Research Progress in Mechanical and Manufacturing Engineering Vol. 2 No. 2 (2021) 869-876
© Universiti Tun Hussein Onn Malaysia Publisher's Office

RPMME

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Effect of V-Shaped Side Groove on Shear Lip Formation of Aluminium Alloy 6061 by Charpy Impact Test using Finite Element Analysis

Muhammad Syabil Muhammad Syafiq Suresh[1], Mohd Azhar Harimon[1]*

[1]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rpmme.2021.02.02.093
Received 10 Aug. 2021; Accepted 01Dec. 2021; Available online 25 December 2021

Abstract: In the automotive industry, aluminium alloy has been widely used for its own qualities which suits the industry. This study is to investigate the fracture properties of aluminium alloy 6061 with the presence of v-shaped side groove which is rarely investigated. Side groove can be characterised as a deep line cut on a specimen surface which is believed can reduce ductile behaviour during impact on the material. Ductile behaviour during impact is crucial as ductile behaviour undergoes plastic deformation before crack compared to brittle behaviour. The major goal of this research is to identify whether will side groove influences the fracture behaviour of Al6061 as shear lip formation will be observed as the main objective of this research. A simulation of Charpy Impact Test with various side groove was conducted utilising ABAQUS 6.18 to identify the shear lip ratio, the absorb energy of the specimen and the displacement of the fracture. 3 different variation of v-shaped side groove depths of 0.5, 1.5 and 2.5 mm has been used as the variable of this research. Based on the research, the shear lip ratio decreased when the side groove depths ratio increased. Besides, it was found that absorb energy decreased when the side groove depths ratio increased. In conclusion, increasing side groove depths ratio will tend to less ductility of Al6061 due to the less shear lip ratio and less absorb energy.

Keywords: Shear Lip Ratio, Side Groove Depths, Ductile Fracture, Al6061, Finite Element Method.

1. Introduction

The composition of the aluminium alloy with other material with aluminium as its dominant material can be categorised as non-ferrous metal. In engineering, for instance, construction structure or any design of the engineering industry, aluminium metal is often used since it is extremely desirable to combine characteristics with the ease to make them in numerous ways [1]. The grade of aluminium alloy is classified. The key material in this research is class 6061. Aluminum alloy 6061 or Al6061 is

---

Corresponding author: mazhar@uthm.edu.my

frequently utilised for the building industry, as are the car components, powertrain casting and suspension components [2]. All materials undergoing a fracture process have their own behaviour as a fracture. The behaviour of the fracture was frequently linked to the micromechanical fracture and the fracture process in the area of stabilisation. The behaviour of this material fracture is commonly known to be ductile or brittle [3]. Because of its characteristics, fractures of pure aluminium frequently suffer a ductile fracture [4].

The side groove is the one that can be defined as a deep line cut on a specimen surface. The presence of side groove may trigger plane strain fracture in thin sections that are normally ductile according to study carried out by J.P. Hess [5]. Thus, it is particularly crucial to utilise side groove for the small specimen and when the experiment is conducted it might raise the percentage of the notch or fracture front [6]. The shear lip is a crucial feature in fracture mechanics, particularly in order to highlight the ductile fracture. Before the fracture strikes the surface, the order can be abruptly switched from transverse to around 45° where it occurs the most. This fracturing surface is referred to as slant fracture or shear lip and is the form of the cone and cup for the key component of the tensile fracture. Moreover, this shape of the lip can be either in single or double form on the surface of the material, when there is a stress state in the plane [7]. The small region of the lip of the shear is equal to the fracture and fast crack development, based on the previous study [8].

Charpy impact test also can be done by using simulation through any related software such as ABAQUS software. The model of this test can be divided into three major parts which are the striker, the anvils and the specimen. Besides. the rigid bodies or elastic body were used for the model of striker and anvils while for the specimen considered as deformable. The type of mesh can be divided into two types which is fine mesh at the notch region and coarse mesh at the remaining part of the specimen. The effect of side groove depths ratio on shear lip formation for Al6061 alloy through simulation of Charpy impact test that conducted on ABAQUS 6.14 version.

2. Materials and Methods

2.1 Size specimen and materials used

For this research, the selected materials are aluminium alloy 6061 for specimen model and stainless steel for striker model.

Table 1: Properties of material of aluminium alloy 6061 and stainless steel

Item	Parameter	Specimen Model	Striker Model	Unit
1	Young’s Modulus	70.0	193	GPa
2	Poisson’s Ratio, ν	0.33	0.31	-
3	Density, ρ	2600	7750	kg/m^3

For the specimen model, the model was design with length of 50 mm, depth of 10 mm and width of 10 mm. For the notch, it was set for 2 mm of depth and 1.66 mm for the length. For the striker model, it was design with 20 mm length, 10 mm width and a 0.8 radius at the tip of the striker model. 3 different side groove depth were choosen as the variable for this test which are 0.5, 1.5 and 2.5 mm. Figure 1 and Figure 2 shows the 2D model of specimen model and striker model respectively.

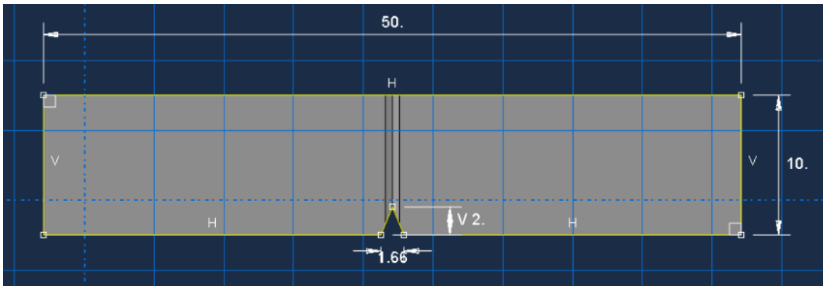

Figure 1: Specimen model

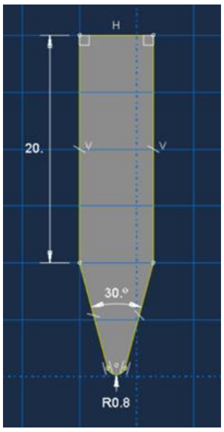

Figure 2: 2D striker model

2.2 Finite element analysis

In ABAQUS the process flow that had been conducted in this study as Figure 3. All step needs to be clearly done before move to analysis the result.

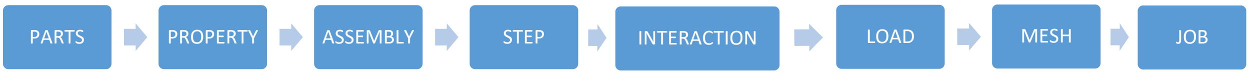

Figure 3: Process flow of simulation using ABAQUS

Next, this study uses Johnson-Cook material model for the simulation of fracture for aluminium alloy 6061. The use of the material model is to predict the failure that has been used in many engineering materials. The material model was applied to the specimen model according to the parameter for aluminium alloy as shown in Table 2 and Table 3.

Table 2: Johnson-Cook material model for aluminium alloy 6061

Item	Parameter Name	Specimen Model	Unit or Dimension
1	A	324	MPa
2	B	114	MPa
3	C	0.002	-
4	n	0.42	-
5	m	1.34	-

Table 3: Johnson-Cook damage model for aluminium alloy 6061

Item	Parameter Name	Specimen Model	Unit or Dimension
1	d1	-0.77	-
2	d2	1.45	-
3	d3	0.47	-
4	d4	0	-
5	d5	1.6	-

Surface contact is needed to develop between the specimen model and the striker to give interaction among surface contact. Striker model will be chosen as master surface while the specimen model will be chosen as the slave surface as shown in Figure 4. The friction coefficient will be set as 0.25. Last but not least, in Figure 5 can be seen as the complete of meshing of Charpy impact test. Meshing was important as it was representing an element while the time required to solve depend on this meshing criteria. In this research, it was set as a hexagonal shape with the sweep technique that been apply to the middle of the specimen model that contain notch while others been apply as a hexagonal mesh shape by structured technique.

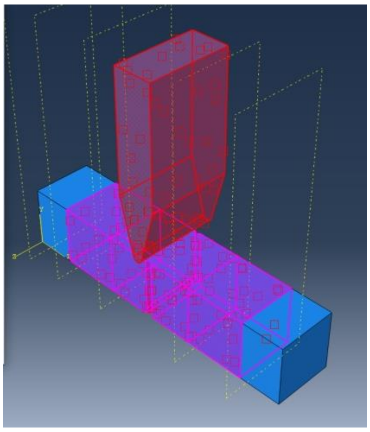

Figure 4: Surface contact

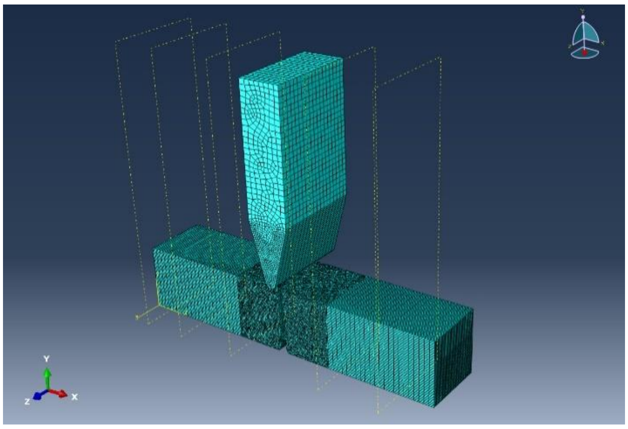

Figure 5: Final meshing of full model

3. Results and Discussion

3.1 The effect of side groove depth on shear lip ratio

So as to compute and examine the shear lip ratio, PEEQ which stands for plastic strain contours in Abaqus is the method which is plotted for respective instance of groove depth at the cross-sectional crack face [9]. The shear lip ratio obtained from this process is then in turn used to determine if the grooves incline to cause brittle or ductile fracture. If the value of shear lip ratio is a lesser amount than 10% the specimen will experience and act as a brittle object [9]. By using what is shown in the Figure 6 that is plotted in accordance to PEEQ contours we can demonstrate the formation of shear lip for each of the case of different groove depths. The distance is calculated by means of tools drop down menu and selecting the query option. Different parameters pop up with distance being amongst them, selecting distance will prompt you to select the nodes between which the distance needs to be measured. After the distance is attained cross match A and B and find the common value of shear lip ratio between them with the table provided by ASTM E23 [10]. That value is the value of shear lip ratio for that particular specimen. From the graph in Figure 7, it can be concluded when side groove depths ratio increases, the shear lip ratio decreases. Thus, the deeper the depth will tend the shear lip ratio to decrease where the ductile fracture tends to become brittle fracture. It is because the smaller the shear lips ratio, the tendency to reach brittle fracture is high.

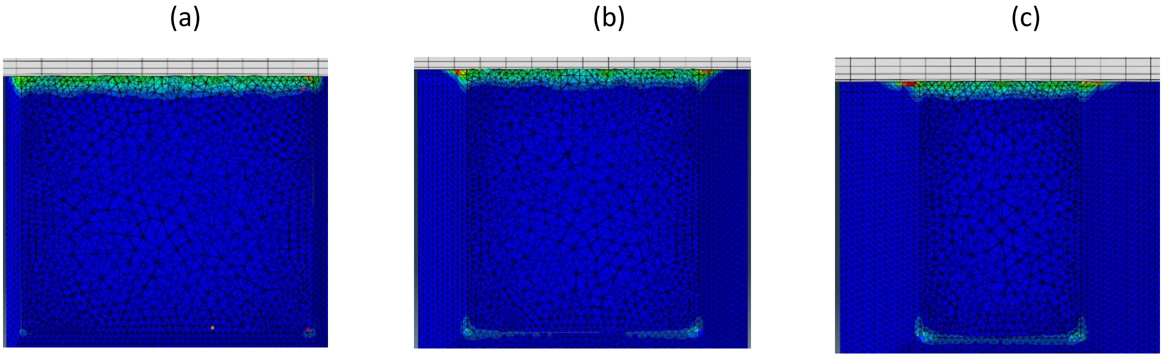

Figure 6: Face crack contain shear lip formation on various side groove depths ratio, (a) 0.1, (b) 0.3, and (c) 0.5.

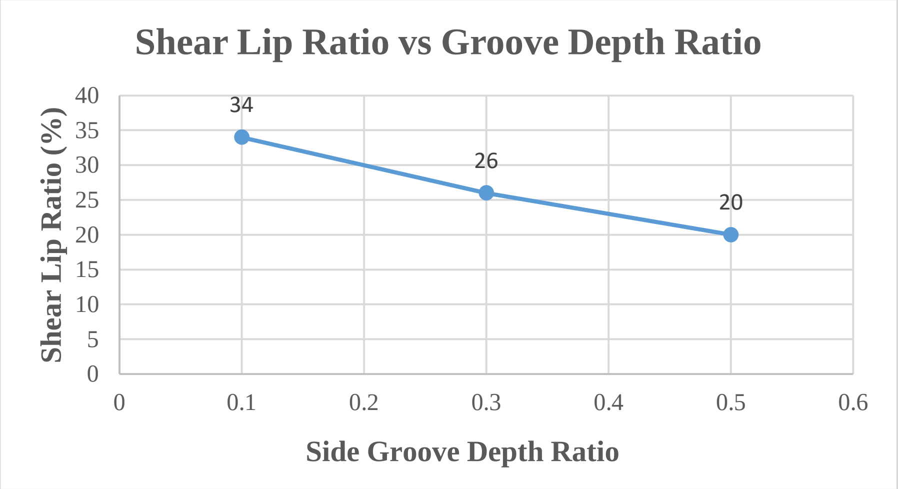

Figure 7: The effect of side groove depths ratio on shear lip ratio

3.2 The effect of side groove depth ratio on the absorb energy

A data and graph as shown in Table 4 showing the trend of total absorbed energy with respect to side groove depth ratio. From the Figure 8, it can be perceived that the maximum absorbed energy decreases with increase in side groove depth meaning lower the absorbed energy more brittle will be the specimen. Therefore, increasing the groove depth would decrease the absorbed energy while carrying out the Charpy impact test. Low absorbed energy would show a fast moving brittle fracture. The trend of result was same as the theory from other research where it indicates when the absorb energy tends to decreases, the specimen will undergo brittle behaviour [11]. Other than that, compare to some research that been conducted by experiment, the result indicates as the deeper side groove will undergo the brittle behaviour [11].

Table 4: Maximum energy absorbed with different groove depth ratio

Item	Side groove depth ratio	Maximum absorb energy (J)
1	0.1	1392.82
2	0.3	961.297
3	0.5	652.166

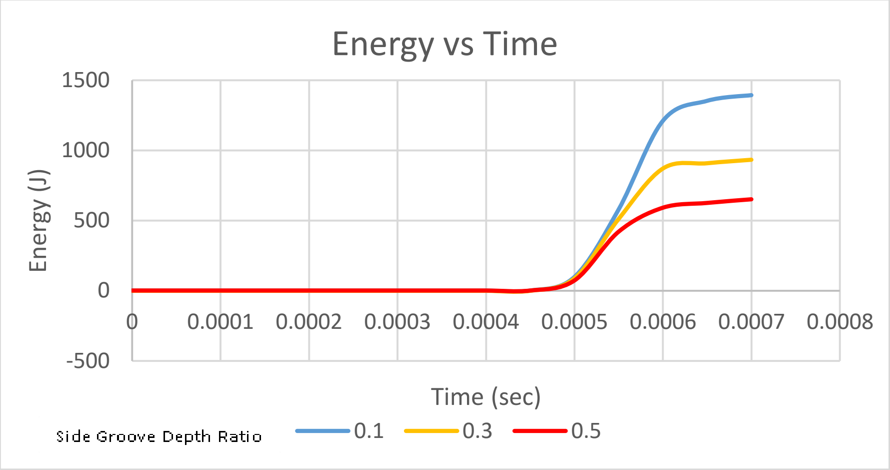

Figure 8: The absorb energy versus time graph of Al6061 for varying side groove depth ratio.

3.3 The effect of side groove depth ratio on displacement

A graph was plotted for displacement versus time for different values of side groove depths and is shown in Figure 9. The higher the side groove depth higher will be the displacement with much steeper curve on the graph. After careful consideration of the displacement time graph data, it is determined that an increase in groove depth will cause failure at a greater rate. At initial stages the lines are parallel to each other and on the x-axis meaning there is no displacement at the initial stages which represents the ductility of the material. A sudden increase in displacement is observed after that which signifies initiation and spread of a crack leading to complete fracture. Values for maximum displacements are shown in Table 5.

Table 5: The maximum displacement for different side groove depth ratio.

Item	Side Groove Depth Ratio	Maximum Displacement
1	0.1	0.525929
2	0.3	2.37961
3	0.5	0.852494

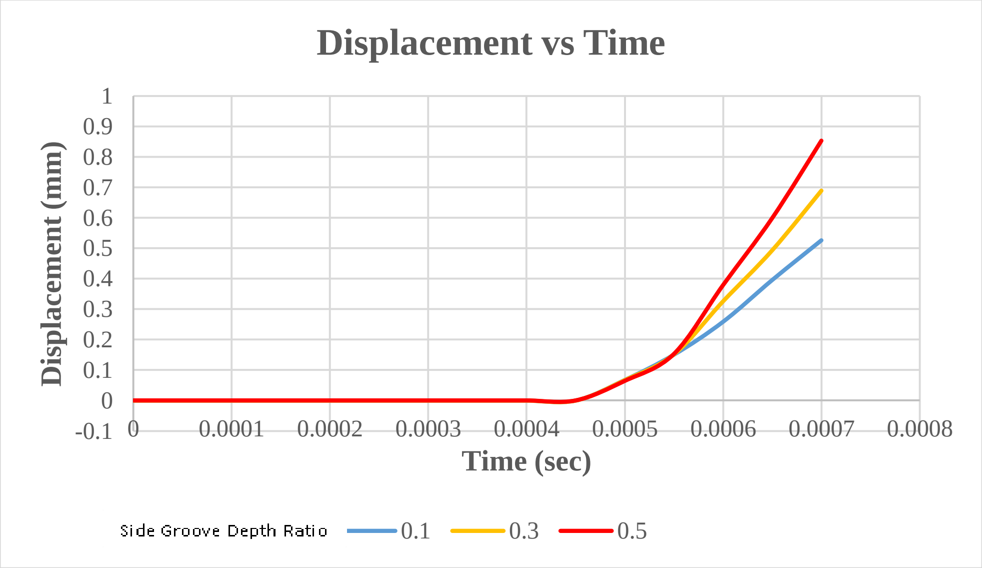

Figure 9: Graph of displacement against time for varying side groove depths.

Figure 10 shows the relationship between absorbed energy and displacement for different groove depths. From this graph it is concluded that higher values of displacement and lower values of absorbed energy will result in deeper grooves. Which in turn means that greater values of displacement and lower values of absorbed energy produce a brittle fracture. Therefore, increasing the groove depths will increase the chances of brittle fracture as the energy that is absorbed is a lot lower with larger values of displacement. Besides, the trend of the graph in Figure 10 shows a good agreement with other research where it shows similar trend as the absorb energy start to increases, the displacement of the crack will be higher [12].

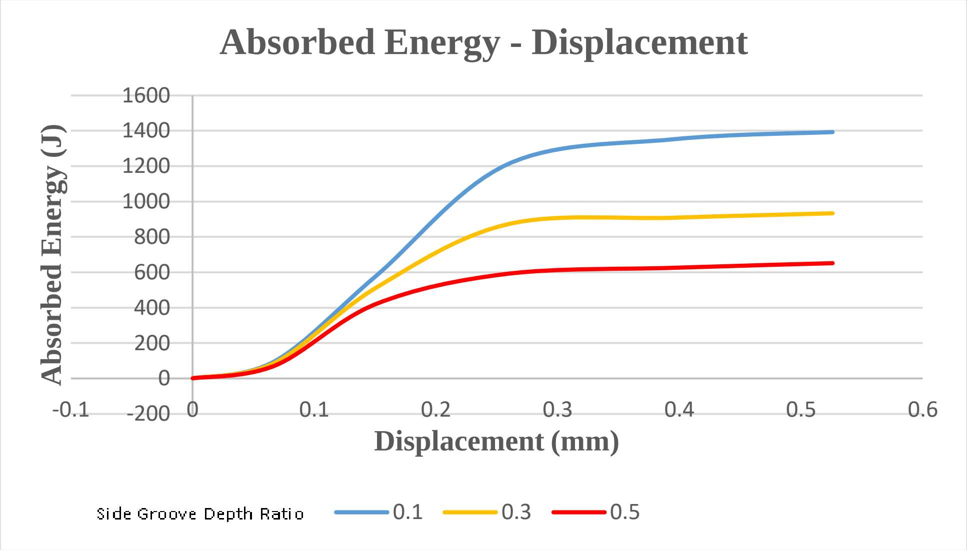

Figure 10: Graph of absorb energy versus displacement for varying side groove depths

4. Conclusion

In conclusion, shear lip ratio of Aluminium Alloy 6061 crucially depends on side groove depths ratio. Besides, other results such as absorb energy and displacement had relationship with the side groove depths ratio. It can be seen that as side groove depths ratio increases, the shear lip ratio decreases, but the shear lip ratio in this study doesn’t reach below that 10 % instead of only 20 %. This can be summarized that as the aluminium alloy 6061 still on ductile fracture behaviour and undergoes plastic deformation before it fully fractured. Besides, it can be concluded that less absorb energy needed when the deeper side groove applied on the specimen model where less absorb energy will contribute to brittle fracture.

Acknowledgement

This research was supported by Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme for Research Acculturation of Early Career Researchers (FRGS-RACER) (RACER/1/2019/TK03/UTHM//2) or Vot No. K152. The authors would also like to thank the Research Management Center (RMC) and Faculty of Mechanical and Manufacturing Engineering (FKMP), Universiti Tun Hussein Onn Malaysia for its support.

References

[1] P. Kumar, "A Study on Mechanical Properties of Aluminium Alloy (LM6) Reinforced with SiC and Fly Ash," IOSR J. Mech. Civ. Eng., vol. 8, no. 5, pp. 13–18, 2013.

[2] J. C. Benedyk, Aluminum alloys for lightweight automotive structures. Woodhead Publishing Limited, 2010.

[3] X. K. Zhu and J. A. Joyce, "Review of fracture toughness (G, K, J, CTOD, CTOA) testing and standardization," Eng. Fract. Mech., vol. 85, pp. 1–46, 2012.

[4] M. F. Hafiz and T. Kobayashi, "A study on the Microstructure-Fracture Behavior Relation In Ai-Si Casting Alloys," Pergamon Press Ltd, vol. 30, no. 4, pp. 475–480, 1994.

[5] J. P. Hess, A. F. Grandt, and A. Dumanis, "Effect of Side-Grooves on Fatigue Crack Retardation," Fatigue Fract. Eng. Mater. Struct., vol. 6, no. 2, pp. 189–199, 1983.

[6] T. Siewert, Pendulum Impact Machines. USA: ASTM Publication, 1995.

[7] J. Lu, V. Ventzke, N. Huber, and N. Kashaev, "Material Influence on Crenellation Effectiveness in Damage Tolerant Design," Procedia Struct. Integr., vol. 5, pp. 263– 270, 2017.

[8] N. A. Latif, Z. Sajuri, J. Syarif, and Y. Miyashita, "Effect of loading rate on fracture behaviour of Mg-Al-Zn alloys," J. Teknol., vol. 78, no. 6–9, pp. 83–89, 2016.

[9] Gallant, B. K., and T. S. Koko. Shear Lip/Plastic Zone Finite Element Model Development. MARTEC LIMITED HALIFAX (NOVA SCOTIA), 2002.

[10] N. A. Latif, A. Auspan, M. S. Mustapa, N. F. M. Joharudin, and N. F. Nasir, "Effect of loading rates and single edge notch bending (SENB) specimen thicknesses on shear lips formation for Al6061 alloy," Malaysian J. Microsc., vol. 15, no. 1, pp. 38–45, 2019.

[11] ASTM E 23-12c, "Standard Test Methods for Notched Bar Impact Testing of Metallic Materials," Standards, vol. 1, pp. 1–25, 2013.

[12] Dasari, Madhusudhan & Chand, Suresh & Ganesh, S. & Saibhargavi, U., "Modeling and simulation of Charpy impact test of maraging steel 300 using Abaqus," IOP Conference Series: Materials Science and Engineering, vol. 330, no. 1, pp. 012013, 2018.