The effect of strain hardening on the limit forming ratio on the single-step incremental hole flanging process on aluminium plates

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Abstract. Hole-flanging is the process of forming a plate to produce a collar around the hole. This formed collar has several important functions to increase the bonding surface area, as a supporting medium for other components, as a guide, increase construction rigidity, etc. This collar is generally formed through conventional hole flanging which involves making the initial hole in the plate, then punch with a certain profile and a larger diameter pressing the plate in one step of the forming process. This forming process will cause the deformation of the plate so that a collar is formed around the hole. In recent studies, it can be found that the collar can be formed not only with one stage of the conventional hole flanging process, but can also be achieved by a multi-stage incremental hole flanging process using a punch with a multi-purpose general profile. In this research, an experimental study was carried out on the effect of 'strain hardening' on the limit forming ratio (LFR) in the single-step incremental hole flanging process on aluminium plates using conical punch. The research hypothesis shows the influence of 'strain hardening' on the limit forming ratio (LFR) in the single-step incremental hole flanging process.

1. Introduction
In the industrial and automotive sectors, connections between pipes are often carried out in production processes. Generally, in the process of connecting pipes, binding is needed by sheet plates in the form of holes with a collar / flange that matches the pipe profile. As shown in Figure 1 the process of making holes with this collar is commonly done by hole-flanging [1].

Figure 1. Exhaust flange and clamp.
Conventionally, the hole-flanging process is commonly used to produce a hole with a collar, as shown in Figure 1. In this process, plates with pre-cut holes are gripped and formed plasticly using a combination of bending and circumferential stretching forces. In the industrial world, many applications can be done through this process such as strengthening the connection to the piping [2]. But as the shape of the holes and collars will be produced, the investment needed will also increase. Because in the conventional hole-flanging process, when there is a change in geometry, the punch and dies also change their shape [3]. This causes, conventional hole-flanging processes are only suitable for mass production. In contrast to conventional hole flanging, this incremental hole flanging method offers a solution for making collars with holes on a small production scale as well as prototyping, and offers a lower investment for dynamic and complex flange designs [4], as shown in Figure 2.

Some of the research that has been done by previous researchers is incremental backward by Petek A. and single-stage incremental by Borrego M. Where in the research conducted by Petek A., it was found that on the DC 05 sheet, using the incremental backward method, data collection and data processing using the Response Surface method at the best variation to produce the optimal collar hole [5]. Meanwhile, Borrego M. researched the AL-7075, using the single-stage incremental sheet forming method, where the focus of his research was getting the limit forming ratio (LFR). At various precut holes, the max LFR is 1.62 [6,7].

**Figure 2.** Conventional hole flanging vs incremental hole flanging [8].

Here we offer a combination of previous research with the incremental backward single stage sheet metal forming method. Where the hole flanging process combines upward movement of the collar formation process with the spiral motion of the forming tool.

The contribution of this research is to analyze and determine the hardening strain that occurs during the formation process using the single-stage incremental backward hole flanging method. In addition, the researchers also analyzed the effect on the limit forming ratio associated with the strain rate that occurred. So that the optimal formation process can be obtained.

### 2. Methods

In this work, the forming method used is single-stage incremental hole flanging, using aluminium plates, conical forming tools, and 3 axis CNC machines. Retrieval of hardness data using a micro Vickers hardness tester. The data were processed using tabulation and graphic methods, to get the effect of strain hardening.

#### 2.1. Single-stage incremental hole flanging

Single-stage incremental backward hole flanging is the process of forming a flange towards the Z + coordinate. This method includes a flexible metal forming. In this work, a plate chuck without a contour is used, which makes it a die less fixture, forming tools that have a conical profile are used during this forming process. The dies are then placed and positioned on the CNC machine table. The workpiece, in this case, aluminium, is positioned on the dies. In one forming motion, the tool moves closer to the aluminium plate that was previously perforated, then performs a spiral motion as a form of the forming process. As shown in Figure 3. Single-stage Incremental Backward Hole Flanging Process [9].
Figure 3. Proposed single-stage incremental backward hole flanging process.

Table 1. Forming setup.

| Specification             | Units                                           |
|---------------------------|-------------------------------------------------|
| Dies Material             | ST 37                                          |
| Holding Dimension         | 150 mm x 150 mm x 1 mm                          |
| Forming Tool Material     | HSS                                             |
| Dimension                 | Dia. 20 mm x 150 mm (45° Conical)               |
| Workpiece Material        | Aluminium                                       |
| Dimension                 | 150 mm x 150 mm x 1 mm                          |

2.2. Forming parameter

The process parameters in this study are as follows, 20 mm diameter of precut hole, which is produced by milling process. Up to 80 mm diameter which is produced by forming process. 50 rpm of Spindle speed, constant step over by 1 mm. 4 variation of feed rate, 500, 1000, 1500, and 2000 mm/min where the variation in the speed of formation or strain rate is represented by the feed rate. The results that have been obtained will be carried out an observation process on the cross section of the collar for changes in hardness caused by strain hardening during the forming process.

Table 2. Forming parameter.

| Specification             | Units                                           |
|---------------------------|-------------------------------------------------|
| Type of steel             | Al 1050-0                                       |
| Hardness                  | 50 HVN                                         |
| Pre-cut Hole              | 20 mm                                          |
| Finish Hole               | Up to 80 mm                                    |
| Spindle Speed             | 50 rpm                                         |
| Forming Step Over         | 1 mm                                           |
| Forming Rate              | 500, 1000, 1500 & 2000 mm/min                  |

2.3. Hardness observation

Hardness testing in this study used a micro Vickers hardness tester. As shown in Figure 4, where the use of this tool is because the observed workpiece cross-section is very small (below 5 mm), the cross-section of the forming result is then cut to produce the cross-section as shown in Figure 5 below. Then the observation points are divided from the edge of the section to the original material.
Figure 4. Micro Vickers hardness tester.

Figure 5. Cross section view of workpiece after forming process and point of hardness observation.

Table 3. Micro Vickers specification.

| Specification       | Units                      |
|---------------------|----------------------------|
| Model               | HM-210 Type A              |
| Fixed test Force    | 10-1000 gf                 |
| Loading Rate        | 60 µ/sec                   |
| Load Dwell Time     | 0-999 sec                  |
| Indenter            | Vickers                    |
| Objective Lens      | 10x, 50x                   |
| Filar Eye Piece     | Dual Line, 10x, 0.01 µ min |

3. Results and discussions
The process of observing changes in the hardness of the cross section of the collar is done using the micro Vickers hardness tester method, as shown in Figure 5. Where in the cross section of the collar is divided into five points of observation, where from the upper end of the collar experiencing thinning, point number one, to the parent material, point number five. As a reference, the average hardness value of the parent material is 50.5 HVN. In this study it was found that, the highest hardness value was found in observation at point number one and in all variations, as shown in Figure 6.

At this point the material experiences the most extreme thinning. This happens due to the strain hardening process during the formation movement. The strain rate was represented as feed rate during
forming process. The lowest hardness value at observation point one is found at the highest feed rate or strain rate variation, which is at 2000 mm / min. This happens because at a high feed rate the material experiences less friction time, so the heat generated is lower which causes the material to be affected by changes in hardness due to the minimal impact of heat treatment during the forming process [10].

At the maximum feed rate or strain rate of 2000 mm/min, aluminium started to crack. At this point, we conclude that maximum forming rate was 2000 mm/min at finish hole of 80 mm. Therefore, the Limit Forming Ratio (LFR) on this study is 80 mm divided by 20 mm equal to 4.0. At forming rate of 2000 mm/min, strain hardening process was at lower point, because of insufficient of friction during the forming process, therefore, the material begins to crack eventually. These phenomena can be shown in figure 7.

Table 4. Hardness value for each observation points.

| F (mm/min) | 1 | 2 | 3 | 4 | 5 | 6 | HVN |
|------------|---|---|---|---|---|---|-----|
| 500        | 60.4 | 59.2 | 52.5 | 48.1 | 46.5 | 49.5 |     |
| 1000       | 58.3 | 56.3 | 53.8 | 55.2 | 52.8 | 50.9 |     |
| 1500       | 57.0 | 54.7 | 52.8 | 52.5 | 50.9 | 50.6 |     |
| 2000       | 54.8 | 49.5 | 50.9 | 44.4 | 48.9 | 49.4 |     |

Figure 7. (Left) Flange produced at 1500 mm/min of forming speed & (Right) Flange produced at 2000 mm/min of forming speed.
4. Conclusions
The conclusion of the research we have done is highest strain hardening was occurred at the edge of the flange, at forming speed of 2000 mm/min at 1mm forming step over and at 80 mm finish hole, aluminum start to crack, below 2000 mm/min at same parameters, there is no sign of crack in the aluminum. Therefore, in this study maximum limit forming ratio (LFR) is achieved at 4.0, at forming speed of 2000 mm/min. In the future, this research needs to consider lubrication during the forming process. lubrication during the forming process is expected to be able to suppress cracks on the plate surface during the forming process.

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