A study on using cold forging process to manufacture bush

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Abstract. This work studied on the feasibility to produce agricultural bush parts using cold forging followed by machining to replace existing processes of piercing operation followed by shaving had been studied. Short tool life of the shaving punch is a major problem for existing processes. From this work, it was found that the maximum force required for cold forging operation is similar to that used on the existing process. Therefore same facility can be employed for a proposed method. A proper selection of billet size was necessary not only to obtain specific shape of final part, but also to yield maximum rate of material utilization. Another factor influencing the process was material flow constraint by cold forging die design. The design with highly constrained would lead to high stress introduced to the part. It is recommended to use forging die design with allow more of free material flow which is expected to improve tool life.

1. Introduction
Metal forming is one of a process used mainly in the industry producing mass production due to the economics of the process and the quality of part produced. Bush, a component for agricultural mechanization is currently produce by piercing with 19 mm punch diameter and shaving operations to obtain required hole diameter of 21.5 mm as shown in fig.1. Shaving is necessary due to too rough cutting surface inside the hole obtained from piercing.

Major problem found in the manufacturing industry is short tool life of both piercing and shaving processes due to large hole diameter as well as high thickness of the components.

Comparison between cold forging from a bar and conventional stamping has been made by K.Mori and T.Nakano [1]. Specific geometry of sharp corner for example was found superior. H. Tumer and F.O. Sonmez [2] studied on the optimum shape design of die and preform for the purposes to improve hardness distribution in backward extrusion cup parts. Multi-stage cold extrusion process design using finite element software to optimize the manufacturing of similar components was studied by G. Giuliano [3]. Simulation results of strain distribution and forces for forward-backward extrusion illustrated promising method to manufacture parts. M.W. Fu et al. [4] studied cold forging and piercing tool life. Several parameters such as web thickness prior to forging and piercing punch geometry were optimized. M. Gariety et al. [5] investigated on the performance evaluation of cold forging lubricants using double cup backward extrusion tribo-test. Friction factor calibration curves which express relationships to cup height ratio had been illustrated for several types of lubricants using finite element simulation (FE). Study of shaving process [6,7] show successful achievement on
smooth cut surface characteristics. However, High values of stresses and force are observed. These will lead to high wear problem.

Fig. 1. Current process sequences producing agricultural bush parts

This work, suggested to utilize cold forging follow by piercing to replace the existing processes. Forging process parameters including initial billet sizes and flow constrained by several tool design were investigated. The benefits of proposed operations have been expected not only to improved tool life but also to increase material utilization.

2. Experimentations

2.1. Cold forging experiments
Forging tool used in the experiment is illustrated in fig.2. Punch geometry according to Bay’s original design [8] used is demonstrated in fig.3. Punch and container are made from cold work tool steel harden to 60 HRC. Billets of simple cylindrical shape of 44 mm diameter and 16 mm height made from AL6063 were employed. The shape of bush final product of 44.5 mm outside diameter, 21.5 mm inside diameter and height of 18 mm are required. Forging Press of 400 Ton capacity was used. Investigations on friction for 3 different test conditions had been made; dry (no lubricant apply), apply with Die forgent – WLA245 (water based lubricant) and Die forgent – AP270 (oil based lubricant). For each condition, 5 repetitions of the experiments had been made.

Fig. 2. Tool assembly

Fig. 3. Geometry of punches
2.2. Forging simulation

Commercial FEM software DEFORM 3D had been used to simulate cold forging operations. Punches and container are set as rigid types. Workpiece material properties (AL6063, ∅44 × 16 mm) and parameters selected in the program are shown in Table.1. Example of deformed model before and after forming are presented in fig.4. Tetrahedron solid type of 50,000 elements of initial billet were selected for this study. Auto remeshing using contact surface ratio factor of 0.7 was set.

| Input data                  | Description |
|-----------------------------|-------------|
| Young modulus (GPa)         | 68.9        |
| Tensile strength (MPa)      | 176         |
| Friction coefficient, µ     | 0.01, 0.12, 0.3 |
| Punch movement, mm/sec      | 1           |
| Object type:               |             |
| Workpiece                  | Elasto-Plastic |
| Upper Punch/Lower Punch    | Rigid       |
| Container                  | Rigid       |

Fig. 4. Simulation models (a) before deformation and (b) after deformation

3. Results and Discussions

3.1. Influences of friction

Cross sections of forging components using tool as shown in fig.2 from various experimental conditions; dry, water based lubricant and oil based lubricant are illustrated in fig.5.

FEM simulation results of 3 cases using coefficient of friction (μ) 0.3, 0.12 and 0.01 as comparable to experimental cases are presented in fig.6. The results revealed that some part of material is flow downward together with the downward direction of upper punch (forward flow) and some part is flow upward against punch movement (backward flow). The measurement of web thickness (w), backward flow height (H1) and forward flow height (H2) as expressed in fig.7 had been examined. The relationship between the height ratio (H1/H2) and friction coefficient has been made as shown in fig.8. The ratio between backward flow height (H1) and forward flow height (H2) is depended on friction coefficient. The ratio is increased with increasing coefficient of friction as the results illustrated in fig.8. The results agree well with T. Schrader et al.’s work [9].
Measuring of backward and forward flow height from cross section of experimental forging parts are also carried out. The average data from 5 repetitive parts per condition are presented in table 2. Correlation to the simulation results from fig.8, coefficient of friction for dry, water base lubrication and oil base lubrication can be estimated to be closed to 0.3, 0.12 and 0.01 subsequently. Friction is reduced when lubricant is used. Oil based lubricant shows better performance to reduce friction as anticipated. The experimental results (fig.5) agreed well with the simulation results (fig.6) in terms of the geometry of final parts.

![Fig. 5. Cross section of parts from experiments using (a) dry, (b) water based lubricant and (c) oil based lubricant.](image)

![Fig. 6. Simulation results of effective stress from 3 conditions of coefficient of friction; (a) µ = 0.3, (b) µ = 0.12 and (c) µ = 0.01.](image)

![Fig. 7. Measurement of backward flow (H1), forward flow (H2) and web thickness (w).](image)

![Fig. 8. Relationship between friction coefficient and the ratio of backward to forward flow height.](image)
Table 2. Measurement results from parts cross sections. (units in mm.)

| Condition          | w   | H1     | H2     | H1/H2 |
|--------------------|-----|--------|--------|-------|
| Dry                | 4.57| 10.91  | 5.22   | 2.09  |
| Water based lub    | 4.37| 10.00  | 6.16   | 1.62  |
| Oil based lub      | 5.13| 8.14   | 6.71   | 1.21  |

3.2. Influences of flow constrain

![Fig. 9. Various cases of flow constrain](image)

FE simulations were carried out to investigate influences of flow constrain. Tool were designed to constrain the flow directions as shown in fig.9. There is no constraint for both backward and forward flow directions for case 1. Material can move freely downward and upward in this case. Case 2, free backward flow is allowed, while forward flow is limited. Case 3 free forward flow is allowed, while backward flow is limited. Case 4, only forward flow of material is possible. The results show that maximum principal stress increases with constrain of flow which are 331 MPa, 493 MPa, 402 MPa and 428 MPa accordingly (µ=0.12). Case 1 which is free flow in both directions indicates minimum stresses.

3.3. Influences of initial billet size

Billet of the same volume having various size of Ø 40 x 19.5, Ø 42 x 17.5 and Ø 44 x 16.0 are simulated with free flow condition (case 1 in fig.9) using 0.12 coefficient of friction. Lateral flow or expansion of the billet took place initially before forward and backward flow for the cases that the diameter of billet smaller than the container. There is no big different in forces and stresses from those 3 conditions as shown in table 3.

Table 3. Simulation results from various billet sizes.

| Billet size | Max Force (Ton) | Max effective stress (MPa) | Max principal stress (MPa) |
|-------------|-----------------|----------------------------|---------------------------|
| Ø40 × 19.5  | 18.9            | 165                        | 317                       |
| Ø42 × 17.5  | 17.4            | 165                        | 237                       |
| Ø44 × 16.0  | 17.8            | 165                        | 331                       |
3.4. Optimized conditions and comparing to the current methods

From the study, machining operation is necessary to yield bush shape as required. Initial billet size has to be adjusted in order to obtain absolute height (fig.10) of 18 mm. Original design for initial billet of 5% allowance in volume is insufficient. The simulation has been made on recalculated billet size of Ø40 × 21. The results showed sufficient absolute height beyond 18 mm., similar level of stresses to the previous cases and small increase of maximum force required (19.2 Ton). Although increasing the initial billet size for the proposed method, improvement in material utilization is calculated to be improved by 5.7%.

![Fig. 10. Absolute height of part](image)

Current method of producing bush comprises of 4 operations of sawing (cut from a bar), machining (for flat surfaces), piercing and shaving. The proposed method also includes 4 operations of sawing, forging, piercing and machining. The critical problem in the current method is short tool life of piercing and shaving tool. Forging operation which is the main process of proposed method is studied and shown to be competitive. The force required is in similar level and the tool life is expected to be superior. Material utilization is also improved from removing smaller amount of material.

4. Conclusions

The conclusions that can be drawn from this work are as follows:
- The proposed method of producing bush by cold forging follow by piercing showed possibility to replace piercing follow by shaving. Existing facility can be employed. Material utilization will be improved and tool life is expected to be increased.
- Design of tool to constrain material flow during forging causes high stresses which will lead to high wear rate.
- The ratio of diameter to height of initial billet in this study has small influences to stresses and forces in forging operation. However, there is an effect on the final geometry due to free material flow allow in some area of the tool used.

Acknowledgement

The authors gratefully acknowledge the financial support provided by the National Research Council of Thailand (NRCT).

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