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The Effect of Forming Parameters on the Sheet Stretch in Incremental Sheet Forming (ISF) process on CNC Lathe Machine

M. Moayedfar[a], Z. Leman[b], H. Mirabi[c] and B.T.H.T. Baharudin[d,*]

Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Malaysia

[a]majidmfi@yahoo.com, [b]zleman@eng.upm.edu.my, [c]mirabi63@yahoo.com, [d,*]tuah@eng.upm.edu.my

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Abstract. The effect of forming parameters during the incremental sheet forming process (ISF) was studied for a circular shape sheet part. ISF is known as a rapid prototyping method to pro-duce sheet metal parts in a batch production series. ISF has found to be useful and advantageous which increases its application in industry. A CNC lathe machine was used in this study because it was easily programmed to move an indenter which worked as the tool, through the sheet metal which was clamped on a plain rounded mold. The work also investigated the influence of some process variables such as spindle speed, tool material; tool feed rate and temperature during the forming procedure. The results showed that a proper spindle speed and tool feed rate at some stage in the forming process improved the surface quality and the rate of penetration.

Introduction

Forming of sheet metal can be carried out using different methods which are usually based on the use of punches and dies. Other methods like stamping and drawing are always in use in mass production. As the cost of dies is relatively high and it doesn't justify the batch production environment; it seems necessary to use a new sheet forming procedure, namely, Incremental Sheet Forming (ISF).

Nowadays, low production and small batch series are more appropriate in many industries (automotive, aircraft industries, rapid prototyping and medical implants) and ISF appears to be significant to fill this gap between the batch and mass production with less lead-time and investment. There are some parameters which are rather important in ISF than in the other sheet forming process such as spindle speed, tool material, feed rate, temperature and so on. Standardized charts and diagrams can help make this method more applicable. However, none of the previous works has produced a valid table or figure in order to successfully use the method in the industrial workshops. In addition, one can change the output from ISF just by changing one single parameter, for example, the tool coordinate. Nevertheless, ISF has some limitations such as the product volume, the shape of the sheet metal part and the surface quality.

There are two methods of finding the optimized parameters in ISF process. The first method is through the use of Computer Numerical Control (CNC) milling machine and the second is by using the CNC lathe machine. In this paper a CNC lathe machine was employed due to its simplicity in programming and low working time which is more suitable to be used as a rapid prototyping machine to receive the program and make a circular shape on a stainless steel 316 sheet metal. Most of the parts used in automotive, ship, aircraft and recently medical implants are made by sheet forming method. These parts have been produced using the conventional sheet forming process either by stamping or drawing which requires the use of dies or punches. If a part needs a replacement, sometimes the delivery of the part is time consuming and it causes long idle time. ISF is an effort to reduce the part lead-time as it is a die-less or punch-less technique. The method is particularly advantageous for customized replacement parts especially in medical implants.

Research Background

ISF is a technique developed to manufacture sheet metal parts quickly. It is treated as a method to produce prototypes from sheet metals. In 1960s engineers found that if the sheet metal was formed incrementally, forming force would de-crease and the process could run on smaller machines so that more complicated shapes could be formed incrementally [1]. This process is called AISF, Asymmetric Incremental Sheet Forming, which includes sheet metal forming process, small sized solid tool, connection between the forming tool and sheet metal; but there is no need to dedicate a die as in conventional forming process [2]. ISF is divided into two important types called TPIF, Two Point Incremental Forming; and SPIF, Single Point Incremental Forming. In both SPIF and TPIF, forming is the combination of stretching and drawing [3]. There are some parameters which are the same as machining parameters but used in ISF such as spindle speed, feed rate, chip depth and so on; but there are some other parameters like sheet thickness, tool radius, step size and wall angle which depend on the forming process [4]. Some other crucial factors are focused on feedback control for part geometry, male and female die tool and path design [5]. Some of these parameters have a close relation to the tools so a high performance tool is needed [6]. All of these parameters take into account the increasing ability of force prediction in the forming procedure [7].

The material of the tools was also considered, as Fiorotto [8] mentioned, it can be made of stainless steel, high speed steel or high carbon steel. It can also be made of brass or bronze depending on the material of the sheet metal. Among all parameters that affect this process, friction between the tool and the sheet metal is an important parameter that needs to be taken care of because it directly affects on the sheet metal surface quality. Shear failure can also occur when there is a lack of lubrication or when there is an over load on the sheet metal that causes heating by friction [2]. If the relative motion between the sheet metal and tool surface is small the heating is minimized during the forming. In addition, if the tool rotates at a high speed, the quality of surface decreases and the temperature at the forming area would rise. Moreover, hot condition causes tool wear which decreases tool life during the process. The amount of friction also depends on some parameters such as lubrication, spindle speed, sheet material, and tool material and so on. If the tool and sheet metal are of the same material, then there is a definite rise in the forming temperature. Previous researchers have found some ways to proportion the amount of friction stress to normal contact stress [10].

Experimental Setup

An experiment was designed to find some technical data and the effect of the mentioned parameters on the rate of sheet stretch in ISF process. A stainless steel sheet clamped on a rounded mold by 8 hexagonal head cap screws as shown in Figure 1. A stainless steel sheet was drilled and fastened to the mold by the screws. The mold was mounted on a CNC lathe machine inside the machine chuck. A spherical head indenter which was used as the tool was held by the tool holder of the machine.

The overall forming process is described as follows. The indenter is directed towards the orbiting mold and forced on the surface of sheet metal at a point known as the start point. The point gets concave depends on the penetration rate that comes from the x-axis of CNC lathe machine. In this work, some different feed rates and spindle speeds are used to find the optimized value. After that the tool moves along the x-axis towards the machine chuck and then moves along the y-axis, depending on the program. The forming parameters change as soon as the layout changes. And machine is then available for a new sequence.

Figure 1: Rounded mold

A finishing process is pre-pared separately in order to increase the surface quality and accuracy. At the first part of finishing step, the operator can change the tool to a smaller one to increase accuracy of the indentation. This act helps to make small angles and fillets as well. The second step of the finishing process is to change the tool motion in order to remove the tool effects and scratches on the surface of the sheet metal. During the process, lubricant is running on the sheet surface and flows around the forming area. It is not advisable to use cooling liquid or other cooling oil because there are some elements in these liquids that react with a very thin profile of the sheet metal surface that can cause chipping which is known as a bad effect on ISF process. It is best to mark the start point of the forming to be the point that will be the lowest point in the final shape. It causes the other points to stay higher than it and deviations reach the minimum value.

Result and Discussion

In this paper, one cone-shaped part was produced by changing the forming parameters and the results are shown in the following figures.

The results show that a suitable spindle speed is recommended to be between the low and high speed. When the spindle speed is at the middle level, the amount of stretching of the sheet metal rises and the surface quality also increases at this spindle speed. The effect of spindle speed on the amount of stretching is shown in Figure 2. Moreover, the tool feed rate has a direct effect on the temperature as well as spindle speed. The horizontal axis shows the spindle speed and the vertical axis shows the rate of sheet stretch. The tool material used in this experiment was aluminum alloy, which is a very tough metal. The tool caused the increase in temperature and earlier shear failure in the sheet part was observed. Next, a smooth metal was employed in this experiment which was brass alloy, however, it deformed during the experiment and decreased the accuracy of sheet part produced. Another tool used was made of bronze alloy. Figure 3 shows the effect of the three tools made of different materials on the rate of sheet stretch.

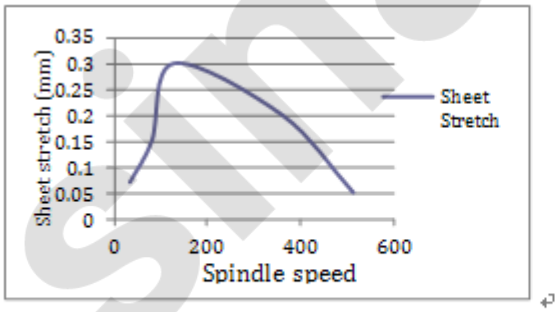

Figure 2: The rate of sheet stretch on different spindle speeds

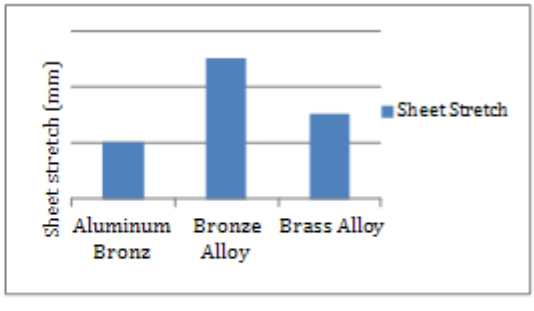

Figure 3: The rate of sheet stretch of three different tool materials

The temperature also has an effect on the amount of sheet stretch. The formability of stainless steel sheet is generally good at low heat but during the ISF process temperature increased very high and caused friction. This phenomenon increased the rate of corrosion and changed the process of forming to chipping. The amount of sheet stretch versus the temperature is shown in Figure 4. The horizontal axis shows the rate of temperature and the vertical axis shows the rate of sheet stretch. Feed rate was also considered in this experiment, as the process used a CNC lathe machine. The feed rate on this machine is referred to as the speed of forming in other sheet forming process such as stamping. The quality of surface depends on the feed rate also, so a program with high feed rate can be a good suggestion in terms of surface quality. Sheet metal shows a brittle behavior when a high feed rate value is applied. The sheet metal would experience shear failure at the very early stage of the forming process. So feed rate also needs to be set at a proper value. Figure 5 illustrates the effect of feed rate on the sheet stretch. In this figure the horizontal axis represents the feed rate whereas curve shows the rate of sheet stretch. As can be seen, the amount of sheet stretch is increasing to the peak gradually but it falls down sharply because of the brittle phenomenon. After the peak, sheet metal forming process moves from elastic area to plastic area. On the other hand, shear failure occurs with high feed rate because the process reaches plastic area soon. It was also observed during the experiment, that the surface quality increased when the feed rate gradually increased but very high feed rate caused the surface quality to deteriorate because of the defects of friction and vibration. Surface quality can be improved with more lubrication.

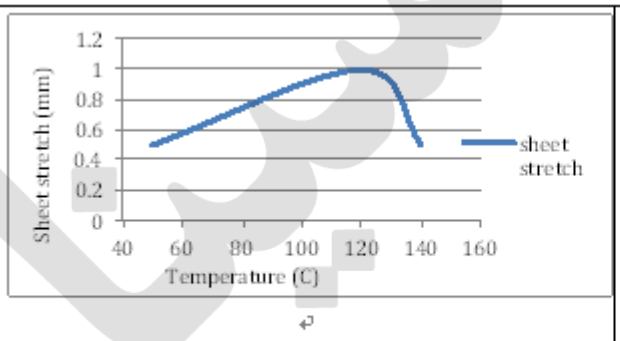

Figure 4: The rate of sheet stretch versus temperature

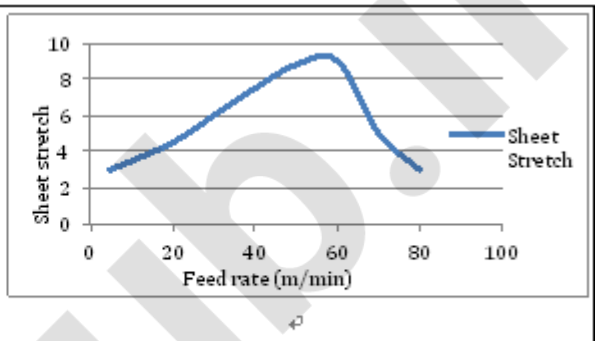

Figure 5: the effect of feed rate on the rate sheet stretch and surface quality

Conclusion

The influence of forming parameters has been studied on stainless steel sheet stretch using a CNC lathe machine. The results show that the forming parameters have a direct effect on the sheet stretch. There are some parameters that have not been calculated in the forming process yet but they have been applied in ISF on CNC lathe machine. These parameters such as feed rate that act like spindle speed on chipping process has more than one effects on the surface quality, part accuracy and working time. The presence of heat as in rise of temperature, also is a parameter that must be controlled during the forming procedure. There are some lubricants that can be used as coolant liquid to decrease the temperature of the forming area. This liquid cannot be the one that is used in the chipping process because coolant of machining react to the thin sheet metal and make it brittle. Figure 6 shows the sheet part that was produced in this work.

Figure 6: Final sheet part produced with ISF on CNC lathe machine

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