Journal of Mechanical Engineering Science and Technology
Vol. 2, No 1, July 2018, pp. 1-6
ISSN: 2580-0817

Damage Simulation of Pre-Forming V-Neck Plates with Variations in Material Type, Time and Temperature Using the Taguchi Method

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ABSTRACT

In metal forming, damage can be caused by several factors: load on the workpiece, initial heating temperature, and temperature due to the friction between the die and the material for pre-forming. The metal forming process can be executed in 2 ways, namely by hot working and cold working. During these two types of mechanical working process, the metal undergoes plastic deformation. In hot working, the required deformation force is relatively low, and changes in mechanical properties are also insignificant. In cold working, a higher force is required, but the strength of the metal will increase significantly. The use of simulation has become increasingly widespread to predict and describe process mechanisms and optimize the pre-forming process. The study was conducted using a three-dimensional (3D) simulation to predict the effect of variations in time, material and temperature on the damage of pre-forming blocks. The simulation results showed that the greatest damage occurred after 0.006 s and at 25 °C to the specimen 1 (Aluminium 1xxx) with the highest damage value of 0.011833 which occurred. Specimen 7 (Aluminium 3xxx) had the lowest damage with the value of 0.011542 which occurred after 0.010 s and at 25 °C.

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Keywords: time, material, temperature, damage

I. Introduction

Metals' forming is a process in which metal is plastically deformed using a compressive force to change its shape or size. This process can be executed in 2 ways, namely by hot working and cold working. It can also be done manually or using a hydraulic machine which generates more powerful pressure. However, if the machine uses a pneumatic power source, the power generated is smaller. Cold working and hot working are two types of mechanical working process where metal undergoes a plastic deformation.

In hot working, the required deformation force is relatively low, and changes in mechanical properties are also insignificant. In cold working, a higher force is required, but the strength of the metal will increase significantly. The recrystallization temperature of metal establishes the boundary between hot and cold working. The hot working is carried out above the recrystallization temperature. The cold working is performed below the recrystallisation temperature and sometimes carried out at room temperature. The recrystallization temperature of steel is between 500 and 700 ºC.

II. Methodology

A. *Workpiece material specifications*

The materials used in this study were top die and bottom die rigid. The workpieces were made of aluminium 1xxx, aluminium 2xxx, and aluminium 3xxx.

B. *Pre-forming modelling*

The materials The modelling of three-dimensional metal forming was performed by involving variations in time (0.006 s, 0.008 s and 0.010 s); temperature (25°C, 35°C and 45°C); material (aluminium 1xxx, aluminium 2xxx, and aluminium 3xxx).

DOI: 10.17977/um016v2i12018p001

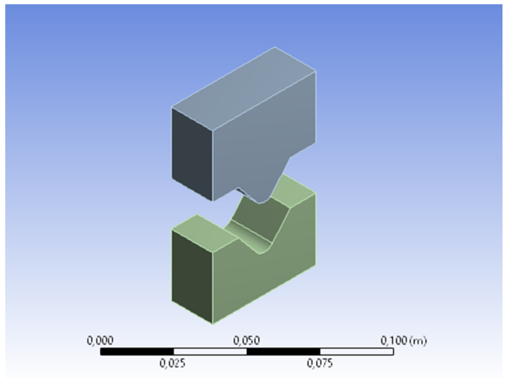


Fig. 1.Top die and bottom die

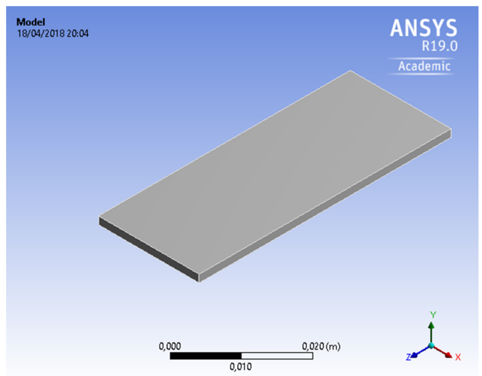


Fig. 2.Workpiece dimensions (4 cm x 15 cm x 0.2 cm)

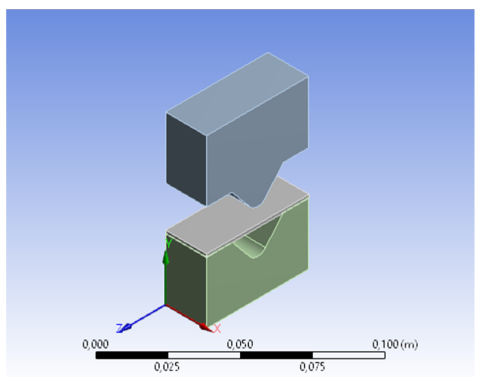


Fig. 3.Workpiece modelling

C. Taguchi method

Table 1 shows three levels of the three process parameters, including material, time, and temperature were applied. The experimental design of FEM simulation using the three levels for three parameters full factorial design (L9), shown in Table 2. Damage was the process responses. In this study, to understand the effects of the process parameters, the Taguchi technique employing a generic signal-to-noise ratio for the "smaller is better" characteristics were considered for the amounts of damage as described in the following equation:

$$SN_s = -10 \log(\frac{1}{n}\sum_{i=1}^{n} y_1^2)$$

Where n represents the number of experiences and y represents the process response.

III. Results and discussion

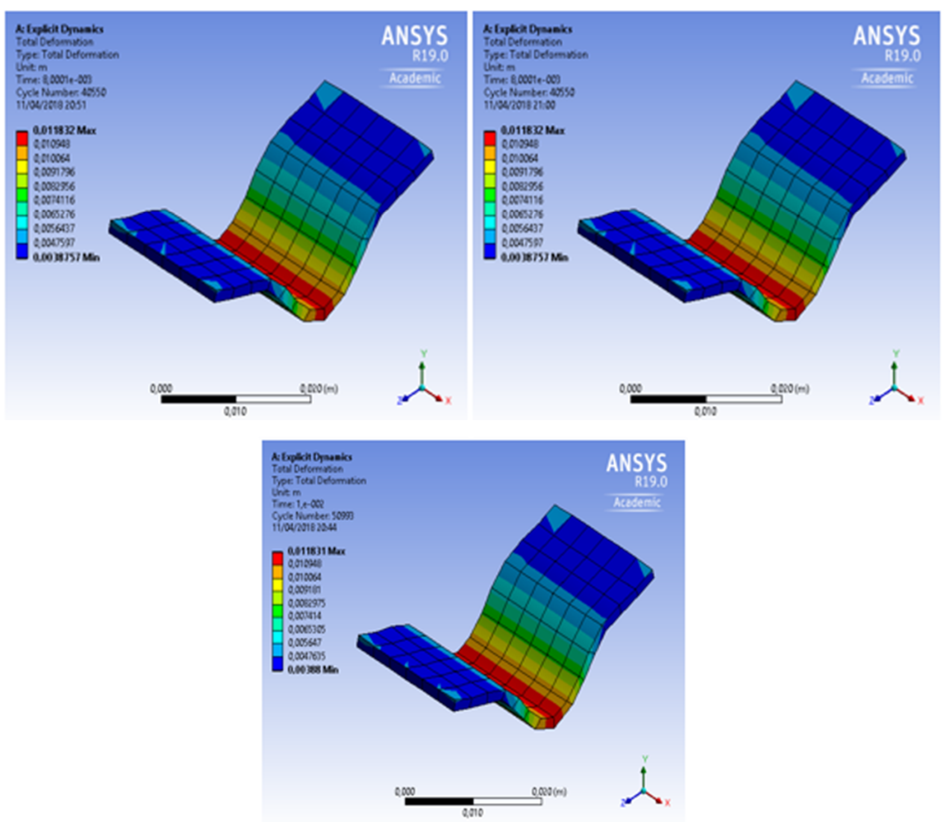
The simulation results showing the effect of friction, speed, material and temperature on the damage of pre-forming blocks are presented in Figure 4 and 5.

Table 1. The Level and Code of Design of Experiment

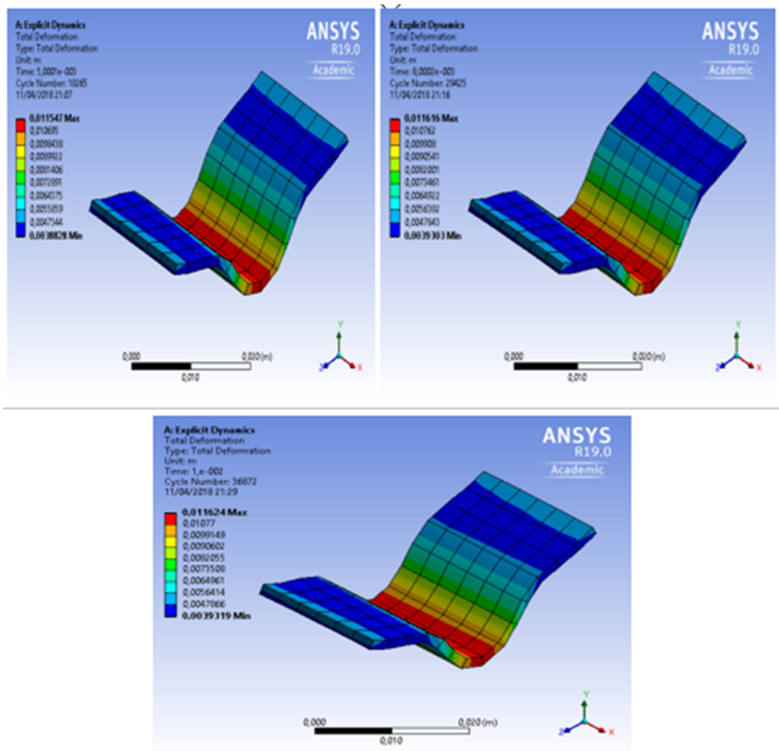
Dimension Variable		Level 1	Level 2	Level 3
A	Material	Aluminium 1xxx	Aluminium 2xxx	Aluminium 3xxx
B	Time	0.006 s	0.008 s	0.010 s
C	Temperature	25 ^{0}C	35 ^{0}C	45 ^{0}C

Table 2. Damage values

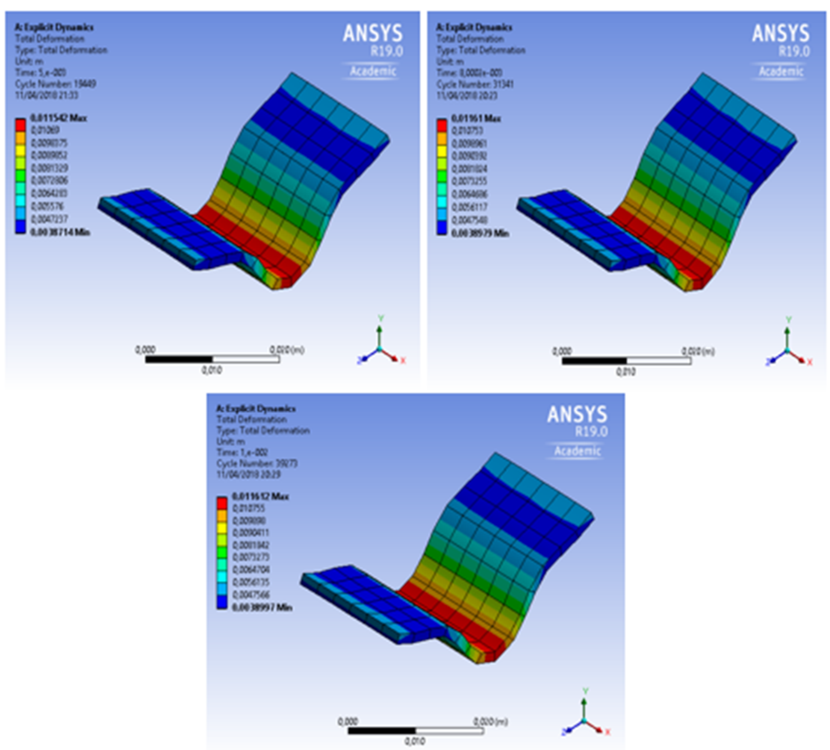
No.	A	B	C	Material	Time (s)	Temperature	Damage
1	1	1	1	Aluminium 1xxx	0.006	25	0.011833
2	1	2	2	Aluminium 1xxx	0.006	35	0.011832
3	1	3	3	Aluminium 1xxx	0.006	45	0.011831
4	2	1	2	Aluminium 2xxx	0.008	25	0.011547
5	2	2	3	Aluminium 2xxx	0.008	35	0.011616
6	2	3	1	Aluminium 2xxx	0.008	45	0.011624
7	3	1	3	Aluminium 3xxx	0.010	25	0.011542
8	3	2	1	Aluminium 3xxx	0.010	35	0.011610
9	3	3	2	Aluminium 3xxx	0.010	45	0.011612



(a)



(b)



(c)

Fig. 4.Damage distribution of pre-forming plates (a) Al 1xxx (b) Al 2xxx (c) Al 3xxx

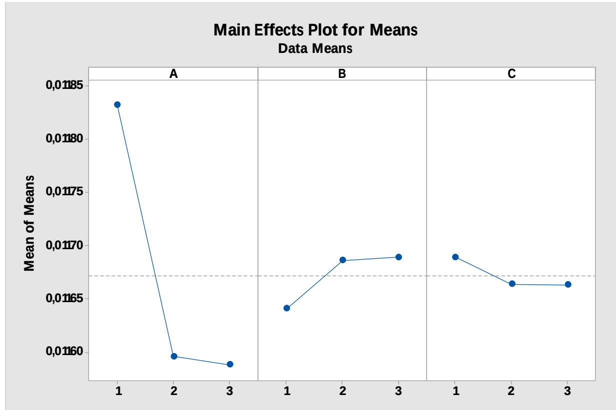


Fig. 5.Main effects plot for means

As shown in Figure 4, specimens 3, 6 and 9 had the greatest damage with the highest value of 0.011832, 0.01162 and 0.011612, respectively. This happened because, before the forming process, specimens 3, 6 and 9 were subjected to a metal heating process carried out at 45 °C. In addition to the metal-softening before and during the forming process, a punch speed of 4.15 m/s also contributed to the damage. An increase in temperature during metal forming resulted in quite a significant deformation.

The slightest damage occurred on specimens 1, 4 and 7 with the highest value of 0.011831, 0.011547 and 0.011542, respectively. These specimens underwent a forming process done at 25 °C. During the forming process, strain hardening occurred in which the metal became harder and its ductility decreased, resulting in limited deformation despite the highest punch speed.

Figure 6 suggests the followings:

1. Time : The greatest damage on the specimen occurred at a time variation of 0.006 s, while the most minimal damage occurred at 0.01s.
2. Material : The specimen made of aluminum 1xxx had the greatest damage, while that made of Al 3xxx had the slightest damage.
3. Temperature : A temperature variation of 25°C caused the greatest damage to the specimen, while the slightest damage occurred due to a temperature variation of 45°C.

The higher the temperature applied, the lower the strength and hardness of the material, and hence the occurrence of plastic deformation. Deformation is caused by a compressive load that changes the initial shape of the workpiece, even when the load is removed. This is in line with the simulation results in this study where, as the temperature increased, the plastic deformation occurred more significantly, and the damage value decreased. However, a different effect existed in the specimens made of Aluminium 3xxx and Aluminium 2xxx where the increasing time caused an increase in the damage of the workpiece. This might be because Aluminium 2xxx and Aluminium 3xxx have low plastic deformation rates.

Table 3. Response table for means

Level	Temperature (˚C)	Material Type	Time (t)
1	0.01183	0.01164	0.01169
2	0.01160	0.01169	0.01166
3	0.01159	0.01169	0.01166
Delta	0.00024	0.00005	0.00003
Rank	1	2	3

As suggested by Table 3, temperature was the most influential factor since it caused a decrease in deformation triggered by the plasticity of the work piece. The type of the material was the second most decisive factor, followed by crushing time.

IV. Conclussion

1. Specimen 7 (Aluminum 3xxx) had the slightest damage. The highest damage value of 0.011542 occurred after 0.006 s and at 25°C.
2. Temperature was the most influential factor in the forming process.
3. Time was the least decisive factor influencing the forming process.
4. With 3D simulation, pre-forming parameters can be developed to reduce damage to the workpiece.

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