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Reducing the punch force in the circular punching process by preheating under the recrystallization temperature

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Abstract
Punch force is the main factor in the success of making holes using the punching process. However, the punching process cannot make a hole when the punch force in the machine is smaller than the punch force in the material. Preheating can be used to reduce the punch force in the material. This research aims to develop the preheating method with low current electricity for reducing the punch force in the material. The preheating method is used two tubular type heating elements with an electric current of about 0.9 A. This method can be heating the material below recrystallization temperature (100 and 150 °C). Preheating at 100 and 150 °C can reduce the punch force by 4 and 11% compared to without preheating. These results can be concluded the material heating below recrystallization temperature is effectively enough to reduce the punch force. Thus, the punching process is able to make a hole even though the punch force in the machine is smaller than the punch force in the material.

Keywords:
Preheating;
Punch Force;
Punching Process;
Pure Titanium;

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INTRODUCTION

The punching process is one of the processes of making components on sheet metal. The punching process has developed on medical, electronic, automobile, and aerospace equipment [1, 2, 3, 4]. The punch force influences the success of the punching process in component manufacturing. This is because if the punch force used is less than the strength of the material, the punching process will not be successful in punching or forming the material. Many studies have been done to reduce the punch force in various materials. Many studies show punch force decreases with decreasing punch speed [5][6]. Punch force decreases with the shear angle in the punch [7, 8, 9, 10] and with preheating [11, 12, 13, 14].

The preheating methods have been developed in the punching process. Mori et al. have developed a heating method that is warm and hot punching on steel [11][12]. Warm punching used temperatures of 650 °C, while hot punching used temperatures of 830, 970, and 1070 °C. Warm punching can reduce the steel punch force by about 40%, while hot punching can reduce the punch force by about 55%. The warm and hot punching process requires an electric current of 7 kA. Mori et al. have also developed local resistance heating [12]. The electric current required to heat the steel material to a temperature of 800 °C is 4.1 kA. This method can reduce the punch force up to 80% without preheating. Tang et al. have developed a heating method with electropulsing [14]. Electropulsing was proposed to help increase the electric current density of aluminum. The electropulsing method with an electric current density of 50 A/mm2 can decrease the punch force by 7%. Several methods show that the heating process requires a large electric current. Therefore, we need a heating method with a smaller electric current. This study aims development a heating method to reduce the punch force using heating under the recrystallization temperature and an electric current of less than 1A.

MATERIAL AND METHOD

The material used in the test is a pure titanium sheet. The material thickness used is 0.6 mm with a hardness of 166 VHN (Nilaco, Ltd). The punch used a FLAT shape made of Height Speed Steel. The punch diameter is 1.7 mm. The punch-die clearance used is 20 µm. The punching process is used a pneumatic punch machine with a punch speed of 35 mm/s. The punching process is carried out under conditions without heating (30 °C) and preheating under the recrystallization temperature (100 and 150 °C).

The location of the under-recrystallization temperature is shown in the phase diagram, as shown in Figure 1. The heating of the material is used two tubular type heating elements with a capacity of 350 ° C and an electric current of about 0.9 A. The schematic of the punching process equipment is shown in Figure 2. The punch force is measured using a mechatronic circuit consisting of a load sensor, Arduino, and computer. The load cells location is under the die with four different positions. It aims to measure the punch force that occurs in several positions. The mechatronic circuit mechanism used to measure the punch force is shown in Figure 3.

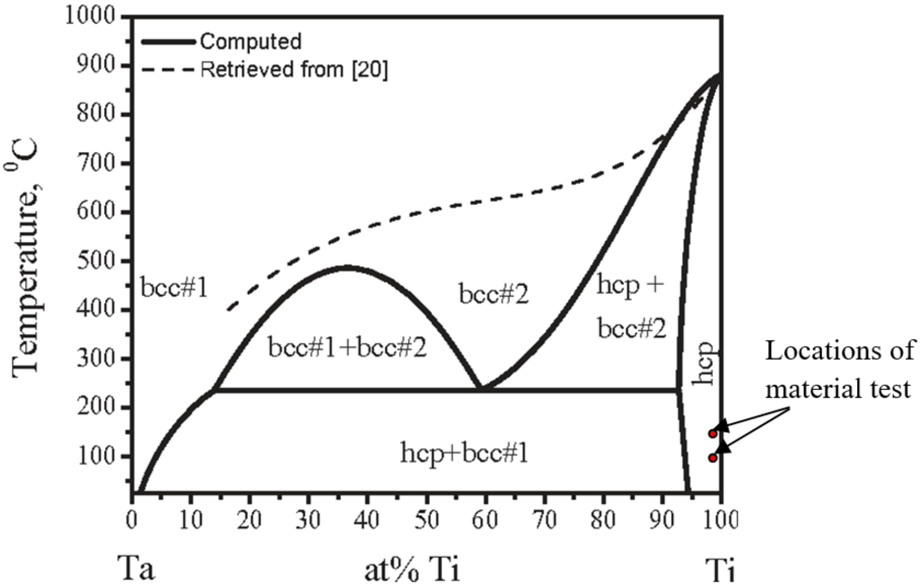

Figure 1. Phase diagram of pure titanium [15]

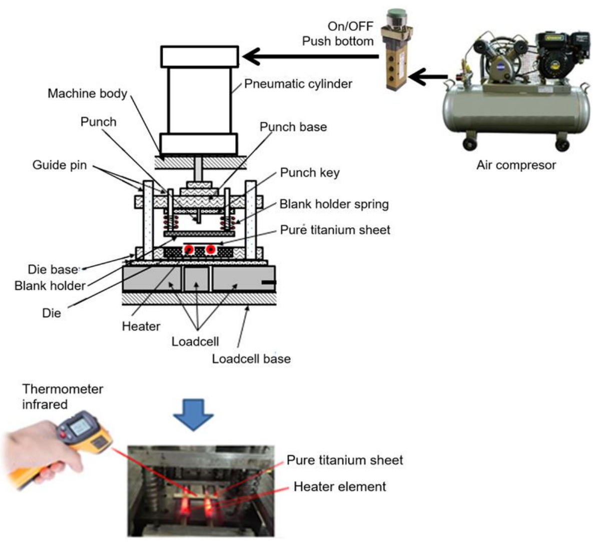

Figure 2. Schematic of the punching process equipment

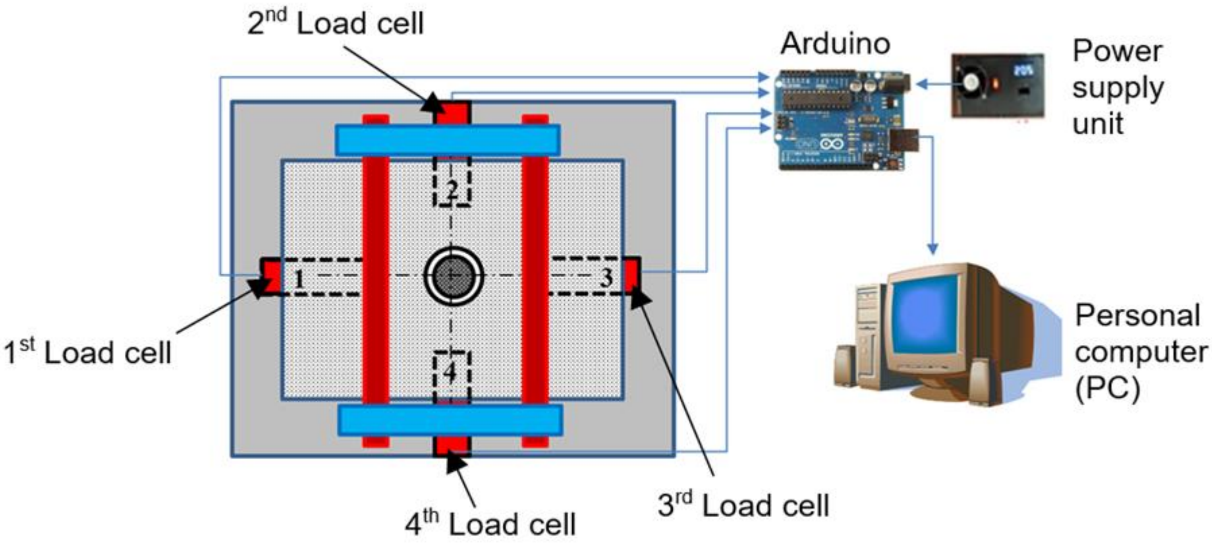

Figure 3. The mechatronic circuit mechanism for measuring punch force

The hole manufacturing with the punching process has several steps. The first step is to adjust the punch speed that will be used. The next step is to place the material on the die upper. And then, turn on the heater and measure the material temperature using a digital infrared thermometer. The material temperature reaches the desired temperature. Next, the start button is pressed to move the punch and blank holder down. The blank holder will press the test material and then press a punch until the material is perforated. The material is perforated. The final step is to press the off button to move the punch and blank holder back up. After the punch returns to the top, the punch force will be present on the computer screen.

RESULTS AND DISCUSSION

The observation result of the punch force distribution on each side is presented in Figure 4. The average value of punch force measured by each load cell is different. Standard deviation seems to intersect between the punch forces at load cell positions 1st and 3rd, 2nd and 4th with differences in preheating if a horizontal line is drawing. The standard deviation that intersects indicates the uncertainty of significant data from punch force at load cell positions 1st and 3rd, 2nd and 4th in differences in preheating. This result does not mean that the average value of punch force at the 1st position load cell is greater than at the 4th position load cell. The punch force average at the 2nd position load cell is greater than at the 3rd.

Punch force in each load cell decreases in the presence of preheating. Therefore, the uncertainty of data differences was analyzed statistically using the ANOVA (Analysis of Variance) test. The ANOVA test results of the punch force with the difference in load cell position and heating temperature can be seen in Table 1.

ANOVA test results show that the *P-value* is less than 0.05, and *F* is more than *F-crit* at the load cell position and heating temperature difference. It has meant a significant difference from the punch force measurement data in the load cell position and heating temperature. These results can conclude that the punch force at the 1st position load cell is greater than the 4th position load cell. At the same time, the punch force at the 2nd position load cell is greater than the 3rd position load cell. Punch force at each load cell decreases with using preheating.

Table 1. ANOVA results of the punch force measurement data at each load cell position

Source of Variation	SS	df	MS	F	P-value	F crit
Loadcell position	3708,99	2	1854,5	8,26	8,27E-04	3,19
Temperature	101114,50	3	33704,8	150,10	2,18E-24	2,80
Interaction	913,51	6	152,3	0,68	6,68E-01	2,29
Error	10778,39	48	224,5			
Total	116515,38	59				

Note: DF is degrees of freedom, *SS* is a sum of squares, *MS* is mean square, *F* is ratios of mean squares, and *F-crit* is critical ratios of mean squares

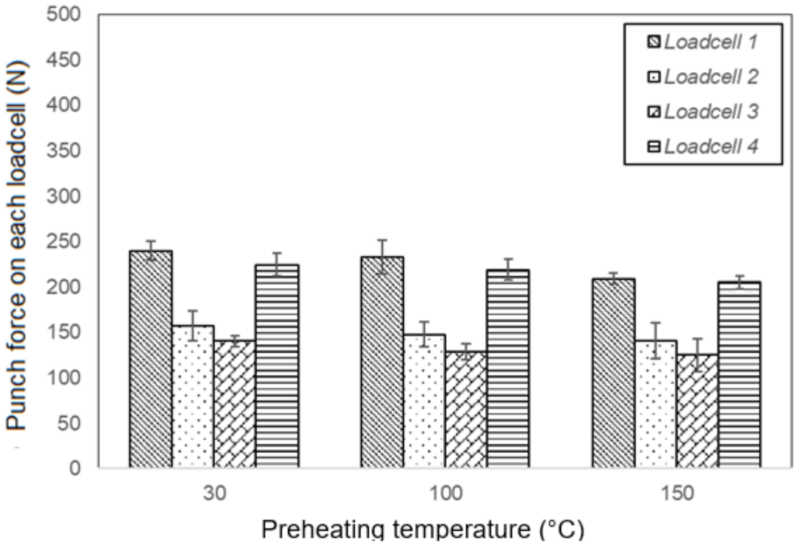

Figure 4. The results of measuring the punch force at each load cell position with the difference in heating temperature

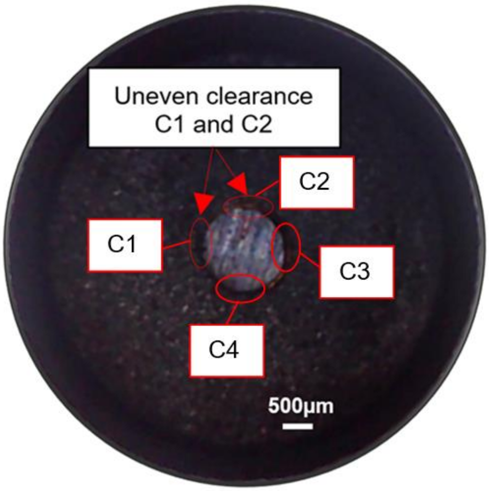

Figure 5. the result of the punch-die clearance observations

Figure 4 also shows the punch force measured at the 1st position load cell is much greater than the punch force at the 2nd position load cell. It is due to the uneven distribution of the punch-die clearance. Figure 5 shows the result of the punch-die clearance observations. The clearance observation is done by giving a light beam from the top of the die, then looking at the distribution of light rays that enter the bottom of the die using a digital dino-lite camera. It shows that incoming light at the 2nd load cell position (C2) is brighter than the 1st load cell position (C1). It meant that the 2nd load cell position has clearance is greater than the 1st load cell position. A large clearance resulting in the plastic zone growth during the punching process increases. It causes a decrease in punch force. Punch force at the 2nd and 3rd position load cell is decreased compared with punch force at the 1st and 4th position load cell. it because the clearance at the 2nd and 3rd position load cell is smaller than clearance at the 1st and 4th position load cell. Uneven clearance is seen of the observation results distribution of light rays that enter the bottom of the die. The incoming light at the 2nd and 3rd position load cells (C2 and C3) are brighter than the 1st and 4th position load cells (C1 and C4). This result has the same trend as prior research [16].

The punch force is the sum of the force measurement result at the load cells fourth. The measurement result of punch force in manufacturing circular holes on a pure titanium sheet is presented in Figure 6. It is shown that the punch force decreases with using preheating. The punch force without preheating reaches 762 N.

Preheating at a temperature of 100 ℃ can reduce the punch force by about 4% compared to preheating. While preheating at a temperature of 150 ℃ can reduce the punch force by about 11%. This result has the same trend as prior research [12, 13, 15].

The punch force reduces by there is preheating. It is because preheating under the recrystallization temperature will make the material soften. Softening of the material is caused by the release of internal stress-energy based on the dislocation movement [16][17]. Therefore, it causes a decrease in the ultimate tensile strength (UTS), as reported in previous studies [18].

The relationship between UTS with punch force is shown in equation 1 [19, 20, 21]. Punch force (*F*) is influenced by Constanta (*k*), Ultimate tensile strength (*UTS*), material thickness (*t*), and cutting edge length (*L*). Equation 1 explained that the punch force is directly proportional to the UTS. The UTS decreases when the preheating material. Therefore, punch force can decrease with there is preheating. This result has the same trend as previous research [12][13]

$$F = k\,(UTS)\,t\,L \qquad (1)$$

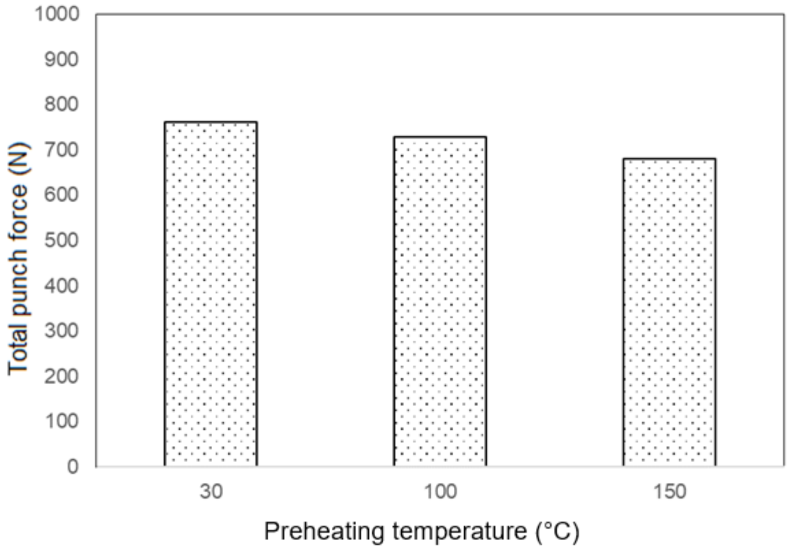

Figure 6. Relationship between heating temperature and punch force

CONCLUSION

Preheating method uses tubular type heating elements is effectively to reduce punch force. The punching process using preheating under the recrystallization temperature can reduce the punching force by 11%. The following research development can observe the quality of the sheared surface on the hole. Besides, this research can develop in the non-circular punching process.

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