Effect of Loading Rates and Single Edge Notch Bending (SENB) Specimen Thicknesses on Shear Lips Formation for Al6061 Alloy

Noradila Abdul Latif [1,] Afiffikri Auspan [1], Mohammad Sukri Mustapa[1], Nurul Farahin Mohd Joharudin [1] and Nurul Fitriah Nasir[2*]

[1]Structural Integrity and Monitoring Research Group (SIMReG), Department of Mechanical Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor.
[2]Energy Technologies Research Group (EnRG), Department of Mechanical Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor

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Abstract

Aluminium alloy is a well-known material that has been widely used in automotive industry as automobile parts i.e., car chassis, engine blocks, cylinder heads and pistons. Aluminium 6061 alloy (Al6061 alloy) was used in current study to fulfill the requirement in automotive industry to have a further investigation on the fracture properties of alloy. It was found that the effect of fractured specimen thicknesses on fracture behavior for metallic materials is infrequently investigated under three-point bending test at various loading rates. Investigation on effect of single edge notch bending (SENB) specimen thicknesses on the shear lips ratio of Al6061 alloy is crucial to identify alloy's behavior under increasing loading rates. Three-point bending test under different loading rates was conducted using different thicknesses of SENB specimen to measure the shear lips ratio on the sides fracture surface of Al6061 alloy. The loading rates of 5, 25 and 50 mm/min, and SENB specimen thicknesses of 10, 15, 20 and 25 mm were performed under three-point bending test. From fractograph of Al6061 alloy, shear lips were formed both sides of notch tip. Shear lips ratio depended on loading rates and SENB specimen thicknesses were determined. Based on the result of analysis, the shear lips ratio was dropped as the thickness of specimen increased and shear lips ratio dropped as the loading rate increased. High loading rate and large thickness of SENB specimen indicated less ductility of alloy due to the less time during plastic deformation for large specimen.

Keywords: shear lips ratio, fracture behavior, ductile

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Corresponding author: Noradila Abdul Latif; e-mail: noradila@uthm.edu.my
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Introduction

Aluminium alloy is known as refined Aluminium added with other elements to improve the material's properties and strength. In addition, it is a frequently used material, especially in the engineering field because of its convenient mechanical and material properties, particularly in terms of building construction and component for any engineering field [1,2]. Mechanical characteristics such as fracture tightening are critical to the layout of the buildings [3-5]. The strength of the fracture may be directively modified, depending on the material properties and production processes, which is associated with the thickness of the material.

In following years, frequent material scientists have undertaken thorough research into the structure, microstructure and heat treatment areas of Al6061 aluminum alloy [7-10]. The Al6061 alloy is broadly utilized, and is the most suitable to be used in the automotive application, for instance, in the parts and structure of vehicle [6]. It is commonly utilized in automotive application because of the important property, as it is beneficial to decrease the weightiness of vehicles. One of the best advantages of lightweight property is it can decrease the utilization of fuel, and improve the effectiveness of the engine which could potentially enhance any vehicle performance [11]. However, there has been limited attention to the fracture toughness aspect and lack of study exists towards Al6061 aluminum alloy material.

In general, on top of having the highest malleability and strength with great machinability, Al6061 alloy also has commendable bearing and wear properties [11]. Thus, huge plastic deformation could happen at the crack tip of the fractured body. In general, in terms of the plastic deformation size at the crack tip, which is also called as shear lips formation, it depends on the width of the fractured body. The malleability of the fractured body depends on the specimen widths through the development of shear lips at the verge of the specimen, characterized as an inclined fracture. Previous studies found that shear lips area with 10% and less tends to get a fragile fracture [13] and fast crack growth [14]. The crack plane that meets with the surface is nearby to the frame of a plane's stress zone when there is an inclined fracture on both shear lips formation [15]. The use of maximum load as the critical load to estimate the fracture toughness is not always correct. Moreover, shear lips formation could also happen due to the distinct range of loading rates throughout testing [16]. In order to find the material behavior, both studies perform distinct test method and use of material. On the other hand, the effect of loading rates, fractured specimen thicknesses and test methods on fracture behavior of Aluminium alloys are rarely investigated. The effect of loading rates and SENB specimen width on shear lips formation for Al6061 alloy is decided throughout this research.

Materials and Methods

In the present study, Aluminium 6061 alloy (Al6061 alloy) was used to carry out a three-point bending test under range of loading rates and SENB specimen thicknesses to obtain the fracture properties and shear lips ratio of alloy. The element compositions of Al6061 alloy are listed in Table 1. By conducting the Vickers Hardness test, the mean hardness for Al6061 alloy was found at 92.23 HV. The hardness of Al6061 alloy was measured to examine its resistivity in order to undergo plastic deformation.

Table 1: Element composition of Al6061 alloy

Aluminium series	**Composition, wt%**							
	Si	Cu	Mn	Cr	S	Ta	Ni	Al
6061	1.857	0.396	0.182	0.159	0.019	0.014	0.005	Balance

A three-point bending test was performed using Universal Testing Machine (UTM) with the capacity load cell of 10kN. Figure 1 shows the test configuration of three-point bending test for SENB specimen. The geometry size of SENB specimen for this test was cut with the width (*W*) of 10 mm, notch depth (*a*) of 5 mm, span length (*S*) of 40 mm and total length of 50 mm. The present study focuses on shear lips formation at the notch tips of different thicknesses (*B*) of specimen i.e., 10, 15, 20 and 25 mm, under three-point bending test at loading rates of 5, 25 and 50 mm/min. The load-load line displacement curve started from notch specimen opening until the fractured surface. The fractured surface was acquired by using stereo microscope to observe shear lips deformation at all SENB specimen thicknesses under different loading rates. Subsequently, shear lips ratio was determined by dividing the average area of both sides of the shear lips by its specimen widths.

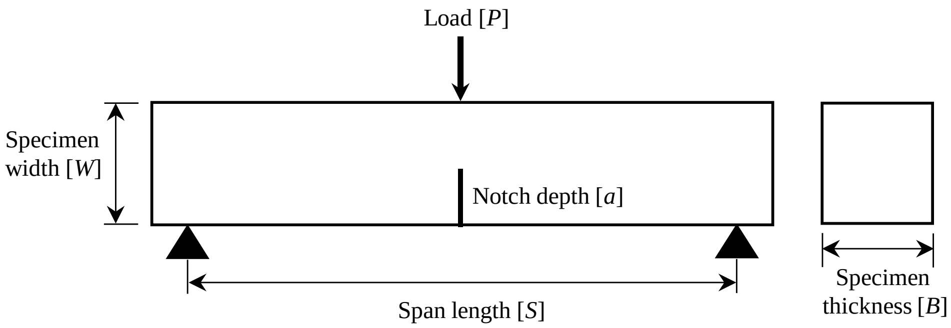


Figure 1: Three point bending test configuration

Results and Discussion

For tensile properties, [17] report that the yield stress, tensile strength and elongation of Al6061 alloy are 270 MPa, 310 MPa and 10%, respectively. From elongation, it is found that Al6061 alloy significantly behaves in ductile manner, since the elongation with more than 5% is categorized as ductile material [18]. For fracture behavior, Figure 2 shows the load-line displacement curves of different SENB specimen thicknesses under various loading rates for Al6061 alloy. This figure indicates all SENB specimens behave in ductile manner due to the elastic-plastic deformation of alloy. Table 2 lists the values of P_{max} and shear lips ratio of all SENB thicknesses under different loading rates. In Figure 2(a) and (b), Al6061 alloy tested under loading rate of 50 mm/min indicates SENB specimen thicknesses of 10 and 15 mm possess the highest peak load, P_{max} compared to P_{max} under 5 and 25 mm/min of loading rates. It can also be seen in Figure 3(a) on the slight increase of P_{max} under increased loading rates for SENB specimen thicknesses of 10 and 15 mm. In previous study, [19] report that high dislocation density in microstructure of alloy under high strain rate contributes to the high of the P_{max}. In Figure 2(c) and (d), however, the highest P_{max} of alloy is not under highest loading rate of 50 mm/min, where P_{max} values are almost similar as all range of loading rates for SENB specimen thicknesses of 20 and 25 mm. Hence, P_{max} of alloy for SENB specimen thicknesses of 20 and 25 mm are independent to the loading rates as shown in Figure 3(a). Next, it is found that the P_{max} of all loading rates increase at increasing SENB specimen thicknesses as shown in Figure 3(b). This is due to the thickness of SENB specimen that is significantly capable to withstand under high load given.

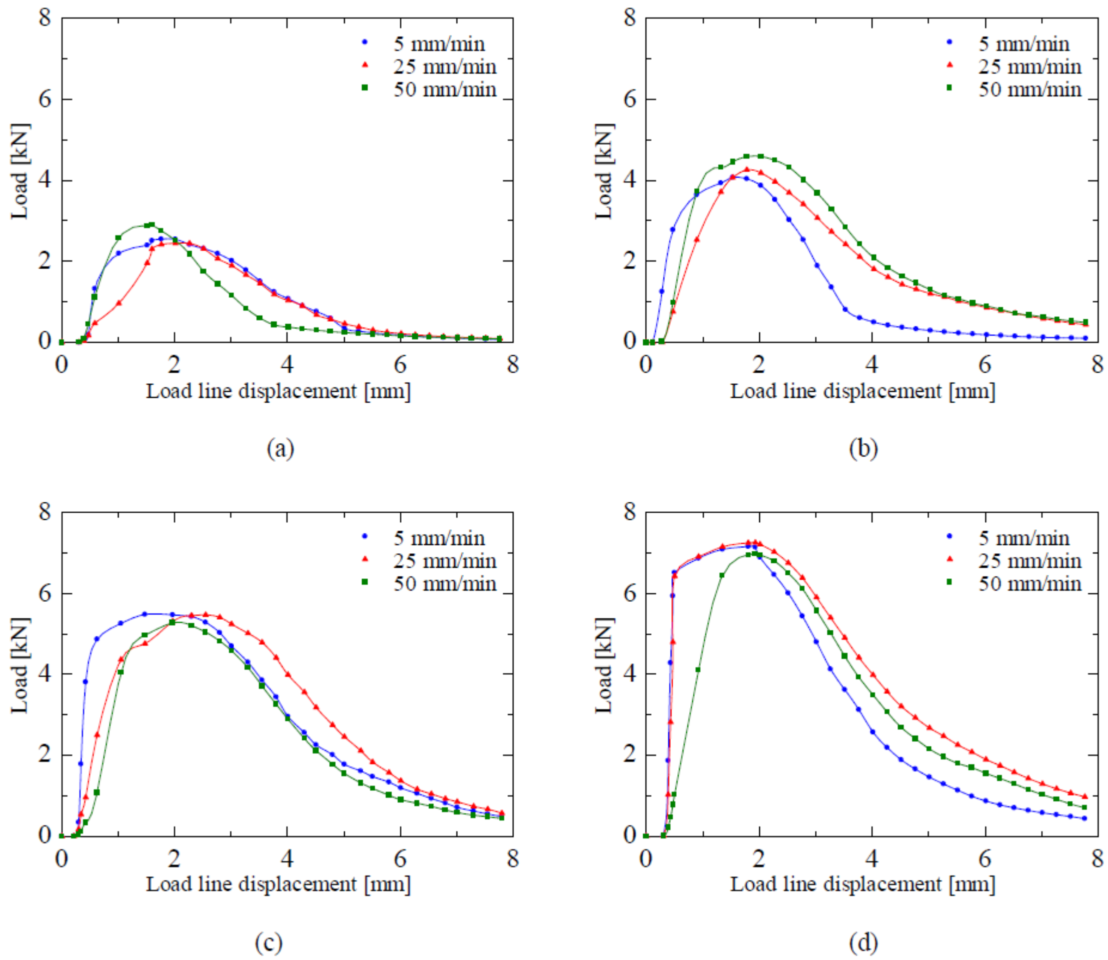


Figure 2: Load-load line displacement curve of Al6061 alloy at SENB specimen thicknesses of (a) 10 mm (b) 15 mm (c) 20 mm and (d) 25 mm

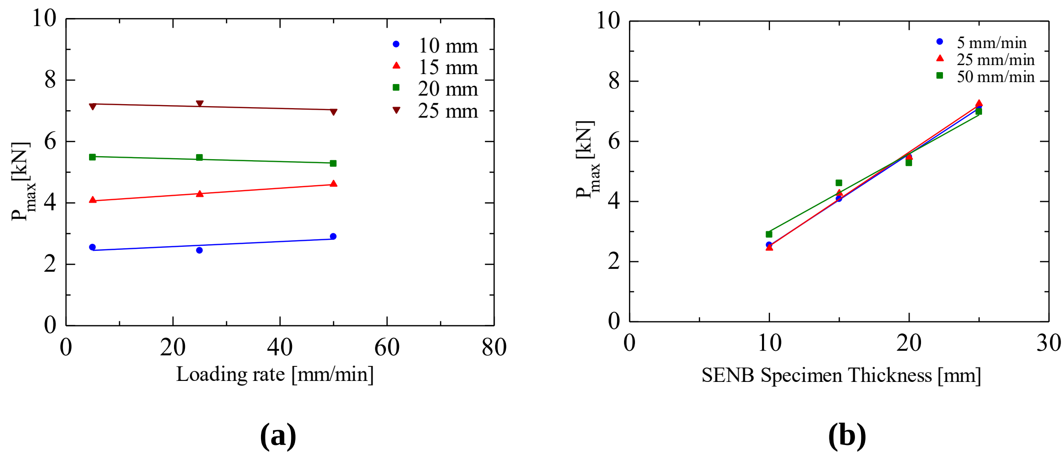
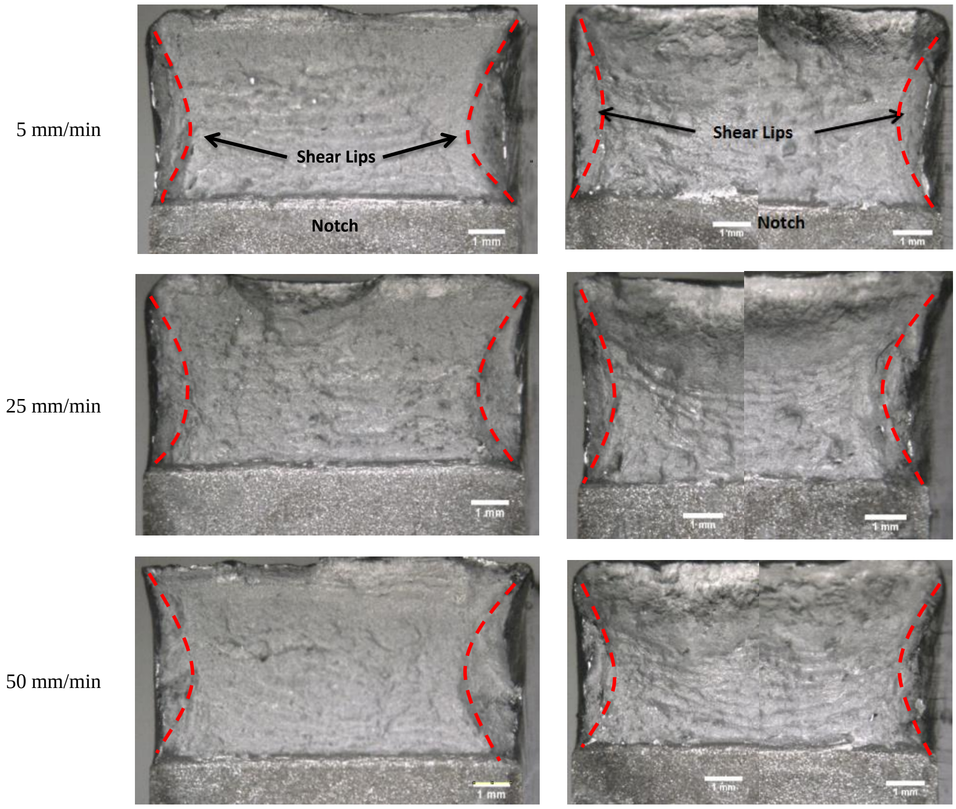


Figure 3: Effect of loading rates and SENB specimen thicknesses on fracture behaviour of Al6061 alloy

Table 2: Fracture properties of Al6061 alloy at different loading rates and SENB thicknesses

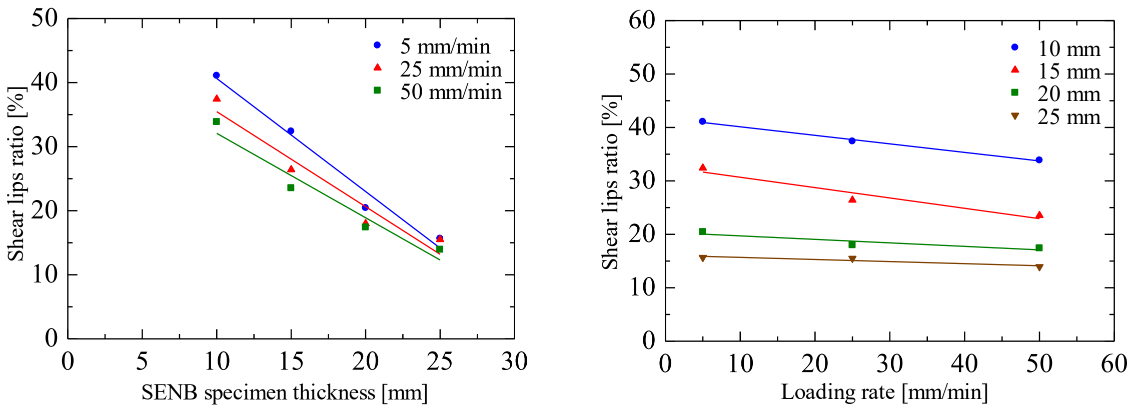
Loading rate	Thickness (mm)	Shear Lips Ratio (%)	P_{max} (kN)
5 mm/min	10	41.09	2.549
	15	32.41	4.083
	20	20.45	5.480
	25	15.66	7.159
25 mm/min	10	37.43	2.447
	15	26.41	4.273
	20	17.99	5.471
	25	15.50	7.256
50 mm/min	10	33.87	2.898
	15	23.54	4.610
	20	17.42	5.276
	25	13.94	6.983

The left and right sides of shear lips formation on fracture surface of Al6061 alloy are shown in Figure 4. Each side shows that the shear lips area is similar to the half of ellipse shape. Shear lips ratio is obtained based on the average shear lips area of both sides by its specimen thickness. Shear lips ratio is measured to identify the behavior of alloy either behaving in brittle or ductile behavior for the notched specimen. Shear lips area with less than 10% tends to the brittle fracture [13], and fast crack propagation occurs on material [14]. In Table 2, it is found that the shear lips ratio of all SENB specimen thicknesses are higher than 10%, where it indicates that the alloy behaves in ductile fracture, and slow crack growth occurs to the alloy. In a previous study, [20] report that as the shear lips' area increases, it will boost the plastic work parabolically. In the current study, the results obtained prove that most of SENB specimen thicknesses behave in ductile fracture and, not brittle fracture behavior. However, Figure 5(a) describes that the SENB specimen thickness is increases, while the shear lips ratio is decreasing at all range of loading rates. It shows that shear lips ratio depends on SENB specimen thicknesses. However, the shear lips ratio decreases when loading rates increase for SENB specimen thicknesses of 10 and 15 mm as shown in Figure 5(b). However, shear lips ratio is seen to slightly decrease at the increasing loading rates for SENB specimen thicknesses of 20 and 25 mm. Hence, Al6061 alloy has the tendency towards low plasticity behavior when high loading rates are given to alloy, since it is the less time to undergo plastic deformation for material [16]. However, shear lips area of Al6061 alloy is significantly present in plane stress condition which is categorized in ductile manner at all range of loading rates and SENB specimen thicknesses. It means that Al6061 alloy experiences slow crack extension to fail in the present study.



(a) **(b)**

Figure 4: Effect of loading rates on shear lips area (left and right sides) for Al6061 alloy at SENB specimen thicknesses of (a) 10 mm and (b) 25 mm



(a) **(b)**

Figure 5: Effect of loading rates and SENB specimen thicknesses on shear lips ratio of Al6061 alloy

Conclusion

In conclusion, shear lips ratio of Al6061 alloy significantly depends on SENB specimen thicknesses and loading rates. P_{max} of alloy increases at increasing SENB specimen thicknesses, while P_{max} of alloy almost increases at increasing loading rates of SENB specimen thicknesses of 10 and 15 mm. As the SENB specimen thickness increases, the shear lips ratio becomes lower, but still more than 10% of shear lips ratio. Thus, shear lips ratio indicates that Al6061 alloy fails in ductile behavior by the occurrence of large plastic deformation at notch tips even at increasing loading rates and SENB specimen thicknesses. It shows that the alloy fractures under plane stress condition, where slow crack extension happens towards alloy.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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