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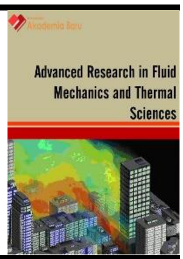

Effects of Temperatures and Strain Rate on the Mechanical Behaviour of Commercial Aluminium Alloy AA6061

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ABSTRACT

Aluminium alloy are widely used in the design of structural parts in the automotive and aircraft components due to their good mechanical properties. Numerous applications are related to high strain rate deformation and adiabatic heating require further intention. The strain-rate effects and temperature effects have not been well studied experimentally. Therefore, the effect of temperature and strain rate on the mechanical behaviour of aluminium alloys (AA6061) is critically examined in this work. The specimen was tested in the longitudinal direction from quasi-static to high strain rates (0.08, 0.8 and 8 mm/min) while temperature was varied from room to elevated temperatures (24, 140, 200 and 250ºC). From the results, it show that the flow stress increase with increasing the strain rate and decrease when increasing temperature. Which means, increasing strain rate and temperature affect the saturation stress of the materials.

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1. Introduction

For many decades, Aluminium Alloys have been used as structural components due to excellent mechanical properties [1]. Aluminium Alloy 6061 are widely used in diverse applications ranging from packaging to the aeronautic industry and in recent years, have attracted significant attention of designer and user of metal structure [2-5]. To characterize mechanical properties of material in reality, it involved with many factors in nature. There are various common modes might be applied such as tensile, compressive, and shear. As can be seen in most materials, the stress and strain rate

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is increase rapidly when load are applied [6] and it is importance for mechanical designer in material selection. The tensile mechanical properties of PMMA at various strain rate has been investigated by Wu *et al.*, [7] and found that with increasing the strain rate, the yield strength of the materials increase [7]. Besides that, design process can be complicated with other factors such temperature and time factors. Temperature is the main weakness of the yield strength of metals and alloys due to their sensitivity. From Lin et al., [2] research, he concluded that yield strength is dominated by temperature dependent modulus and melting point [8]. This brought a high demand to understand the yield behaviour of metals at different temperatures. Much researchers has been studies phenomenological and physical based models in characterizing yield behaviour [9] and the strain-rate effects and temperature effects have not been well studied experimentally. Therefore, this work is conducted to examine the mechanical behaviour of Aluminium alloys (AA6061) at different strain rate and temperature. The results from these work thus give perception of mechanical behaviour on effect of temperature and strain rate [10,11]. This lead a good knowledge of the behaviour of aluminium alloy include yield and ultimate tensile strength.

2. Methodology

2.1. Material

The material studied is a sheet of commercial Aluminium Alloy 6061 with dimension 10mm×600mm×300mm supplied by HENAN JIANHI Construction Machinery Co. Ltd. The chemical composition is listed in Table 1. The XRD pattern of sheet Aluminium Alloy 6061 as shown in Figure 1.

Table 1
Chemical composition of the Aluminium Alloy 6061

Element	Weight (%)	Atomic (%)
C	26.16	38.66
O	27.91	30.95
Mg	2.58	1.88
Al	43.35	28.51
Total	100	

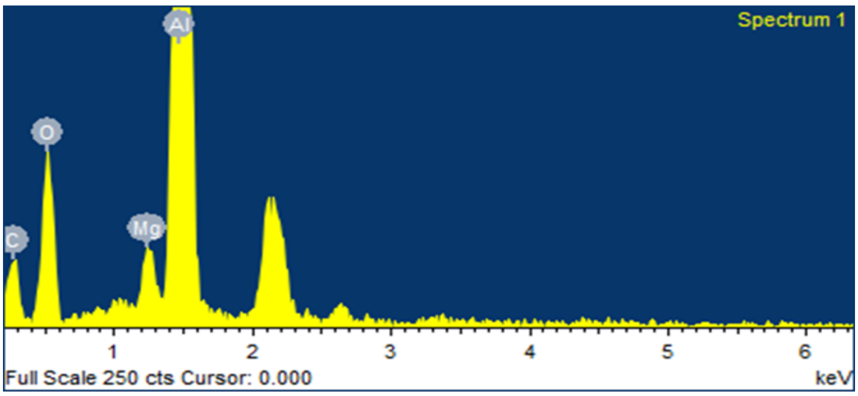

Fig. 1. XRD Pattern of sheet AA6061

2.2. Specimen Preparation

Metal plate of the AA6061 has been check using XRD test to ensure the material composition. According to ASTM E8 (Figure 2) and ASTM E21 (Figure 3) standard, the thickness is remove from 10mm to 4mm using milling machine and cut into dog-bone shape using CNC Machine. The total specimen prepared is 72 pieces and has been tested for 3 times each test to check the accuracy of the result.

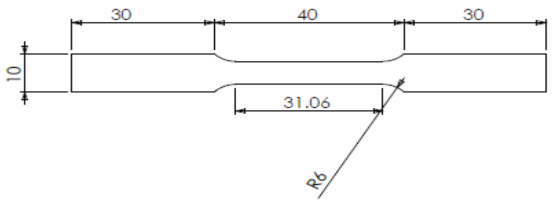

Fig. 2. Configuration ASTM E8

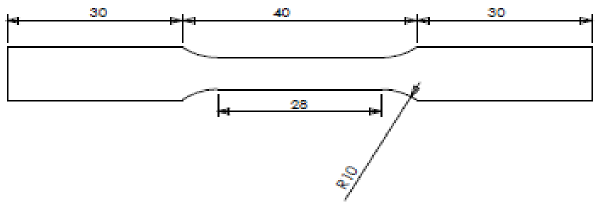

Fig. 3. Configuration ASTM E21

2.3. Uniaxial Tensile Test

Uniaxial tension tests were carried out ASTM E8 (room temperature) and ASTM E21 (elevated temperature) specimens using Uniaxial Tensile Test ZWICK Roell Z030. The specimen was tested in the as-received conditions, with no heat treatment being performed from quasi-static to high strain rate (0.08, 0.8 and 8 mm/min) and temperature was varied from room temperature to elevated temperature (24, 140, 200 and 250ºC). Extensometer is used to measure the deform length in order to obtain a more accurate result. Each tensile test require 3 repetition per test and each test used a new specimen to ensure the accuracy of the result. Tests were performed start with ambient temperature to elevated temperature. Thermocouple was used to measure the temperature on the surface of the specimen. The test matrix of the experiment is shown in Table 2.

Table 2
Test Matrix of Uniaxial Tensile Test

Temperature (°C)	Cross Head Speed (mm/min)
24°C	0.08
ASTM E8	0.8
	8
140°C	0.08
ASTM E21	0.8
	8
200°C	0.08
ASTM E21	0.8
	8
250°C	0.08
ASTM E21	0.8
	8

3. Results

Figure 4 (a-d) shows the stress-strain curve of AA6061 at different strain rates and temperature undergoing uniaxial tensile test. From the result, some of the most important features can be determined.

The mechanical properties (elastic modulus, yield strength and ultimate strength) can be define and was clearly exhibited in stress strain curve. As can be seen the result in the below figures, the difference in the flow stress are clearly observed referring to the effects of different strain rate and temperature.

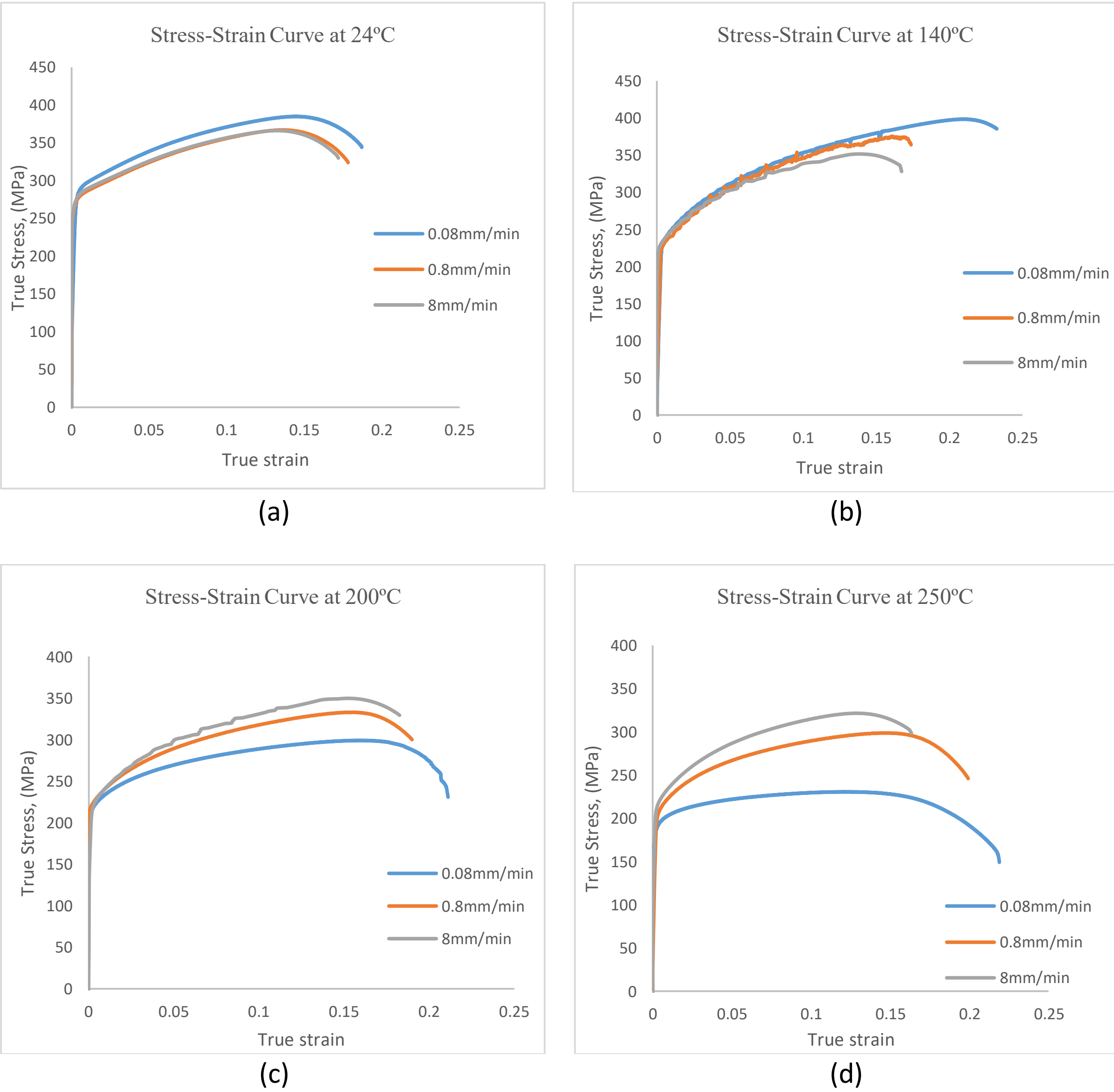

Fig. 4. (a-d) AA6061 Stress-Strain curves at different strain rates and temperature

As shown in Figure 4(a-d), the whole flow process (stress-strain curve) are represent into four stages. In the first stage (hardening stage), the deformation of the flow stress become larger. The flow stress increase rapidly to the peak. To enter into the plastic deformations, the aluminium alloy starts to yield. At the higher strain rate or lower temperature, there was no obvious transition for tension condition.

The peak stress declined constantly when the strain rate decrease or temperature increase. The second stage (softening stage) has been characterized by the uniform and stable flow softening. When the plastic deformation began, the flow stress rapidly become lower until necking. The sample was uniform in the tension part and demonstrating constant deformation. In the third stage (necking stage), the stress-strain curves was deformed and the flow stress drop immediately because of necking. In the last stage, the sample finally fractured.

Tables 3 shows the mechanical properties of the AA6061 at ambient temperature to elevated temperatures for uniaxial tensile tests at the intermediate and high strain rates. The results of Young's Modulus E, Yield Strength σ_Y, and Ultimate Tensile Strength σ_{UTS}, are changing in various strain rate and temperature.

Table 3
Mechanical properties of tested Aluminium Alloy 6061 specimen at different temperature and different strain rate

Temperature (°C)	Strain Rate, $\dot{\varepsilon}$	Young Modulus, (GPa)	Yield Strength, (MPa)	Ultimate Tensile Stress, (MPa)
24	2.53×10^{-3}/s	75	272	384
	2.53×10^{-2}/s	89	270	366
	2.53×10^{-1}/s	93	271	365
140	2.53×10^{-3}/s	78	233	398
	2.53×10^{-2}/s	80	228	374
	2.53×10^{-1}/s	99	228	320
200	2.53×10^{-3}/s	96	218	299
	2.53×10^{-2}/s	86	231	332
	2.53×10^{-1}/s	99	222	349
250	2.53×10^{-3}/s	50	192	299
	2.53×10^{-2}/s	85	220	333
	2.53×10^{-1}/s	318	208	349

The yield strength and ultimate tensile strength can be observed increase during increasing strain rate and decreasing temperature. This condition will cause hardening effect on the specimen or known as strain rate hardening and indicate the increasing of flow stress [12-15]. At high strain rates, the specimen deformation becomes a higher softening rates and shorter stage of hardening. The range of strain leading to hardening for the deformation at $\dot{\varepsilon}$ =$2.53 \times 10^{-1}s^{-1}$, $2.53 \times 10^{-2}s^{-1}$ and $2.53 \times 10^{-3}s^{-1}$ are 0.12, 0.13 and 0.15, respectively. At different strain rates, the specimen deformation produce an identical slope of the true stress-strain curves within softening. However, the flow behaviour for the temperature effect is opposite to the strain rate effect. Where the temperature effect increase, the strain rate effect decrease and vice versa. The total elongation will decreased with increasing the temperature.

4. Conclusions

The mechanical behaviour of Aluminium Alloy AA6061 over the range temperature and strain rate has been examined in this study. The material was characterized at varied temperature 24ºC, 140ºC, 200ºC and 250ºC and varying strain rate 0.08 mm/min, 0.8 mm/min and 8 mm/min. The stress–strain curve was described from increasing and decreasing a peak in flow stress. The peak stress is highly dependent on the temperature and strain rate. The peak stress will reduce continuously with increasing or decreasing temperature and strain rate. Based on the result from uniaxial tensile test, it can be concluded that effects of the deformation strain rate and temperature on the flow behaviour were clarified. When the strain rate increase or when temperature is decreased, the yield strength and ultimate tensile strength is observed increase. The same effect on the mechanical property can be observed when increasing (or decreasing) temperature and decreasing (or increasing) strain rate.

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References
[1] Khadyko, Mikhail, Calin Daniel Marioara, Stephane Dumoulin, Tore Børvik, and Odd Sture Hopperstad. "Effects of heat-treatment on the plastic anisotropy of extruded aluminium alloy AA6063." *Materials Science and Engineering: A* 708 (2017): 208-221.

[2] Lin, Peng, Yonggang Hao, Baoyou Zhang, Shuzhi Zhang, and Jun Shen. "Strain rate sensitivity of Ti-22Al-25Nb (at%) alloy during high temperature deformation." *Materials Science and Engineering: A* 710 (2018): 336-342.

[3] Meyers, Marc A., A. Mishra, and David J. Benson. "Mechanical properties of nanocrystalline materials." *Progress in materials science* 51, no. 4 (2006): 427-556.

[4] Li, James CM. *Mechanical properties of nanocrystalline materials*. Pan Stanford, 2011.

[5] Izadi, Ehsan, Saul Opie, Harn Lim, Pedro Peralta, and Jagannathan Rajagopalan. "Effect of plastic anisotropy on the deformation behavior of bicrystalline aluminum films–Experiments and modeling." *Acta Materialia* 142 (2018): 58-70.

[6] R. L. Sierakowski, Strain Rate Behaviour of Metals and Composites, Civil and Environmental Engineering and Geodetic Science, Ohio State University, Columbus, Ohio USA.

[7] Wu, Hengyi, Gang Ma, and Yuanming Xia. "Experimental study of tensile properties of PMMA at intermediate strain rate." *Materials Letters* 58, no. 29 (2004): 3681-3685.

[8] Zhang, Xianhe, Weiguo Li, Jianzuo Ma, Peiji Geng, Jiaxing Shao, and Xiaozhi Wu. "A novel temperature dependent yield strength model for metals considering precipitation strengthening and strain rate." *Computational Materials Science* 129 (2017): 147-155.

[9] Abedini, Armin, Clifford Butcher, Michael J. Nemcko, Srihari Kurukuri, and Michael J. Worswick. "Constitutive characterization of a rare-earth magnesium alloy sheet (ZEK100-O) in shear loading: Studies of anisotropy and rate sensitivity." *International Journal of Mechanical Sciences* 128 (2017): 54-69.

[10] Cao, Yu, Johan Ahlström, and Birger Karlsson. "The influence of temperatures and strain rates on the mechanical behavior of dual phase steel in different conditions." *Journal of Materials Research and Technology* 4, no. 1 (2015): 68-74.

[11] Schulthess, Jason, Randy Lloyd, Barry Rabin, Michael Heighes, Tammy Trowbridge, and Emmanuel Perez. "Elevated temperature tensile tests on DU–10Mo rolled foils." *Journal of Nuclear Materials* 510 (2018): 282-296.

[11] Barlat, F., M. V. Glazov, J. C. Brem, and D. J. Lege. "A simple model for dislocation behavior, strain and strain rate hardening evolution in deforming aluminum alloys." *International journal of Plasticity* 18, no. 7 (2002): 919-939.

[12] Zhang, Weiliang, Xinfeng Chen, Bochen Zhuo, Peijie Li, and Liangju He. "Effect of strain rate and temperature on dynamic mechanical behavior and microstructure evolution of ultra-high strength aluminum alloy." *Materials Science and Engineering: A* (2018).

[13] Yaghoobi, Mohammadreza, and George Z. Voyiadjis. "The effects of temperature and strain rate in fcc and bcc metals during extreme deformation rates." *Acta Materialia* 151 (2018): 1-10.

[14] Schulthess, Jason, Randy Lloyd, Barry Rabin, Michael Heighes, Tammy Trowbridge, and Emmanuel Perez. "Elevated temperature tensile tests on DU–10Mo rolled foils." *Journal of Nuclear Materials* 510 (2018): 282-296.

[15] Suttner, Sebastian, and Marion Merklein. "A new approach for the determination of the linear elastic modulus from uniaxial tensile tests of sheet metals." *Journal of Materials Processing Technology* 241 (2017): 64-72.