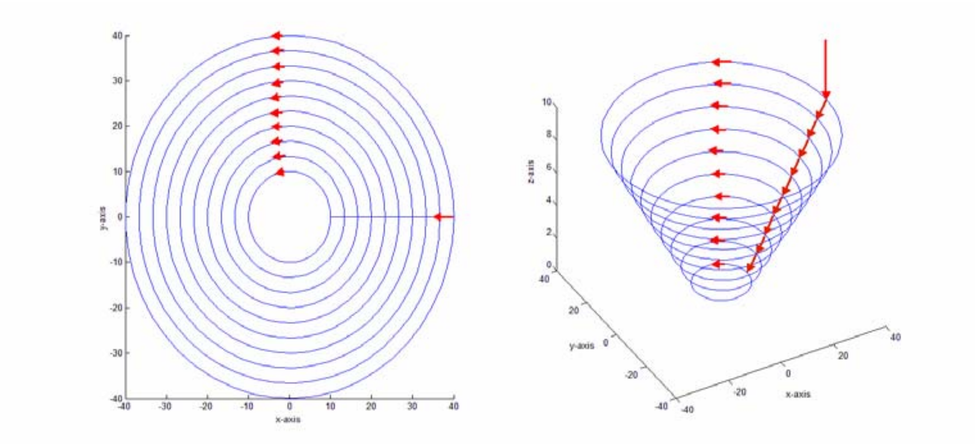


Figure (3) Isoplaner tool path.

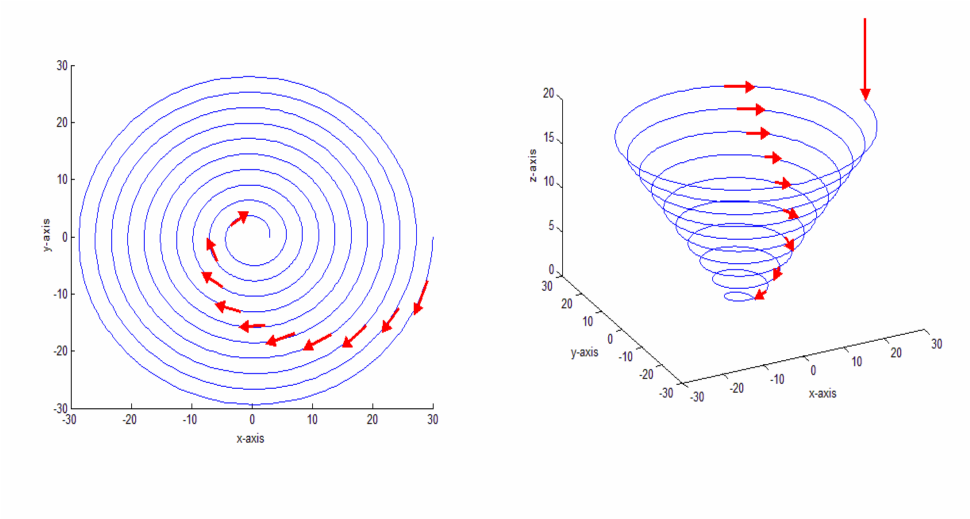


Figure (4) Helical tool path.

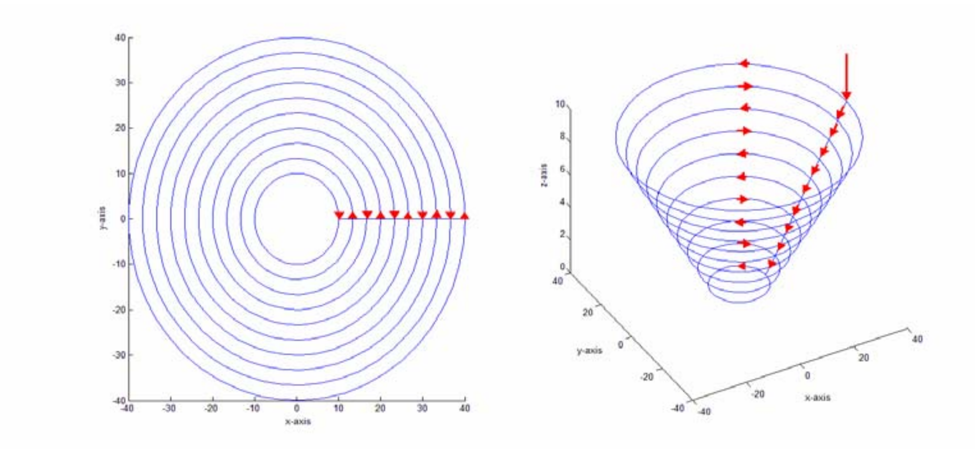


Figure (5) Adaptive tool path of present work.

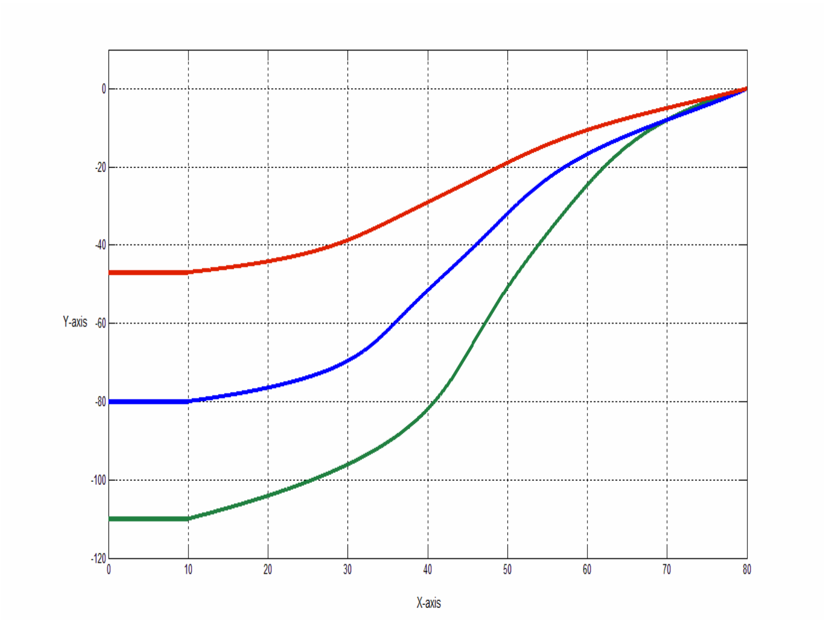


Figure (6) Conical cup profile using Lagrange method of 50, 80 &110mm depth.

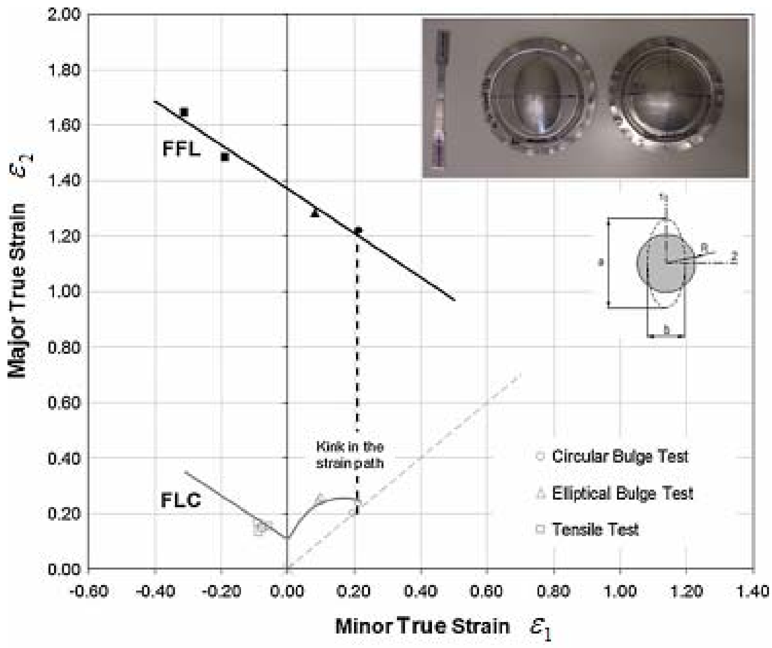


Figure (7) forming limit diagram of AL1050.

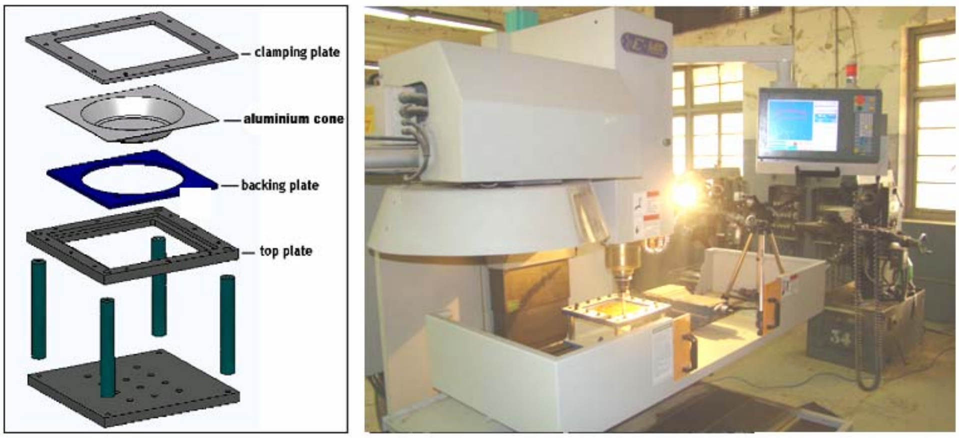


Figure (8) C-Tek vertical CNC milling machine

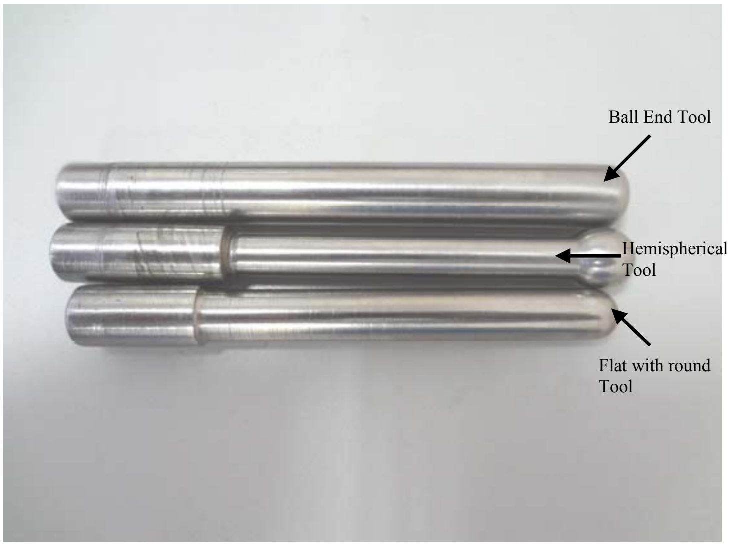


Figure (9) Tool geometry.

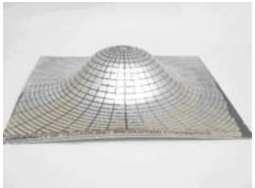
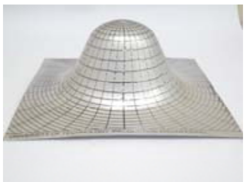
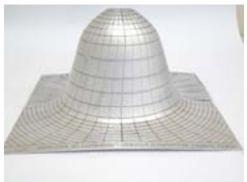
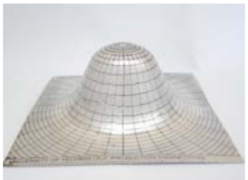
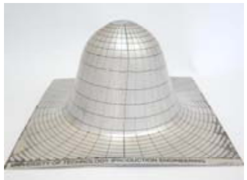
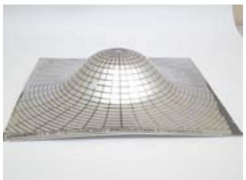
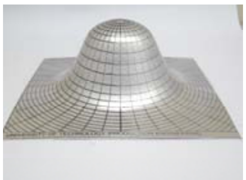
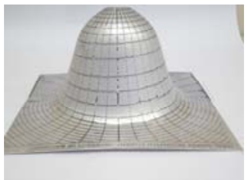
	Depth (50mm)	Depth (80mm)	Depth (110mm)
Isoplaner Toolpath			
	Actual forming time=55.5 min	Actual forming time=95.4 min	Actual forming time=134.9min
Helical Toolpath			
	Actual forming time=60.8 min	Actual forming time=104.7 min	Actual forming time=148.1min
Adaptive Toolpath			
	Actual forming time= time=55.5 min	Actual forming time= time=95.4 min	Actual forming time=134.9min
Maximum Forming angle	38.6^o	63^o	71^o

Figure (10) produced conical shapes.

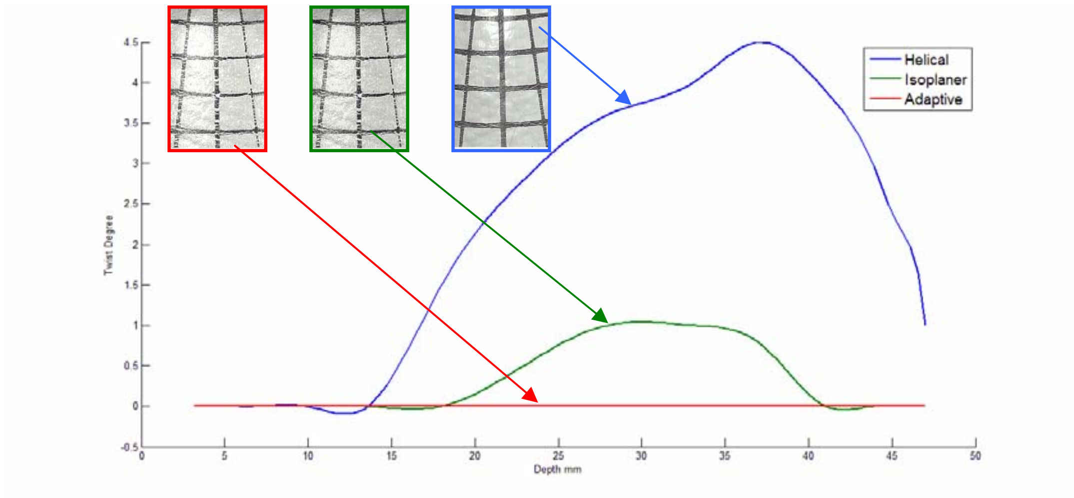


Figure (11) Relationship between twist angle value and forming depth equal to 50mm.

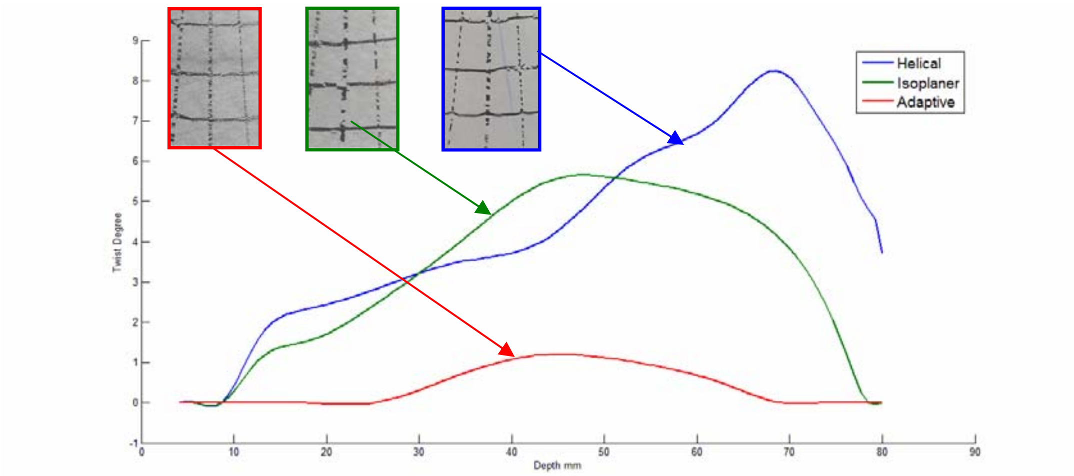


Figure (12) Relationship between twist angle value and forming depth equal to 80mm.

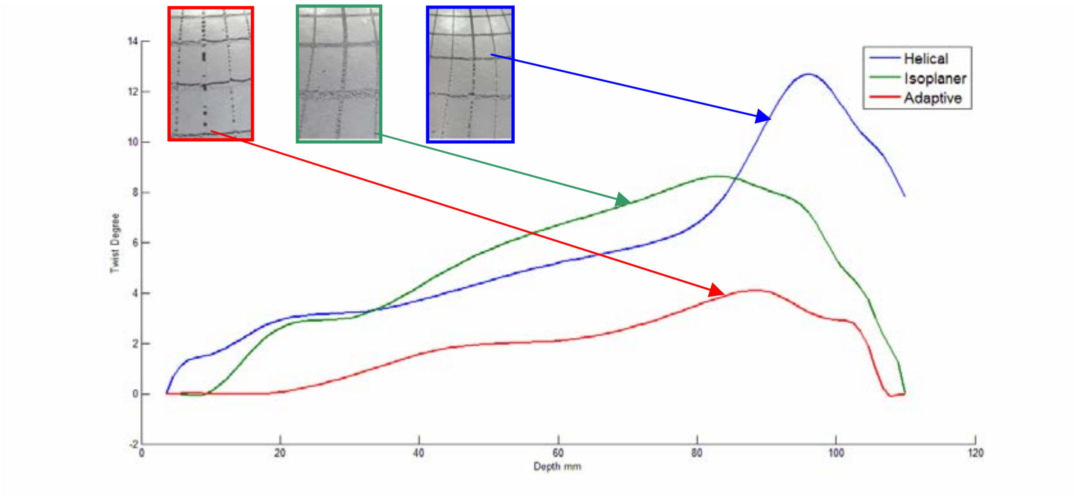


Figure (13) Relationship between twist angle value and forming depth equal to 110mm.

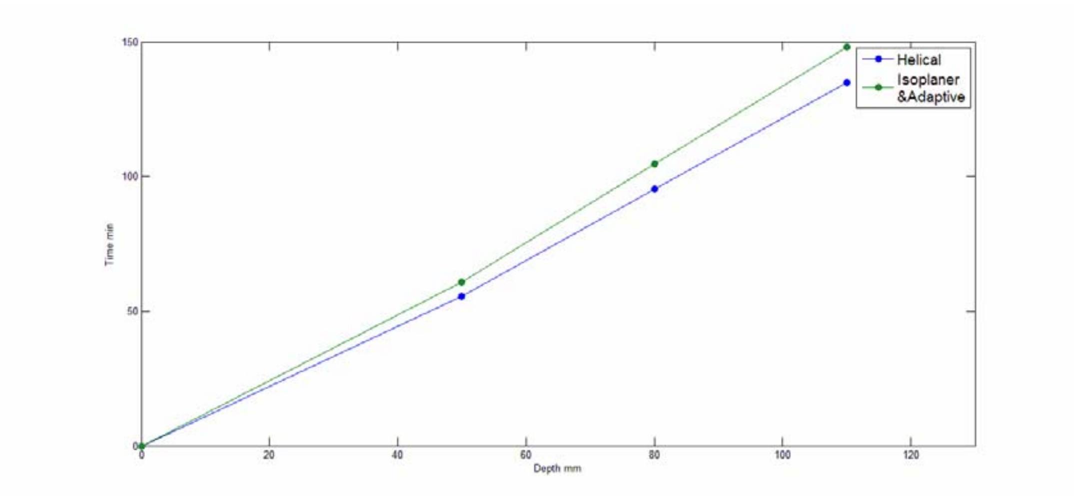


Figure (14) Relation between depth and forming time for the produced conical shapes.