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ScienceDirect
Procedia Engineering 97 (2014) 1983 – 1990
Procedia Engineering
www.elsevier.com/locate/procedia

12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014

Comparison of FLD and thickness distribution on AA5052 aluminium alloy formed parts by incremental forming process

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Abstract

Incremental forming process is one of the most promising newer techniques in metal forming process. Formability of analysis has to be carried out in order to obtain successful forming process. This paper aims to study the forming behavior of AA5052 aluminium alloy through incremental forming process. Truncated square pyramid and cone are formed to study the formability of AA5052 aluminium alloy at room temperature. A computer controlled numerical machine was used for forming. Forming limit diagram (FLD) is used to study the behavior of sheet metal. FLD and thickness distribution has been predicted and compared for both the shapes. The forming limit diagram obtained through incremental forming very much varies from conventional forming limit diagram. Comparison of FLD and thickness distribution shows that cone has higher forming limit than square cup and the thickness after forming is better in cone shapes than in square cups.

Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014

Keywords: Incremental forming; forming limit diagram; thickness distribution.

1. Introduction

Incremental forming is one of the newer forming technologies where complicated external shapes can be formed without using punches and dies. A hemispherical tool is pressed over the sheet metal to form the desired shape. The tool path is controlled by a CNC machine. It is based on the methodology of producing the designed shaped by progressive movement of the hemispherical tool. Since localized deformation is developed during forming, more stretching occurs than in conventional forming. This process is mostly applied due to more flexibility and less

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Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014
doi:10.1016/j.proeng.2014.12.353

tooling cost. Due to slow forming process, this can be limited only to small batch production systems. This process is capable of forming sheet metal which is used in automotive, biomedical and aerospace industries [1]. To improve the formability of sheet metal, many researchers have studied the process mechanics [1-2]. Deformation in single point incremental forming (SPIF), is due to combined shear and stretching [3]. In few cases, bending of sheet metal also involved in addition to shear and stretching. The stretching and shearing of sheet metal induces wall thinning in parts, which can be predicted by Sine's law [4]. The wall thickness mainly depends on the forming wall angle that the sheet metal can withstand without fracture. The formability of the sheet metal can be predicted by forming limit diagram (FLD) which separates the forming region and failure region. It is represented in terms of major strain and minor strain under plane stress condition [5-7]. FLD is controlled by the sheet thickness, forming speed, tool diameter and step depth [8-10]. Tool path influences the formability and surface finish of sheet metal. SPIF has high forming limits in comparison to conventional stamping process [11-12]. This study aims to compare the FLD obtained by forming a square cup and cone in aluminium alloy sheet.

2. 2. Material and Methodology

Interest in utilization of aluminium alloys has developed to produce light weight vehicles with high fuel economy. Since aluminium magnesium alloys have good corrosion resistance and high formability AA5052 alloy have been highly utilized in aerospace and automotive industries [13]. A truncated square pyramid with 100 x 100 mm top square and 50 x 50 mm bottom square with height 50 mm and a truncated cone with wall angle 45°, with outer diameter of 100 mm and inner diameter of 50 mm as shown in figure 1, is formed from a square sheet blank (150 x 150 mm) by SPIF. AA5052 aluminium sheet blank with 1 mm thickness obtained in cold rolled condition was held into a specially designed fixture as shown in figure 2(a). A hemispherical tool of diameter 12 mm was used to form the parts (figure 2(b)). The tool moves along a circular path with increasing step depth until the designed depth is obtained. The forming parameters are: tool speed 1500 rpm, feed 50 mm/rev and step depth 0.5 mm. The forming parameters are controlled with the help of CNC machine.

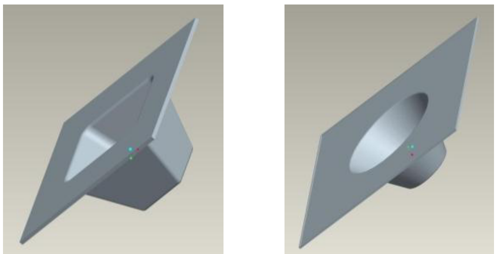

Fig. 1 Truncated square pyramid and cone to be formed

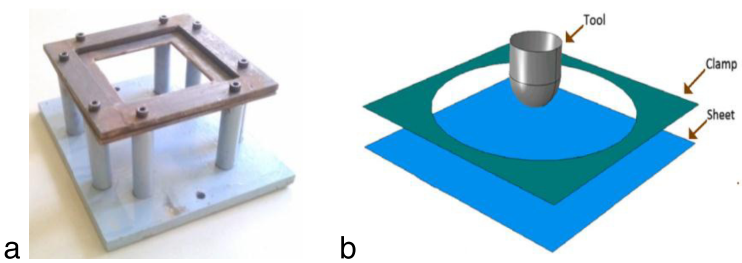

Fig. 2 (a) Fixture for sheet metal clamping (b) sheet assembly along with tool

Formability mainly depends on the material properties such as tensile strength, strength coefficient, strain hardening and percentage of elongation [14]. Percentage of elongation plays a vital role in metal forming processes. More the elongation of sheet metal and more the formability. The mechanical properties are evaluated by conducting tensile tests over specimens prepared according to ASTM E8 standards. The chemical composition of AA5052 was given in table 1 [15].

Table 1 Chemical composition of Al 5052 alloy both nominal and actual (wt %)

Composition	Mg	Cr	Si	Fe	Cu	Mn	Zn	Al
Nominal	2.23	0.18	0.14	0.31	0.01	0.05	0.001	Rem
Actual	2.2-2.8	0.15-0.35	0.25 Max	0.40 Max	0.10 Max	0.10 Max	0.10 Max	

The properties of AA5052 are: yield strength is 243.4 MPa, ultimate tensile strength is 272.5 MPa, percentage of elongation is 13% and average hardness is 96.63 (HV 0.5). To carry out the experiments, numerically controlled milling machine HAAS V2 was used. The whole fixture along with the sheet metal is mounted on a CNC machine as shown in figure 3.

Fig. 3 Fixture with sheet metal mounted on CNC machine

3. Experimental Procedure

3.1. Forming procedure

In SPIF, a hemispherical tool imposes local deformation plastically on the sheet metal. Two types of deformation characteristics occur in this forming method. When the tool path is straight on a horizontal plane, at the starting and ending points the deformation that occurs is biaxial stretching. Plane-strain stretching deformation occurs between these points. When the tool movement is in curved path, more biaxial stretching deformation occurs. The other characteristic is the formability of the deformation. As the tool diameter or the step depth decreases, the formability increases. For aluminium sheet, the formability can be expressed as a scalar number of $\varepsilon_{major} + \varepsilon_{minor}$ [16].

3.2. Tool trajectory

Tool path on a plane is a closed loop usually consists of smooth curves, straight lines and corners. Dimensional accuracy, processing time and surface roughness is mainly affected by tool path [17-18]. The tool trajectory is determined from the CNC program. CNC machine controls the tool motion and defines the tool trajectory. Rotating tool caused local plastic deformation and tool movement causes biaxial stretching and plane stretching. The tool moves in a square manner, completes one cycle and then the depth is given reducing the size of the square for truncated square pyramid and for the cone the tool moves in a circular manner, completes one circle and moves down reducing the diameter of the circle. The tool path trajectory for truncated square pyramid and cone is shown in figure 4.

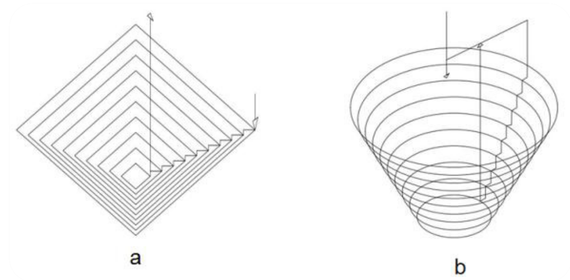

Fig. 4 Tool path trajectory for truncated square and cone

3.3. Electrochemical Etching

The basic principle of this method is to generate the grid pattern on the blank sheet metal. The experimental setup for grid pattern printing is shown in figure 5. Initially the power source is attached to the electrode and the sheet blank. Desired pattern stencils then carefully placed on the surface of the sheet which in our case was around grid pattern of circle 3mm. Over the stencil felt pad is placed and the electrode wheel is made to press the felt pad over the stencil. Desired voltage is supplied for few seconds and the roller type electrode wheel with an attached power source is reciprocated on the felt pad and thus current is passed from the electrode to the blank resulting in pressing out of the etching solution through the contours of the stencil on the surface of the sheet by means of the pressure generated by the roller wheel. After etching the sheet metal is washed with a neutralizing solution. Thus circular grid pattern is generated.

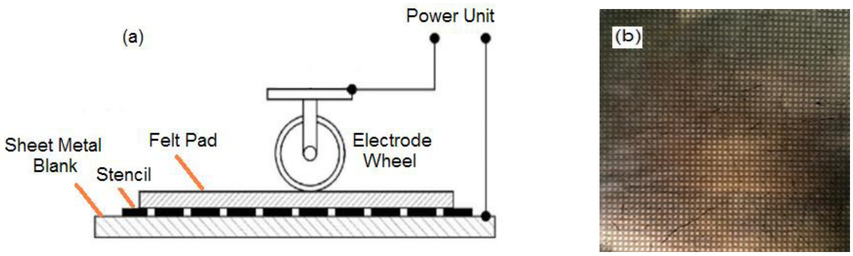

Fig. 5 (a) Electrochemical etching process and (b) Formed pattern on sheet metal

3.4. Forming limit diagram

FLD is a tool used to determine the formability of the material. FLD is constructed using minor strain as abscissa and major strain as ordinate. FLD can be calculated by measuring the deformed circular grids obtained after forming. Researchers started the first research on this field using circular grids which deformed into elliptical after forming. They obtained the right side of the FLD known as tension/tension side ($\varepsilon_{minor}>0$, $\varepsilon_{major}>0$). Later research continued on FLD gave the left hand side called tension/compression side ($\varepsilon_{minor}<0$, $\varepsilon_{major}>0$). They both used hemispherical punch test to obtain the FLD. The comparison FLD for conventional and incremental forming has been given in figure 6. In this test, incremental forming procedure is used to compare the FLD for truncated square pyramid and cone.

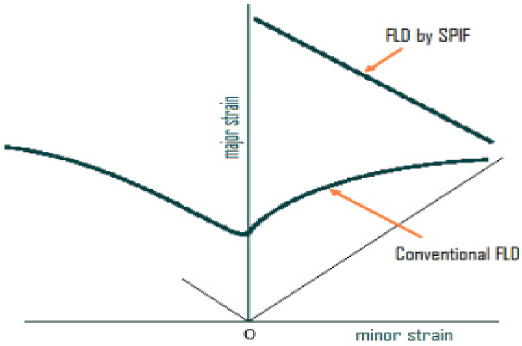

Fig. 6 Comparison of conventional and incremental FLD

4. Result and Discussion

4.1. Strain Measurement

The formed parts are shown in the figure 7. For formability analysis, circle grid measurement is done. This method provides the basis to predict the failure in sheet metal forming. The developed strain can be measured by comparing the circle before and after forming. During forming, the circle grids are converted into ellipse, and the major and minor strains can be calculated by measuring the lengths of the major and minor axes, d_1 and d_2 [19]. The principal strains are calculated by

$$\varepsilon_1 = ln(d_1/\, d_0) \quad and \qquad \varepsilon_2 = ln(d_2/\, d_0) \tag{1}$$

A Mylar tape is used to measure the strains in the major and minor axis and is tabulated. FLD graph is plotted against minor and minor axes for the truncated square pyramid and cone separately as shown in figure 8. A combined FLD for the parts are shown in figure 9. Cone has higher major and minor strain than truncated square pyramid. Combinations of FLD for both the parts shown that cone shaped parts have higher formability than squared shaped parts. This is mainly due to absence of corners in cone.

Fig. 7 Formed truncated square pyramid and cone with grid pattern

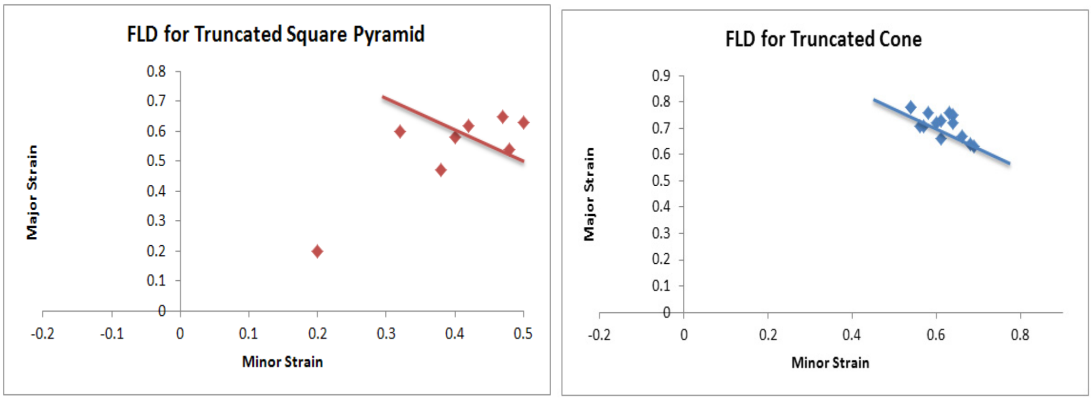

Fig. 8 FLD for truncated square pyramid and cone

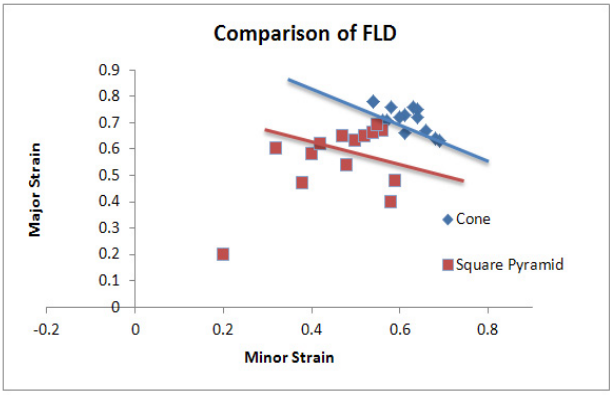

Fig. 9 Combined FLD for square pyramid and cone

4.2. Thickness measurement

The material thickness used in this analysis is 1 mm. Thickness before and after forming is measured using dial gauge as shown in figure 10. The values are taken from various regions for analysis. A comparison graph between the thickness measurement from square pyramid and cone is drawn. The variation in thickness along with forming depth is shown in figure 11. Thinning in cone is lesser in cone than in square pyramid. This is due to free flow of metal during incremental forming for higher forming radius in cone than for smaller radius corners in square pyramid. Thinning takes place more at the bottom part than at the top.

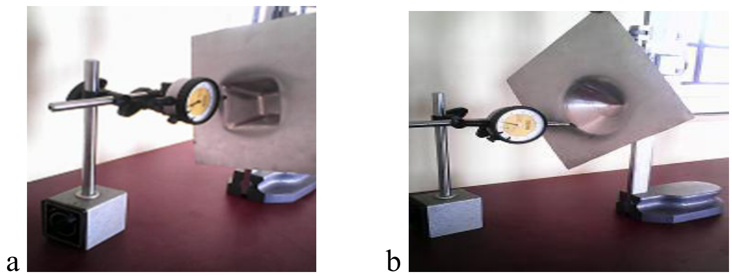

Fig. 10 Thinning measurement for (a) truncated square pyramid and (b) cone

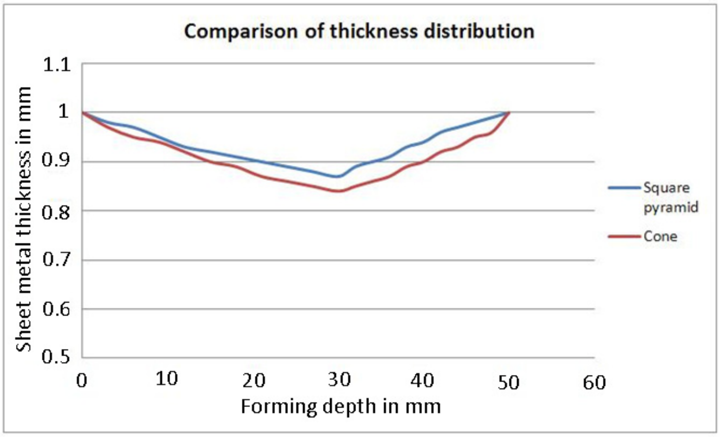

Fig. 11 Comparison of formed thickness

5. Conclusion

In this paper, formability of AA5052 aluminium alloy sheet metal with 1 mm thickness at room temperature was investigated through formation of truncated square pyramid and cone by single point incremental forming processes. Formability analysis and thickness distribution study was carried out over the sheet metal. The conclusions are:

a) Comparison of FLD shows that higher formability can be obtained with higher forming radius than with sharp corners
b) As far the smooth curve tool path occurs the flow of materials is high and high formability can be obtained
c) Smooth surface finish can be obtained when the tool travels in curved path than in straight path, due to more contact of tool with the sheet metal
d) Restrictions to tool path reduces the flow of material thus decreasing the formability

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