Effect of punch velocity on punch force and burnish height of punched holes in punching process of pure titanium sheet

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Abstract. Punch velocity is one of the important parameters in the punching process. The choice of punch velocity is difficult because it has a different influence on each material. Therefore, it is important to know the effect of punch velocity on the material to be worked. The purpose of this study was to investigate the punch velocity effect on punch force and burnish height of the punched holes in the punching process of pure titanium sheets. The punching process used was a pneumatic punch machine with punch velocity of 10, 35, 70 mm/s. The result shows that when punch velocity of 10, 35, 70 mm/s, punch force that occurred each by 357, 408 and 434 N. Burnish height resulted by 0.194, 0.200 and 0.241 respectively. It indicates that punch velocity affected on punch force and burnish height of punch holes. When punch velocity increased, punch force and burnish height of the punched holes increased.

1. Introduction
The forming process has been widely used for manufacturing products or components in the fields of biomedicine, electronics, automobiles, and aerospace [1][2]. Blanking and punching are forming process type. The research on these processes has been carried out on various materials for investigating the influence of parameter process. One of the process parameters studied is punch velocity.
In the blanking process, punch velocity effect on blanking investigated by Lubiz and Mahardika on copper [3]. It also studied on brass by Ristiawan and Mahardika [4]. Maiti et al. [5] used finite element method to study of parameter process effect on blanking.
In recent year, the influence of punch velocity also studied in the punching process. In brass, Xu et al. [6] in his research found burnish height increased and surface roughness (Ra) burnish decreased with increased punch velocity. When increase punch velocity with ∆v = 47.5 mm/s causes the burnish height to increase of 28% and the surface roughness value (Ra) of burnish decreased by 0.16 µm. The research conducted by Larue et al. [7] in steel material shows that punch force increased with increased punch velocity. Increased punch speed is characterized by reduced cutting time. Cutting time of 50 µs, punch force is 10.3 kN. While cutting time of 260 µs, punch force is 8.9 kN. While in copper, an increases in punch velocity does not always increases the hardnees of upper surface holes [8]. Where, the change in punch velocity of 0.01 to 0.05 mm/s, the hardness resulted was change from 55 to 65 HV. While the change in punch velocity of 0.1 mm/s to 0.3 mm/s, the hardness was changed from 62 to 60 HV. In aluminum, the hardness resulted with low punch velocity is higher than high velocity[9]. When uses
clearance of 1% with punch velocity of 0.1 mm/s, the hardness resulted at a distance of 1 mm from shear drop is 63 HV. While at punch velocity of 10 mm/s, the hardness is 50 HV. Base on some literature review, punch velocity has different effects on each material type. The research of punching process in pure titanium is rarely done. Some research has been done, such as investigation of punch wear effect on punched holes [10][11]. Study effect of processing time on finishing of micro holes [12]. Effect of punch velocity on pure titanium has not been found in the literature review. Development of the punching process in the manufacture of medical components must determine the effect of punch speed on the desired punch force and cutting edge, so as to determine the speed of the punch to be used. Therefore, this paper aims investigation of punch velocity effect on punch force, burnish height and workhardening in punching process of pure titanium.

2. Materials and Methods
Testing material used was commercially pure titanium (CP-Ti) with a thickness of 0.4 mm and hardness of 160 VHN. The testing apparatus used was a pneumatic punch machine with maximum force capacity of 16000 N. Schematic of the testing apparatus is shown in figure 1. Punch velocity used was 10, 35 and 70 mm/s. Punch material used was high speed steel SKH9 with a material hardness of 63 BHN. Punch fabricated process by grinding machine. Punch type used was the single shear angle with the shear angle of 17° and a punch diameter of 1.7 mm. Clearance punch-die used was 10 µm. Punch force was measured with loadcell. Loadcell capacity each of 500N. Punch force is the sum of punch force in loadcell 1 until loadcell 4. The sheared surface shape is shown in figure 2. Burnish height of the sheared surface was measured by a digital microscope (Dino-lite, AM4515 series).

3. Results and Discussion
3.1. Punch force
The observation result of punch force distribution on each side with the difference of punch velocity is shown in figure 3. Punch force that occurs on each side were different between loadcell 1, 2, 3 and 4. The biggest punch force is shown in loadcell 1. Punch force that was read on loadcell 3 is smaller than
loadcell 1. This result occurs because of uneven clearance distribution, this uneven clearance was due to using the single shear angle punch.

The phenomenon of clearance change on punch of single shear angle is illustrated in figure 4. The initial position of the punch before the punching process, the clearance 1 (C1) is equal to clearance 3 (C3). After the punch to penetrates the test material, the clearance 3 (C3) is greater than clearance 1 (C1) thus punch force that was read on loadcell 1 and 3 was different. The clearance affects punch force because increased clearance causes increased plastic zone growth when the punching process, plastic zone increased cause punch force decrease [5].

**Figure 3.** Punch force distribution on each side with the difference of punch velocity

**Figure 4.** Illustration of the punching process with punch single shear angle type : (a) initial position of punch and (b) punch position on penetration start.

Punch force that was read on loadcell 2 and loadcell 4 showed differently. This result was due to the misalignment of punch and die. The misalignment of punch and die was observed with a digital microscope (Dino-lite). The observation result is shown in figure 5. Clearance 2 (C2) seen is smaller than clearance 4 (C4), so punch force that was read at loadcell 2 is greater than loadcell 4. It was found that using four loadcells on four different punch sides can predict the alignment of punch and die.
The measurement result of punch force with loadcell is shown in figure 6. At punch velocity of 35 mm/s, punch increased by 14% compare to punch velocity of 10 mm/s. While with punch velocity of 70 mm/s, punch force increased by 6.5% compare to punch velocity of 35 mm/s. This indicates that punch force increased with increased punch velocity. These occur due to when punch velocity increase, change of momentum rate also increased. Base on Newton's second law of motion, the rate of change of momentum of an object is equal to the net force applied to it [13]. Therefore, when punch velocity increases, the momentum increases thus punch force is also increases.

![Figure 5. Clearance position.](image)

3.2. **Burnish height of the punched holes**

The observation result of the punch holes is shown figure 7. The upper surface showed uneven in A-side and B-side. On the A-side, the cutting edge is sharper than the B-side. That is because of there are differences of clearance on the A-side (C1) with B-Side (C3), clearance on the A-side is smaller than clearance on B-side.

![Figure 6. The measurement result of punch force](image)
The observation result of the burnish height in A-side and B-side is shown in figure 8 and figure 9 respectively. Burnish height in A-side is higher than B-side. In A-side and B-side, burnish height when using punch velocity of 35 mm/s is higher than using punch velocity 10 mm/s. However, burnish height with punch velocity of 35 mm/s is shorter than with punch velocity of 70 mm/s.

The measurement result of burnish height in A-side is shown in figure 10. At punch velocity of 35 mm/s, burnish height increased about 3% of burnish height when punch velocity of 10 mm/s. While with punch velocity of 70, burnish height increased about 21% compare to punch velocity of 35 mm/s. The measurement result of burnish height in B-side is shown in figure 11. At punch velocity of 35 mm/s, burnish height increased about 12% of burnish height when punch velocity of 10 mm/s. While with punch velocity of 70, burnish height increased about 3% compare to punch velocity of 35 mm/s. This indicates that burnish increased with increased punch velocity. This phenomenon occurs may be due to existence a slight increase in material ductility when there is a collision between the punch and the test material. Based on the conservation of energy and momentum in collisions, some kinetic energy is converted into heat energy when inelastic collisions occur [13]. Not only that, in the punching process after burnish formation, the punch is still downward movement until the slug is released. The movement of the punch causes friction in the burnish area. The possibility of this heat and friction which causes happen increase in burnish height.
Figure 9. The shape of burnish height in B-side when punch velocity: (a) 10 mm/s, (b) 35 mm/s, and (c) 70 mm/s

Figure 10. The measurement result of the burnish height

4. Conclusions
Punch velocity can affect on punch force and burnish height in the punching process of pure titanium. Punch velocity increased, punch force and burnish height increased. Other than that, the punch geometry also affects on punch force distribution and burnish height of the punched holes. The punch geometry of single shear angle causes punch force distribution and burnish height on each side is different.

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