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DEVELOPMENT OF A NOVEL TOOL FOR SHEET METAL SPINNING OPERATION

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Abstract-- The spinning process design still highly relies on experienced spinners using trial-and-error. Challenges remain to achieve high product dimensional accuracy and prevent material failures. This paper aims to convert this skilled work of metal spinning into a technique on conventional lathe machine by employing experimental method. By using this technique, the time and materials wasted by using the trial-and-error can be decreased significantly. In addition, it may provide a practical approach of standardized operation for the spinning industry and thus improve the product quality, process repeatability and production efficiency.

Formability of the material has been studied to form a cylindrical cup with spinning using conventional tool and spring loaded tool. It has been found that more cup depth can be produced with spring loaded tool. This will help to device spinning technique independent of skilled spinner.

I. INTRODUCTION

Metal spinning refers to a group of forming processes, where a flat metal blank is formed into an axisymmetric part by a roller which gradually forces the blank onto a mandrel. As shown in Figure 1.1, in the spinning process, the metal blank is clamped between the mandrel and back plate, these three components rotate synchronously at a specified spindle speed. Materials used in the spinning include non-alloyed carbon steels, heat-resistant and stainless steels, non-ferrous heavy metals and light alloys [1]. The process is capable of forming a workpiece with a thickness of 0.5 mm to 30 mm and diameter of 10 mm - 5 m. Due to its incremental forming feature metal spinning has some advantages over other metal forming processes. These include low forming load, process flexibility, non-dedicated tooling, good surface finish and improved mechanical properties of the spun part . Therefore, the sheet metal spinning process is widely used to produce components for the aerospace, medical, construction and automotive [2].

There are two types of sheet metal spinning: one is conventional spinning, as shown in Figure 1.2(a).

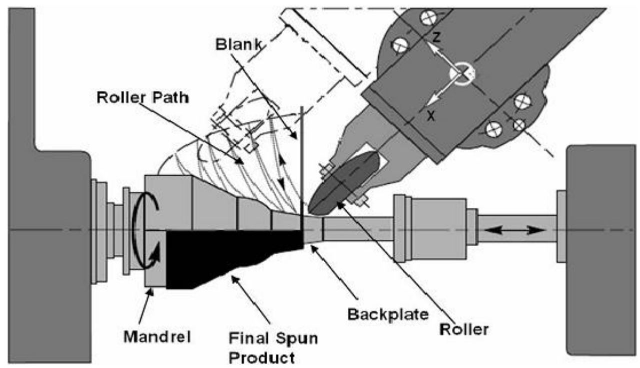
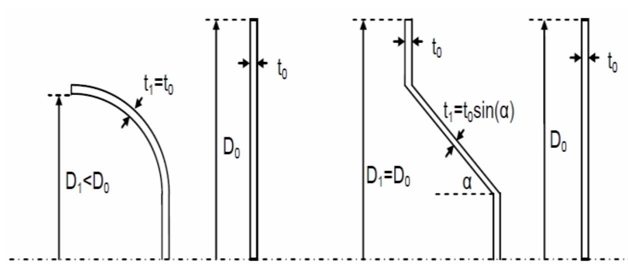


Fig. 1.1 Setup of metal spinning process

In conventional spinning shape of a blank is formed into the desired shape by multiple tool passes in order to maintain the original wall thickness (t_0). However, the diameter of the spun part (D_1) is reduced from the original diameter (D_0). Whereas, only one single tool pass is required for shear forming to deform the blank completely as shown in Figure 1.2(b). In shear forming, diameter of the spun part (D_1) remains unchanged but the wall thickness of the spun part is reduced deliberately. The final thickness of the spun part, t_1 can be determined by the sine law: $t_1 = t_0$. Sin α. Where t_0 is the original thickness of the blank [3], α is the inclined angle of the mandrel.



(a) Conventional spinning (b) Shear spinning

Fig. 1.2 Conventional spinning and shear spinning

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1.1 Failures in Spinning

Common material failures in the sheet metal spinning process are: wrinkling, circumferential cracking and radial cracking, as shown in Figure 1.3. During spinning wrinkling is caused by buckling effects of the unsupported flange of the metal sheet. Once the compressive tangential stress in the workpiece exceeds a buckling stability limit, wrinkling will occur. In the sheet metal spinning process, excessive stresses in either radial or tangential direction of the spun part are undesirable. High tensile radial stresses lead to the circumferential cracking failure, mainly in the area close to the mandrel, as illustrated in Figure 1.3(b). The radial cracking shown in Figure 1.3(c) is normally caused by the bending effects over existing severe wrinkles [4].

(a) Wrinkling (b) Circumferential cracking (c) Radial cracking

Fig. 1.3 Spinning failures

II. METHODOLOGY

Number of experiments conducted to survey the technological possibility of the conventional spinning of cylindrical cup with a cylindrical mandrel, using A1050-H commercially pure aluminum sheets of 0.9 mm thickness. This grade of aluminium is soft and ductile and has excellent workability. Before using aluminium sheet for our experimental work a metal test had conducted from government approved NABL Accredited Testing Lab.

2.1 Development of Experimental Setup

In this preliminary phase, set up has been arranged on a lathe machine using different necessities. A circular blank disk of different outer diameters and thickness t_0 = 0.9 mm was supported on the end of a cylindrical mandrel of outer diameter d_m = 70 mm. The cylindrical mandrel rotated at a different number of revolutions with the main spindle of a lathe machine.

Fig.2.1 Experimental setup

The mandrel does not incur excessive forces, as found in other metalworking processes, so it can be made from wood, plastic, or ice. For hard materials or high volume use, the mandrel is usually made of metal. For our experiment, we are using wood mandrel that is teak wood. And the shape of our mandrel is cylindrical.

The tool which we are using for our experimental work is only a single spherical tip tool, which simplified the set-up and enabled metal movement in the deformation zone. The spherical tool has a radius of 7.5 mm in the workpiece contact region. Material of the tool is mild steel.

2.2 Measurement of Forces

A lathe tool dynamometer is used to measure force in Y axis and Z axis where Y axis represents tangential force and Z axis radial force. A lathe tool dynamometer is a multi-component dynamometer that is used to measure forces during the use of the machine tool. With advances in technology, lathe tool dynamometers are increasingly used for the accurate measurement of forces and for optimizing the machining process. These multi-component forces are measured as an individual component force in each co-ordinate, depending on the coordinate system used.

The maximum spinning force induces in X axis that is axial force which we calculated with the help of literature review. The process of finding forces using lathe tool dynamometer is same as normal spinning operation. Lathe tool dynamometer is having tool of radius 2.5 mm.

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2.3 Spring Loaded Tool

The working principle of spring loaded tool is same as normal spinning tool except that it has spring loaded with it. This spring enables the tool to move back from sheet metal whenever force exceeds from maximum spinning force limit.

Fabrication work of following tool is done on the basis of conceptual design as shown in figure below.

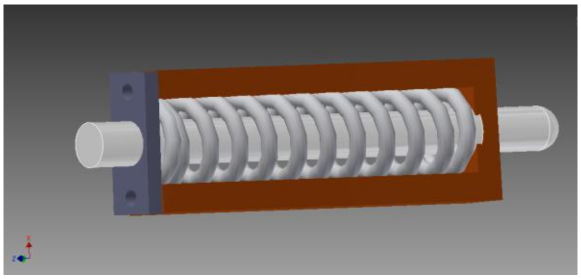

Fig. 2.2 Tool design

2.4 Thickness and Depth Measurement

As thinning of sheet material is not desirable for conventional spinning. So we measure the thickness variations along the curvilinear length of spun parts with the help of digital micrometer, as shown in figure below.

Fig. 2.3 Digital Micrometer

In last we measure and compare the depth of spun parts deformed by both ordinary and spring loaded tool.

III. RESULTS AND DISCUSSION

The manual spinning is more labor intensive process and also the quality of product e.g. tolerances and surface roughness is dependent on skill of the worker. Those disadvantages of manual spinning lathe machine can be overcome by using new spinning tools that can be compatible with conventional lathe machine, so that the uniformity of product can achieved easily and accurately. As we are using commercial pure Aluminium sheet of 0.9 mm thickness for our experimental work. Below table 1 is showing mechanical properties of sheet material.

Material	Aluminium
Specimen Width in (mm)	13
Specimen Thickness in (mm)	0.85
Gauge Length (mm)	20
Yield Proof Load (KN)	1.58
Ultimate Load (KN)	1.82
Final Gauge Length (mm)	21.3
Yield Stress N/mm^2	142.98
U.T.S. N/mm^2	164.70
Elongation %	6.50

Table 1 Mechanical properties of sheet material

3.1 Spring Loaded Tool

A rigid tool is used to practice manual spinning operation, which is completely relies on ones skills. Same practice is conducted on manual lathe machine which results in material failure. Hence a soft tool, that is spring loaded tool is required to overcome defects of rigid tool. The spring used with this tool enables it to move back from sheet metal whenever force exceeds from maximum spinning force limit. To set the dimensions of spring, we calculate the value of maximum force induces in spinning process. A lathe tool dynamometer is used to measure forces in Y direction (tangential force) and Z direction (radial force) of tool. Table 2 is showing readings of force which induces during conventional spinning process with the help of lathe tool dynamometer.

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The maximum spinning force induces in X direction that is axial force, that we calculate from following ratio of forces: Fa: Fr: Ft = 16: 5: 1 [5]

So from above ratio we can conclude that maximum force induces in conventional spinning is 1020 N, as we have average value of tangential and radial force from table 2, that is 65 N and 335 N. As per our force value, it is required to select a helical compression spring subjected to maximum force of 1020 Newton. The deflection of the spring corresponding to the maximum force should be approximately 10 mm. The spring is made of stainless steel wire. The ultimate tensile strength and modulus of rigidity of the spring material is 2050 and 81370 N/mm^2 respectively. Spring design data is referred from design data hand book [6]. The main dimensions of a helical spring subjected to compressive force are as follows:

Wire diameter of spring (d) = 3.5 mm
Inside diameter of spring coil (D_i) = 20 mm
Outside diameter of spring coil (D_o) = 28 mm
Mean coil diameter (D) = 24 mm
Free length (p) = 30 mm
Pitch of coil = 10 mm

Fig. 3.1 Spring loaded tool

3.2 Experiments

Before conducting experiments we consider certain process parameters, as the feed rate of the tool per revolution was changed from 0.2 mm to 0.4 mm. Experiments conducted using multiple tool passes so that the tensile radial and compressive tangential stresses are induced gradually, hence material failures can be prevented. Tool path design which we use is the convex curve path, which helps to maintain the original wall thickness. Tool profile with large nose radius would lead to a smaller reduction of wall thickness [1]. Considering tool of nose radius 7.5 mm for all the experiments. Experiments conducted at different tool angles with respect to mandrel axis that is 20˚, 45˚ and 60˚. Below table 3 is showing results of ordinary spinning tool work, whereas table 4 is showing results of spring loaded tool work.

Experiments	Tangential Force (N)	Radial Force (N)
1	60	320
2	70	400
3	60	280

Table 2 Readings of force

Sr. No	Blank Outer Dia (mm)	RPM	Initial Thickness (mm)	Final Thickness (mm)	Tool Angle
1	240	45	0.877	0.481	45˚
2	180	112	0.878	0.470	45˚
3	180	180	0.873	0.396	60˚
4	160	280	0.856	0.312	20˚

Table 3 Shows the different parameters at which different experiments have conducted

Sr. No	Blank Outer Dia (mm)	RPM	Initial Thickness (mm)	Final Thickness (mm)	Tool Angle
1	200	280	0.896	0.403	45˚
2	120	280	0.930	0.330	45˚
3	120	450	0.870	0.300	45˚

Table 4 Shows the different parameters at which different experiments have conducted

Fig 3.2 Pictorial view of spun parts

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Table 3 is showing results of ordinary spinning tool which conclude that thinning of sheet material taking place in each experiment as there is big difference between initial thickness of sheet and final thickness of sheet at crack point. As thinning of sheet material is not desirable for conventional spinning. By observing spun parts another defect occurring infront of us is circumferential cracking mainly in the area close to the mandrel, as illustrated in figure below.

Figure 3.3 Circumferential cracking

Table 4 is showing results of spring loaded tool which conclude that thinning of sheet material taking place in each experiment as there is big difference between initial thickness of sheet and final thickness of sheet at crack point. By observing spun parts another defect occurring in front of us is wrinkling failure as illustrated in figure 3.4.

Fig 3.4 Wrinkling Failure

Role of process parameters like blank diameter and tool angle has been cleared after conducting experiments. Following points concluded the influence of two main parameters are as follows

- Blank diameter has no significant effects on wall thinning and cylindrical cup depth.
- Almost same results are coming with different blank diameters.
- Tool angle has no effect on wall thinning, as thinning is taking place at each set angles.
- 45˚ tool angle has good impact on depth of cylindrical cup.

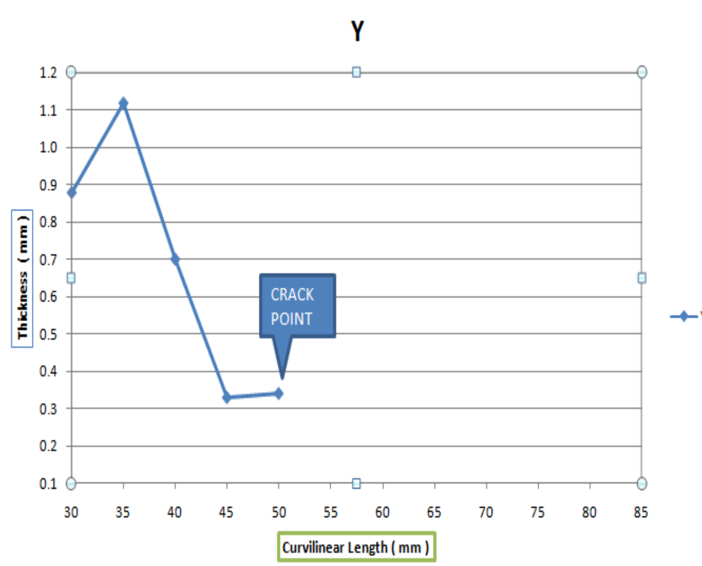
In this section we are comparing results of rigid spinning tool and spring loaded tool on basis of depth and wall thickness. Depth of cylindrical cup can be defined as the maximum deformation of sheet material in a perfect cup shape up to the crack point. Two samples have been taken to compare the maximum depth, where sample 1 is deformed by rigid tool and sample 2 is by spring loaded tool as illustrate in table 6.

Sample	Tool	Depth (mm)	Material Failure
1	Normal	26	Circumferential Cracking
2	Spring Loaded	40	Wrinkling

Table 5 Spun part dimensions

Table is clearly showing that maximum depth of 40 mm is the result of spring loaded tool. This tool also helps in uniform cylindrical deformation up to crack point.

Now for the thickness comparison same samples have been used which were used in depth measurement. Figure 3.5 shows comparison of measured values of the wall thickness along curvilinear length of the sample 1 and sample 2. Taking starting point of curvilinear length at 30 mm from the centre of spun part.



(a) Sample 1

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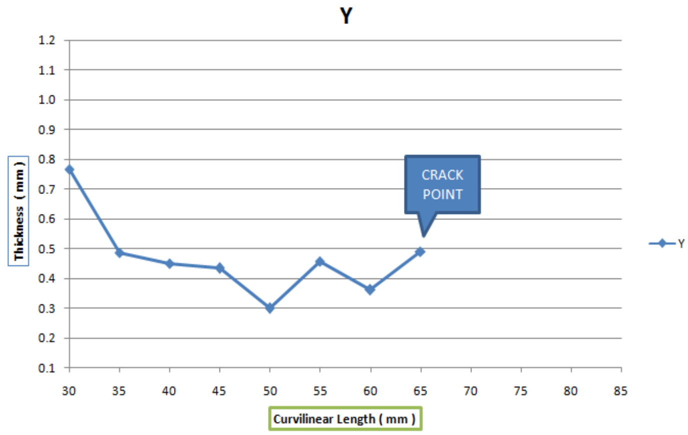

(b) Sample 2

Fig 3.5 Comparison of wall thickness of the spun parts: (a) sample 1; and (b) sample 2

Crack point of sample 1 and sample 2 is at almost same thickness value, as we have discussed in the section 4.3 that thinning of spun parts is taking place in each experiments drastically. But the crack points along curvilinear length show different result. Sample 2 curve shows more deformation before cracking, which was spun by spring loaded tool.

IV. CONCLUSIONS

Based on the experimental investigation of the conventional spinning process using the normal tool and spring loaded tool, the following conclusions are drawn:

- Experiments were conducted to find out the forces involved in the spinning operation and a spring loaded tool has been developed.
- It has been observed that the formability of the cylindrical cup is maximum when the angle between the tool axis and mandrel axis is 45^0.
- Spring loaded tool helps to obtain circumferential crack free parts but results in wrinkling failure.
- Thinning of sheet material at failure is found to be 66 % in both the components formed with the help of conventional tool and spring loaded tool.
- The cup depth can be increased from 25 mm to 40 mm using spring loaded tool.

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