# Effect Of Tool Eccentricity On The Joint Strenght And Fatigue Strenght In Mechanical Clinching Process

Dr. Wang Chan Chin, Faculty of Engineering and the Built Environment, SEGi University
Kam Heng Keong, Faculty of Science and Engineering, Universiti Tunku Abdul Rahman
Ir. Dr. Tan Yong Chai, Faculty of Engineering and the Built Environment, SEGi University

**Abstract**

The effect of tool eccentricity on the joint strength in clinching process was investigated. The objective is to understand the mechanical behaviour of the clinched joint where proper control on the alignment setting of tools can be considered. In this research, a clinching process to form a round joint was carried out by offsetting the centre line between the upper punch and lower die. The experimental results were compared between offset and without offset conditions. The factors which determine the quality of joint strength such as the interlock and the neck thickness obtained from cross section geometry were examined by opening mode and tension-shearing mode tests. Coated mild steel and aluminium alloy sheets were used for the evaluation. It is found that the strength values by offset clinching exhibit variation in sinusoidal relationship with respect to the in-plane offset direction. These values are generally lower by 10-36% for mild steel and 60-70% for aluminium alloy. The fatigue strength of a clinched joint with offset generally 5-10% weajer cinoared to the one without offset.

**Keywords:** Mechanical clinching; tool eccentricity; offset clinching; joint strength test.

## 1.Introduction

Mechanical clinching is a cold joining process commonly used to join several metal sheet components into a single piece structure by local hemming. This method is widely used because of its short time and low running cost merits where no additional materials for riveting or heat energy for welding, are consumed. The process also exhibits flexibility in joining different types of metal sheets such as aluminium alloy with steel to reduce weight of a vehicle structure in automotive industry. Among the researches made on the mechanical clinching method, Varis and Lepistö (2003) established important parameters for clinching process by experimental method and finite element method (FEM). Varis (2003) examined the joint strength of various shapes to determine the suitability for making building frames with high-strength structural steel. Varis (2006) further studies the economic merit from the point of tool service life by comparing the unit cost produced by the mechanical clinching over the self-pierce riveting. Abe et al. (2007) studied the method to join aluminium alloy with mild steel sheets by investigating the flow stress of deformed sheets. Lee et al. (2010) applied FEM on tool design to achieve higher joint strength which fulfills the automotive industry standard. Coppieters et al. (2011) presented a set of analytical methods by simplifying the material geometries and stresses to predict the pull-out strength in box-test. Abe et al. (2011) reported that the joint strength of rectangular shape displays higher values than the one of round shape. A metal flow control method was introduced by Abe et al. (2012) to overcome facture failure of high strength steel when clinching with aluminium alloy sheet. Mori et al. (2012) compared the fatigue strength between mechanical clinching and self-pierce riveting, and explained the mechanism of superiority by mechanical clinching method. Carboni et al. (2006) found that a tensile-shear loaded clinched joint can last for $2\times10^7$ cycles at 50% of ultimate tensile strength.

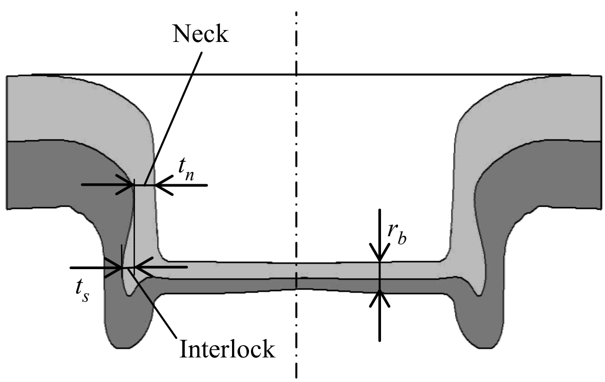
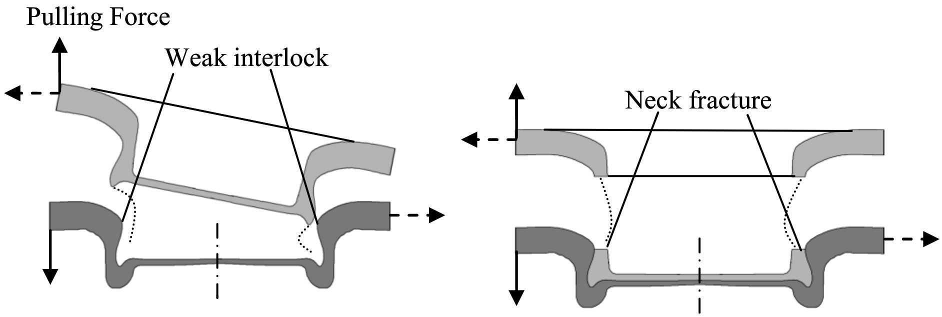



Figure. 1. The cross section of a clinched joint and parameter terms, interlock $t_s$, neck part $t_n$, reduction of bottom thickness $r_b$.




(a) Button separation (b) Neck fracture

Figure. 2. Failure modes.

It is reported that the strength of a clinched joint is generally determined by the parameters which can be measured from the cross sectional geometry of a deformed shape, i.e., the interlock $t_s$ and neck part $t_n$ as denoted in Figure.1. These parameters influence the structure to hold the resistance against pulling force and the occurrence of failure modes as illustrated in Figure. 2. A typical example of a mechanical clinching process is shown in Figure.3 where two brackets are clinched with a metal based panel at four locations to form a holding frame for electrical appliances. For quality inspection purpose, the clinched samples are taken for strength test where a pair of vertical tension force is applied to separate the joint part at each location by sequence. The joint strength is evaluated by the maximum pulling force required to separate the joint part.

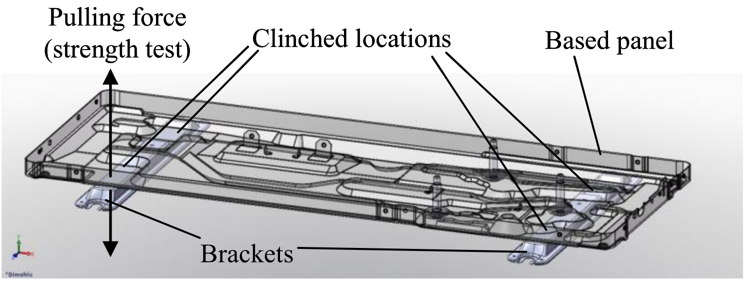



Figure. 3. Clinched structure and pulling force direction for strength test.

In clinching process, it is common that many small punches and dies are placed inside a die-set at specific locations to clinch metal sheet pieces simultaneously in one stroke. Because of the complexity in setting the alignment for many punches and dies inside a die-set, a minor eccentricity due to the displacement between the center axes of upper punch and lower die may occur at the initial stage or after a long period of service. Assuming the die clearance is given 1mm, a deviation of 100μm (10% offset ratio) about the centre axis is sometimes ignored within the range of tolerance. In addition, the occurrence of minor eccentricity is difficult to be alerted during the press operation because of the total forming load shows almost no change and the shape irregularity is not noticeable by simple visual inspection at the site. Therefore, an evaluation of joint strength by offset clinching is essential to provide better understanding about the mechanical behaviour of the clinched joint where proper control on the alignment setting of tools can be considered.

## 2. Evaluation Methods For Offset Clinching

### *2.1 Offset clinching conditions*

Figure. 4 shows the layout and dimensions of upper punch and lower die used for the offset clinching experiment, and Figure. 5 shows the top view plane of the centre axis position *O* and the loading point at *P*. By considering to move the upper punch in specific direction and increment, two parameters are introduced to define the offset condition for moving the upper punch. The in-plane offset direction $\theta$ shown in Fig.5 represents the direction angle about the centre point *O* relative to the loading point *P* (Line *OP*). When $\theta=0°$, it indicates the punch is moving to the direction away from the loading point *P* (See Figure. 6(a)), whereas $\theta=180°$ is towards the loading point *P*. (See Fig. 6(c)). $\theta=90°$ and 270° are in parallel distance (See Figure. 6(b) and Figure. 6(d)). The offset ratio $\Delta e$ shown in Figure. 6 is defined by the value of punch offset distant from the center point *O* with respect to the initial die clearance.

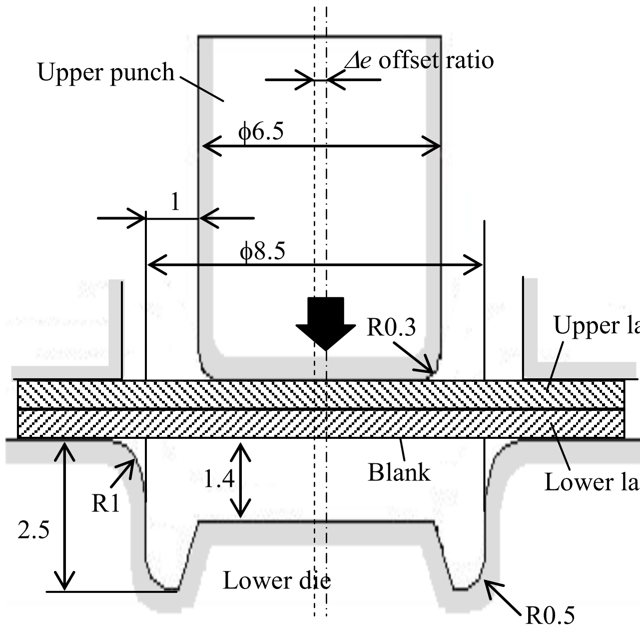



Figure. 4. Layout of offset clinching tool.

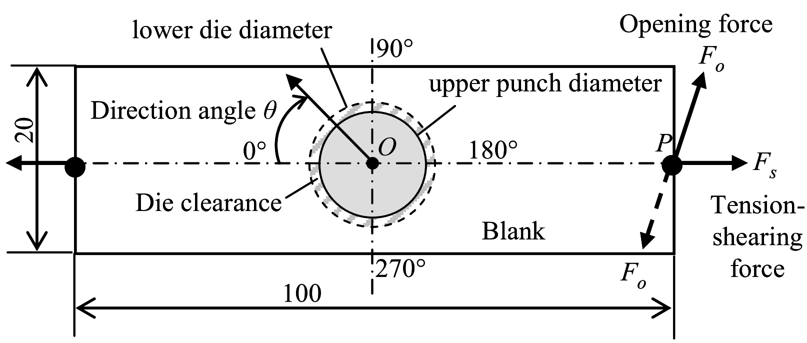
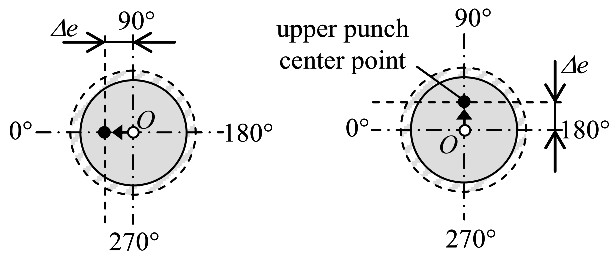
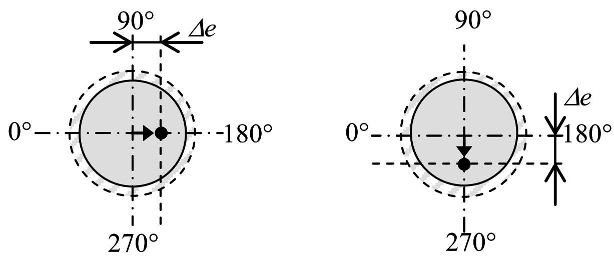



Figure. 5. Tool center position and loading point.




(a) Offset at $\theta$=0° (b) Offset at $\theta$=90°



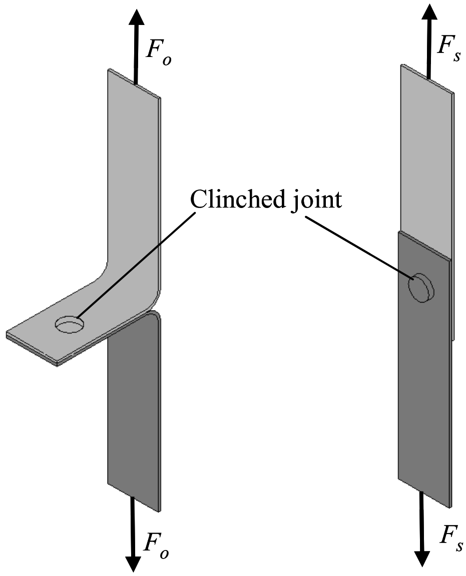

(c) Offset at $\theta$=180° (d) Offset at $\theta$=270°

Figure. 6. Offset direction of upper punch.

### *2.2 Loading tests for joint strength and fatigue strength*

Loading tests are carried out to evaluate the joint strength of clinched specimens with offset and without offset conditions. Two type of loading mode (See Figure. 7), i.e., opening test and tension-shearing test are considered for the evaluation. The maximum force in opening test $F_o$ and tension-shearing test $F_s$ are measured until the joint structure starts to fail. The conventional method of cross-tension test is not considered despite it is an industrial standard for evaluation. The opening mode chosen in present research is mainly because the button separation failure and neck fracture caused by the opening test (Button separation mechanism) is much convenient as it is similar to the inspection procedure carried out by the industry in Fig. 3.

Fatigue tests are carried out on clinched joint of with offset and without offset condition at different load level to obtain F-N curves (load vs number of cycle). Fatigue limit is set as $2 \times 10^7$ cycles quoting from Carboni et al. (2006).




(a) Opening test (b) Tension-shearing test

Figure. 7. Joint strength tests.

## 3. Offset Clinching And Joint Strength Tests

### *3.1 Offset clinching*

In this research, two types of material are prepared for comparison purpose. Table 1 shows the material properties in tensile test and blank thickness, and Table 2 shows the offset conditions for implementing the clinching tests.

| Materials | Thickness / mm | Tensile Strength / MPa | Flow stress / MPa | Elongation / % |
|---|---|---|---|---|
| Coated mild steel GL400 FN AZ150 | 1.1 | 380 | $\bar{\sigma} = 503\bar{\varepsilon}^{0.32}$ | 28 |
| Aluminium alloy A1100 H14 | 1.0 | 120 | $\bar{\sigma} = 138\bar{\varepsilon}^{0.024}$ | 18 |

Table 1: Material properties and blank thickness.

| | |
|---|---|
| In-plane offset direction $\theta$ | 0°, 90°, 180°, 270° |
| Offset ratio $\Delta e$ | 0% (without offset), 25%, 50%, 75% |
| Die clearance | 1 mm |
| Lubrication | Without lubricant |
| Specimen size | 100mm(length) x 20mm(width) |

Table 2: Offset clinching conditions

Clinching tests were carried out at different offset direction $\theta$ to investigate the effect of tool eccentricity on the forming load. The forming load curves by each offset direction $\theta$ from experimental results are plotted in Figure. 8. It is interesting to see that the results by offset conditions show no significant differences with the one without offset. This implies that the tool eccentricity is difficult to be detected during the press operation.

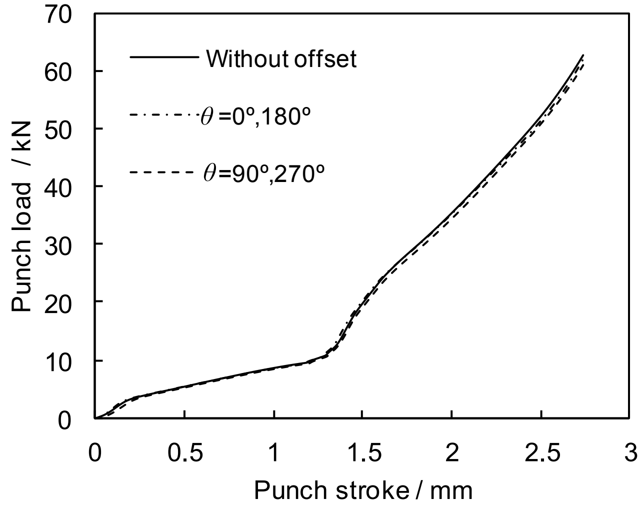
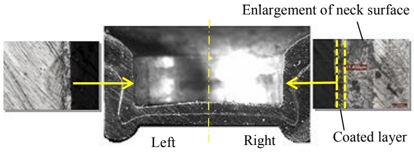
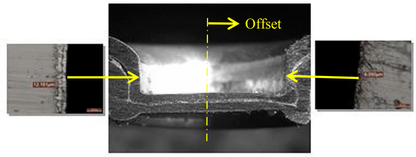



Figure. 8. Comparison of punch load curves with different offset direction $\theta$

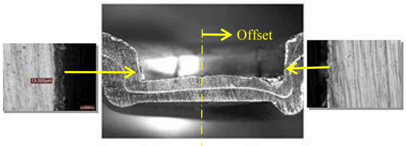
(□$e$=50%, $r_b$=60%, coated mild steel).



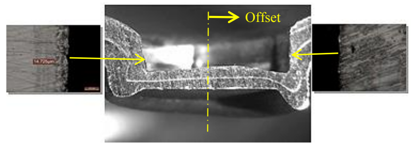

(a) Without offset




(b) □e=25% offset



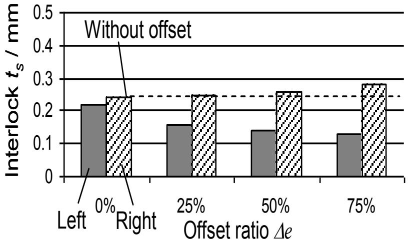

(c) □e=50% offset



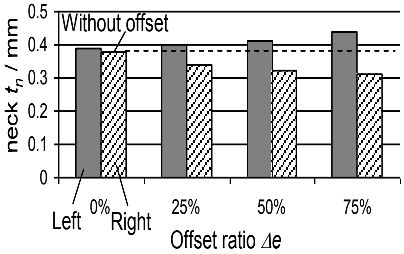

(d) □e=75% offset

Figure. 9. Cross section of clinched joint at different offset ratio ($\theta$=180°, $r_b$=60%, Coated mild steel).

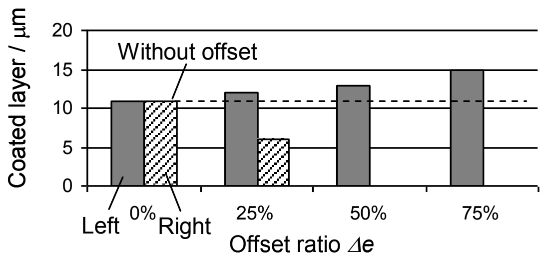
Figure. 9 shows the experimental results where the cross section of clinched joint, interlock $t_s$, neck thickness $t_n$ and coated layer on both sides of clinched specimens are examined with respect to the offset ratio $\Delta e$. The punch is offset to $\theta$=180° direction (moved to the right) to form smaller die clearance on right side. The extruded part (ear shape) at the bottom side can be seen larger on the right side and uneven ear shapes appear at both corners when offset the ratio □$e$ is given larger than 50%. The results by examining the cross section are compared in Figure. 10.




(a) Interlock $t_s$




(b) Neck part $t_n$




(c) Coated layer

Figure. 10. Comparison of thickness parameters between left and right side of offset clinched joints ($\theta$=180°, $r_b$=60%, coated mild steel).

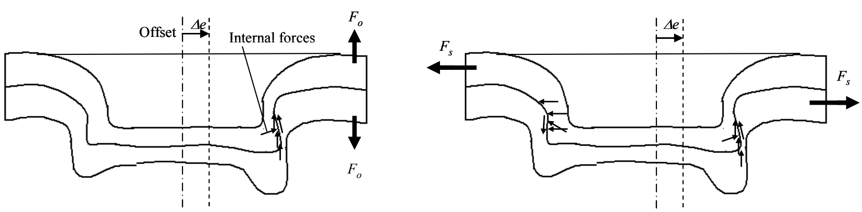
In Figure. 10(a), the interlock $t_s$ value increases on the right side while it decreases on the left side with the increment of offset ratio $\Delta e$. The different is more than 20% at offset ratio $\Delta e$ =75% when compared with the one without offset. The results imply that higher resistance is expected if the loading point is placed on the right side while it is weaker on the left side in opening mode.

On the other hand in Figure. 10(b), the neck part thickness $t_n$ decreases on the right side due to smaller die clearance given while it increases on the left side with the increment of offset ratio $\Delta e$. The different at offset ratio $\Delta e$ =75% is about 15% when compared with the one without offset. The thinning occurred at the neck part may easily induce fracture failure when loading point is placed on right side.

The coated layer is examined by microscope at the neck part of upper layer since this location is most likely to cause fracture failure due to large stretching. Fig. 10(c) shows a drastic reduction of coated layer on the right side when offset ratio $\Delta e$ is increased to 50%, while the values on the left side remains intact as its original coated thickness. The coated layer seems to be completely peeled off due to severe deformation and surface friction when the material enters into the narrow die clearance by tool offset.

### *3.2 Joint strength tests for offset clinching*

Mucha (2011) studied the lock forming mechanism of a clinched joint by describing that when a pair of pulling force is applied to separate the joint, the internal resistant forces will appear on the layer boundary and react at the side corners. The similar phenomenon can be applied to describe the case for an offset clinched joint. From the illustration in Figure.11, the non-symmetrical deformed shape becomes obvious for one to make assumption that the joint strength yields different value depending on the positing of loading point and the pulling force direction. This is because the influencing parameters, the interlock $t_s$ and the neck thickness $t_n$, on the left and right sides of the joint are found varied at different offset conditions as shown in Fig. 10(a) and (b).




(a) Opening test. (b) Tension-shearing test

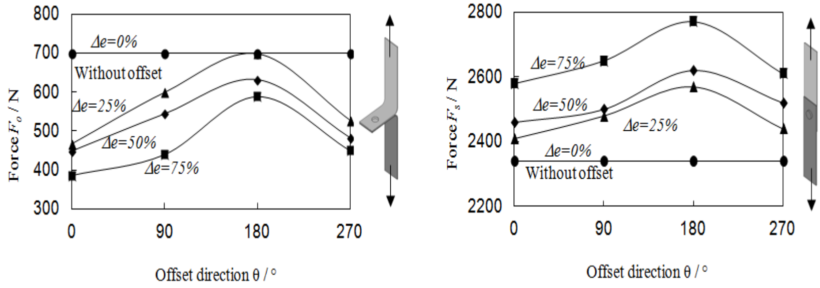
Figure. 11. Illustration of internal force interactions at the layer boundary of offset clinched joint.

Figure. 12(a) and (b) shows the experimental results of joint strength at different offset conditions for coated mild steel in opening test and tension-shearing test, respectively. The maximum pulling force $F_o$ in opening test and $F_s$ in tension-shearing test are plotted against the offset direction $\theta$. In addition, different sets of data by varying the parameter of offset ratio $\Delta e$, are obtained and plotted together when the blanks are compressed until the bottom thickness reduction $r_b$=60%. The straight line at $\Delta e$=0% represents the one without offset for comparison purpose. From the data distribution pattern, it can be seen that the $F_o$ and $F_s$ values display a sinusoidal relationship with respect to the $\theta$ parameter where a minimum value exists at $\theta = 0°$ and a maximum at $\theta = 180°$. The maximum value at $\theta = 180°$ can be explained by referring to Figure. 11(a) where the upper punch is offset to the right of center axis. In this case, the internal resistant forces against the opening on right side, appear to be maximum due to largest interlock $t_s$ is formed on right part. Similar situation can be explained by Figure. 12(b) where at $\theta = 180°$, the neck part $t_n$ formed on the left side becomes largest, and thus the internal resistant forces increase to the maximum against shearing. However, the situation is reversed at $\theta = 0°$ where the strengths turn to minimum with smallest interlock $t_s$ formed on right side and smallest neck part $t_n$ formed on left side.

In opening test from Figure. 12(a), the strength curves by offset clinching are generally below the one without offset ($\Delta e$=0% line), and the trend is further down with the increase of offset ratio $\Delta e$. However, it is interesting to see the strength curves by offset clinching in Figure. 12(b) behave in opposite sense in tension-shearing test. The phenomenon can be explained by the strain hardening effect takes place at the neck part $t_n$ for mild steel material (See Table 1 for the material flow stress) and thus shows higher values than the one without offset, and the trend is further up with the increase of offset ratio $\Delta e$.

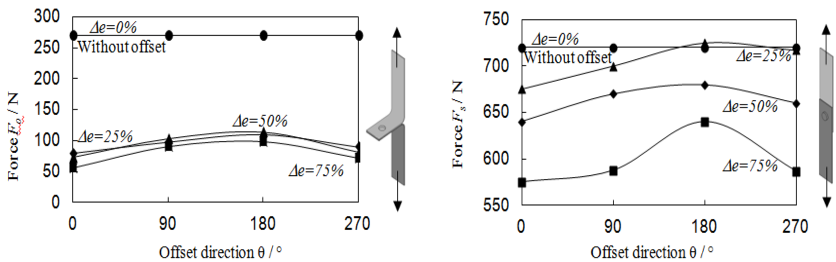
For the case of opening test for aluminium alloy in Figure. 13(a), although the strength curve by offset clinching shows similar pattern with the one of mild steel, the values compared to the one without offset drop drastically at the same offset ratio $\Delta e$=50% (Only data at $\Delta e$=50% is considered in present research). This is because the fracture failure takes place at the neck part for aluminium alloy, whereas only button separation failure is observed for mild steel when the blanks are compressed up to the bottom thickness reduction $r_b$=60%. An early clinching experiment result at $\Delta e$=0% for aluminium alloy shows that the stress at the neck part is somewhere reaching the ultimate tensile stress and the material is less ductile to cause neck fracture when the blanks are compressed to the bottom thickness reduction $r_b > 40\%$.

For the case of tension-shearing test for aluminium alloy, the strength curve by offset clinching shown in Figure. 13(b) is below the one without offset. The trend is opposed to the case of mild steel where the curves are all located in upper region of $\Delta e$=0% line in Fig. 12(b). As mentioned before, this phenomenon is due to the fracture failure prevailed at $r_b$=60%.




(a) Opening test (b) Tension-shearing test

Figure 12. Joint strength tests at different offset conditions for coated mild steel (Reduction $r_b$=60%).




(a) Opening test (b) Tension-shearing test

Figure 13. Joint strength tests at different offset conditions for aluminium alloy (Reduction $r_b$=60%).

### *3.3 Fatigue tests for offset clinching*

The tensile loading and unloading fatigue tests are performed at a frequency of 10 Hz- 30 Hz. Figure. 14 shows the comparision of fatigue test result in tension-shearing mode for coated mild steel clinched joint of condition Δe=0%, θ=0° and Δe=50%, θ=0° for coated mild steel sheet metal. The fatigue limit of a clinched joint without offset is 50% of maximum pulling force, whereas the fatigue limit of a clinched joint with Δe=50% offset is weaken to be 42.5%

maximum pulling force. At 50% of maximum pulling force, the clinched joint with Δe=50% offset raptured at 2.5x$10^6$ cycles which is 87.5% lower to that of without offset clinched joint

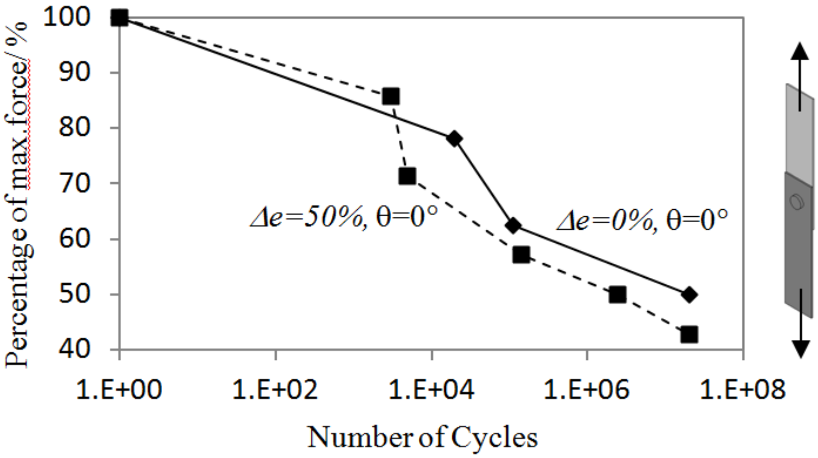



Figure. 14. Fatigue of tension-shearing mode with offset clinching for coated mild steel (Reduction $r_b$=60%).

**4. Discussion**

The present research is intended to provide a reference on the behaviour of joint strength by considering the tolerances of tool alignment for mechanical clinching. Generally, the joint strength is less influenced by tool eccentricity factor if the material possesses higher strain hardening and ductility, such as mild steel is superior than aluminium alloy. Although at the same amount of offset distance given, the joint strength behaves a great variation with respect to offset direction of the punch relative to the loading point. Thus, the data is useful for one to make precaution on tool alignment during the tool setting or inspection by considering the positions of the clinched joints relative to the loading point. For instance at $\Delta e$=50% in Fig. 12(a), the strength reduces to 36% (449N) at $\theta$=0° but only 10% (633N) at $\theta$=180°. Therefore, the tool alignment can be done in proper way to control the quality of joint strength by using these data. Let say the allowable strength is set within 10% fluctuation, the range of deviation in tool alignment is acceptable up to $\Delta e$=25% if $\theta$=180°±60° or $\Delta e$=50% if $\theta$=180°±20°. However, for clinching the aluminium alloy sheets, more cautious measure is necessary for the tool alignment to be controlled within a narrow range of tolerance since the experimental results show that the material strength drops drastically by offset clinching and the neck fracture failure is likely to occur. Interpolation can be made between the available curves to obtain values at specific offset conditions. The evaluation of joint strength in opening test is much critical where the pulling forces generally yield lower values (about 3 times) than the one of tension-shearing test.

Although the maximum pulling force with $\Delta e$=50% offset yields higher value than the one without offset in tension-shearing mode, but the fatigue limit of $\Delta e$=50% exhibit lower value. The fatigue strength of clinched joint is reduced by 7.5%. This is due to neck thickness, $t_n$ on the left nand side (see fig. 11(b)) of $\Delta e$=50% offset is thinner to $\Delta e$=0%. The crack prevailed earlier at thinner neck.

## 5. Conclusions

The effect of tool eccentricity in mechanical clinching was carried out to study the joint strength by offsetting the centre line between the upper punch and the lower die. When moving the upper punch, two parameters were introduced to define the offset conditions, i,e, the in-plane offset direction and the offset ratio for evaluating the joint strength in opening test and tension-shearing test. The following results were obtained:

1. The total forming loads by offset clinching show no significant difference with the one without offset despite extreme offset conditions are given (up to 75% offset ratio).
2. However, the interlock and neck thickness values obtained by offset clinching show great differences because of the non-symmetrical deformation and thus create an impact on the joint strength.
3. From the strength test results, the maximum pulling force displays a variation of distribution with respect to the angle of offset direction at specific offset ratio and the curve is assumed to be in sinusoidal relationship.
4. For the case of opening test at 50% offset ratio, the joint strength is reduced by 10-36% for mild steel, and 60-70% for aluminium alloy (consider the range between minimum and maximum

points). While for the case of tension-shearing test, the joint strength shows an increase trend by 5-12% for mild steel due to strain-hardening effect, but in decrease trend by 6-11% for aluminium alloy.
5. The coated layer at the neck part seems to be completely peeled off at 50% offset ratio due to the blanks are stretched through a narrower die clearance at one side by tool offset.
6. The fatigue strength of a clinched joint with offset is generally 5-10% weaker to a clinched joint without offset.
7. The present research is intended to provide a reference on the behaviour of joint strength by considering the tolerances of tool alignment for mechanical clinching.

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