Impact of mechanical properties on sheet metal forming processes by using single-point incremental shaping method

T.Srinivasan¹, P.Ramu², G.Suresh³, Y.S.Govardhan⁴ and S.Srinivasan³

¹ Dept. of Mechanical Engineering, Koneru Lakshmaiah Educational Foundation, A.P., Vaddeswaram, Guntur, India
² Dept. of Mechanical Engineering, Sri Sai Ram Institute of Technology, TN, Chennai, India.
³ Dept. of Mechanical Engineering, Rajalakshmi Institute of Technology, TN, Chennai, India.
⁴ School of Mechanical Engineering, Vellore Institute of Technology, TN, Chennai, India

¹Corresponding Author: seenusreeja@gmail.com,

Abstract

The usage of single tool using Computer numerical control (CNC) machines in processes. These flexible processes satisfying the need of the manufacturer through the Single point incremental forming (SPIF). Modern and die less sheet metal forming technique applied in this technique mainly for small batch and custom made items of different shapes and dimensions. It offers many advantages compared with traditional sheet processes, especially in terms of flexibility and material formability. The basic idea is to build the knowledge about the advanced manufacturing process and do preliminary investigation on the applicability of single point incremental forming process. In obtaining the mechanical properties, two types of tests are being conducted. They are tensile test and composition test. These test conducted according to ASTM E8M and ASTM B209 respectively. The present work is to be carried out on Aluminium alloy which have very important industrial application with a light weight to strength ratio. In this work the stress, strain, formability, wrinkles, deformation will be studied.

1 Introduction

Forming processes are known to be the basic manufacturing processes that allow use of acceptable stresses such as compression, friction, shear or combined stresses, which in turn induces plastic deformation to the materials creates the necessary shapes. Metals are the main material used in these processes because they have very strong properties of formability and malleability. Because of the huge need for different goods demanded by the public metallic materials plays the lead role as the raw materials in the processes of formation. Nevertheless, due to a wide demand for plastic based goods, other compounds like plastic also nowadays used as the raw materials in most of the fabrication industries, where as during the forming operation of metallic materials, no substance is extracted during the entire process of formation of materials instead materials are deformed and displaced. Forging, extrusion, rolling, rotary swaging, explosive formation, electromagnetic formation and sheet metal working are some of the following examples of forming techniques. Single point incremental forming (SPIF) is a new fabrication methodology which allows complicate profileusing the Computer Numerical Control (CNC) movement of a hemispherical forming tool. Due to size factor, the development of thin sheet metal forming processes is limited in the manufacturing
processes since it requires the massive state of art technology as it needs the miniature size of CNC machines. The initial grain size during the forming processes also plays a major role in during formability processes [1].

Aluminum alloys combination are highly usage in aero and automobile industrial applications owing to their density low and good tensile properties, lower corrosive, wear and less thermal co-efficient of expansions as matched to regular metals alloys combination [2]. Normally the unique contrast during the operation is happen between the two hardened metals during the deforming operation by considering the spring back effect and thickness of the metals. Similarly the outcome of the compared models are checked with two consecutive specimens. Atlast the final formed part has to come across the cumulative of all parameters of the forming operation [3]. Most of the leading fabrication industries having wide knowledge in the forming processes are limited their service in making the miniature size products with help of the forming technology, since it needs the massive machine investment and special type of state of art technology as well as the formation of the grains after the fabrication processess must be elaborately studied into microscale [4].

The sheet metal is one of the leading metal forming process considered as the economically accepted one in most of the industries, small intricate shapes and size products can be easily formed with help of the forming processes. Moreover during the forming metals are often coming across the thin sheets and subjected with the tension, compression and shear forces. Most of the everyday usage products are completely manufactured with help of this forming technology. Similarly depends upon the usage of the raw materials the metals are produced with various thickness, it varies from 0.1 mm to 6 mm, beyond the size of the 6 mm materials are considered as the structural steels. Importance to analysis the different reasons for affecting the friction surface. There are so many scientific journals discussed and reported about friction in different way [5].The strength of the aluminium alloys based on the strain hardening effect of alloying elements such as silicon,iron and magnesium [6-7]. Increasing the weight of an automobile can decrease fuel efficiency and maximise its impact on the environment. Our main need is to reduce the vehicle weight therefore to arrange alternate aluminium alloys [8]. The micro level analysed for the evenscattering of the material and the mechanical studies such as Tensile strength, hardness and impact strength of the composition were evaluated for varying alloying materials with varying percentage [9-12].

2 Materials and Tool

A 6061 T6 square aluminium foil (130mm×130mm×1mm) was hold on the specially design fixture frame and was formed by SPIF. The raw material or semi - finished or finished piece which is formed by executing various processes. The workpiece is commericially obtainable aluminium alloy sheet of grade 6061 T6 series soft-Temper Foils with 1mm thickness and 2.7 gcm³, young’s modulus of 70 GPa and Poisson’s ratio of 0.3. The Figure.1 shows worksheet and single point tool of varies size and shapes. A hemi spherical end tool is used for making various shape elements, flat shape single point tool is usedfor fabricating of flat shape components. The shape and diameter of a tool has a highly stimulus on forming characteristics and process.
3. Methodology

3.1 Mechanical Test

The widely considered parameters such as r-value, n-value, K-value force and their consecutive percentage elongations are the prime and main technical interest in tensile studies during forming processes. The tensile specimens are been cut from the rolling direction, from the sheet with different orientations, namely transverse (90), rolling (0) and diagonal (45) are prepared according to the ASTM standard specifications like ASTM-E8M-9. The above set of parameters for all three sheet orientations is tested in this work, and this has been used in this work. Using the relationships, the mean value of parameters such as n-value, r-value, K-value and planar anisotropy can be determined. The figure 2 shows the specimens before subjecting with the tensile test.

Where,

- T1 (x-axis) 0º = Rolling Direction,
- T2 (y-axis) 90º = Transverse Direction,
- T3 (z-axis) 45º = Diagonal Direction.
3.2 Single Incremental Forming

Single incremental shaping process is based on the technique of creating the desired portion and shape by attempting to move a punch, following a predetermined tool direction as shown in Figure 3. A comprehensive investigational and numerical analysis of sheet incremental formation technique by using a universal purpose CNC machine, fitted with a special instrument and forming the sheet with distinct die geometries, is shown in the following set up. The key challenge associated with this method is to manufacture parts with adequate precision and consistency in the measurements. The forming tool feed rate is 10 mm/min and oil coolant was supplied as a coolant to minimize the friction.

![Figure 3. (a) Experimental setup and (b) Input parameters of the part processed [13]](image)

4 Result and discussion

4.1 Mechanical Properties

Where, n is that the strain hardening exponent and K is that the strength coefficient. A log-log plot of true stress and true strain to maximum load will end in a line. The linear slope of this is often n and K is that the true stress at $\varepsilon = 1.0$ the strain hardening exponent may have values from $n = 0$ to $n = 1$. If $n = 0$, perfectly plastic solid and $n = 1$, elastic solid. Most of the metal have $n$ values between 0.1 to 0.5. The strain hardening exponent (n-value), plastic strain ratio (r-value) as well as strength coefficient (K-value) and finally nr-value formability properties are described in table 1. The void parameters for the experiment are enlisted in the response of major strain resulting from fracture and forming limits for the experiment. Figure 4 shows the after tensile test specimen. The trend of the force is regular which have single peaks and valleys as shown in the figure 5.
Average plasticisation strain ratio,
\[ R_{av} = \frac{(R_0 + R_{90} + 2R_{45})}{4} \] (1)
Average strain hardening exponent,
\[ n_{av} = \frac{(n_0 + n_{90} + 2n_{45})}{4} \] (2)
Average strength coefficient,
\[ K_{av} = \frac{(K_0 + K_{90} + 2K_{45})}{4} \] (3)

In a similar manner, the average intensity coefficient was also estimated. The metal sheet's compressive strength, as well as the common stresses like tensile stress, ultimate tensile stress, strain rate, percentage of elongation, strain hardening exponent component, plastic strain ratio of the metals and atlas the strength coefficient are stated. The forces obtained from the experiments are plotted in the form of graphs with respect to stroke.

| Orientation | Yield Stress (MPa) | True Tensile Stress (MPa) | % Elongation | Strain Hardening Exponent, n | Strength Coefficient, K | Plastic Strain Ratio, R |
|-------------|-------------------|--------------------------|--------------|------------------------------|------------------------|------------------------|
| 0°          | 286.49            | 309.27                   | 8.06         | 0.508552                     | 422.4                  | 0.489                  |
| 45°         | 241.35            | 270.00                   | 6.64         | 0.516908                     | 393.96                 | 0.578                  |
| 90°         | 257.20            | 278.07                   | 7.42         | 0.566855                     | 677.43                 | 0.672                  |
| Average     | 261.68            | 285.78                   | 7.37         | 0.39807                      | 373.45                 | 0.43475                |
4.2 Forming With a Tumbler

The initial trial was carried out on single point incremental process to optimize the force and surface finish of the fabrication of aluminium metal forming. The final part of the profile are shown in Figure 6. First phase of forming, the shear and compression force were governing the process of Tumbler shape profile of Al6061 T6 alloy. The second phase of plastic deformation, the uniaxial strength is extremly influence sheet forming. The major strain, stress & displacement within the limit. The speindle speed, depth and forming angle is used for SPIF in 500 rpm, 40mm and 60° repectivley. Figure 7 shows the Crack and Poor surface finish, Tool Failure during the SPIF process.

![Figure 6. Final Product](image)

![Figure 7. Mode of Failure](image)
Conclusion

Thus, the advanced manufacturing process study and preliminary investigation on the applicability of the incremental fabrication process for a single point was carried out. From the results of tensile test, it is confessed and clear that the three operating parameters that influences the formability of single point incremental forming was derived and studied for the analysis. The outcomes of the modelling study which evolves empirical relations in the view to find out the formability parameters such as n-value, K-value and R-value have been found out. From the above work, it is also observed that the parameters or factors which are responsible for the failures such as crack, wrinkles, roughness and tool failure were found from the iterations. Based on the iterations, the suitable parameters for the forming was evaluated and the wrinkle-free parts have been formed out successfully.

Reference:

[1] R. Ben Hmida, S. Thibaud, A.Gilbin, F. Richard, 2013, Influence of the initial grain size in single point incremental forming process for thin sheets metal and micro parts: Experimental investigations, Materials & Design, Vol.45, pp: 155-165.
[2] Sathyaraj S., Venkatesan K., Srikanth J.(2018), ‘Fabrication of aluminium 6061- SiC-Al2O3 mmcn and hmnm by stirr casting technique and comparing the mechanical properties’, International Journal of Mechanical and Production Engineering Research and Development, Vol.8(1), PP. 635-642.
[3] Gabriel Centeno, Isabel Bagudanch, A.J. Martínez-Donaire, M.L. García-Romeu, C. Valdellano, 2014, Critical analysis of necking and fracture limit strains and forming forces in single-point incremental forming, Materials & Design, Vol.63, pp: 20-29.
[4] Sivakandhan C., Babu Loganathan G., Murali G., Suresh Prabhu P., Marichamy S., Sai Krishnan G., Pradhan R. (2019), ‘Material characterization and unconventional machining on synthesized Niobium metal matrix’, Materials Research Express, 7(1), PP:1-22
[5] Seshacharyulu K., Bandhavi C., Naik B.B., Rao S.S., Singh S.K.(2018), ‘Understanding Friction in sheet metal forming-A review’, Materials Today: Proceedings , 5(9), PP. 18238-18244.
[6] Chakravarthi, KVA; Koundinya, NTBN; Murty, SVSN; Rao, BN, 2018, Microstructure, properties and hot workability of M300 grade maraging steel, DEFENCE TECHNOLOGY, 14, 51-58.
[7] T. Sampath Kumar, A.VinothJebbaraj, E.Shankar, N.Tamiloli, K.Sivakumar, 2019, Metallurgical and mechanical characterization of TiCN/TiAlN and TiAlN/TiCN bilayer nitride coatings, Surfaces and Interfaces, Vol.15, pp: 256-264.
[8] Nagabhyrava R., Kota S., Geda A., Gudi S.H. (2017), ’Investigation of mechanical properties of AL 7075/SIC/GR hybrid metal matrix composites’, International Journal of Mechanical Engineering and Technology, 8(5), PP.265-269.
[9] Venkatesulu M., Rama Kotaiah K. (2019), ‘Production and mechanical properties of AL 6063/B4C composites’, Journal of Mechanical Engineering Research and Developments, 42(1), PP.46-49.
[10] Rao T.B., Goutham Karthik M.S.V.S., Raviteja Ch.K.S., RajaSekhar Reddy G., Sravan Kumar Reddy N., Shanmukha Prasad V.(2018), ‘Microstructural and mechanical properties of AL6061/GR composites processed through stir casting’, International Journal of Mechanical Engineering and Technology , 9(4), PP. 28-34.
[11] Rao T.B., Venkata Sai Prem K., Yashika N., Chevvakula S., Nalli V., Prasad V.S.(2018), Microstructural and mechanical properties characterization of Al6061/nano TICP composites fabricated through stir casting, International Journal of Mechanical Engineering and Technology, 9(5), PP. 193-199.

[12] Rao, TB. 2018, An Experimental Investigation on Mechanical and Wear Properties of Al7075/SiCp Composites: Effect of SiC Content and Particle Size, Journal of Tribology-Transactions of the Asme, 140(3).

[13] M. Rimašauskas, K. Juzėnas, R. Rimašauskienė, E. Pupelis, 2014, The research of single point incremental forming process for composite mould production, MECHANIKA, Vol. 20(4), pp: 414–419.