VOL. 19, NO. 8, APRIL 2024 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

IMPACT ENERGY IN HEAT-TREATED ALUMINIUM ALLOY 6061 AND 7075

H. Zainuddin[1] and M.B. Ali[2]
[1]Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
[2]Faculty of Industrial and Manufacturing Technology and Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
E-Mail: basri@ute.edu.my

ABSTRACT

Instrumented Charpy impact is one of the promising methods to assess the impact energy; toughness and resilience of a material. The test consists of the Charpy machine and instrumentation equipment which is the strain gauge and the data acquisition system. Impact energy evaluations are important to understand the material behaviour subjected to sudden impact loading. Aluminium 7075 has good strength strength-to-weight ratio than aluminium 6061 and hence the AL 7075 is usually used in the aerospace industry, whilst the AL 6061 is commonly used in the automotive industry. The objective of the study is to observe and analyse the impact response of the Aluminium 6061 and 7075 at different heat-treated conditions; O-anneal and T6 temper. In addition to the impact energy absorbed value, the impact strain signal is recorded too. Theoretical impact energy is calculated as well based on the information given by the Charpy machine software. Aluminium 7075 exhibits a lower value of impact energy absorbed and a smaller area under the curve compared to Aluminium 6061. The energy absorption capacity for each material grade and heat-treated condition are different from one another. O-anneal aluminium has a lesser energy absorbed value and a smaller area under the curve than the T6 temper aluminium. The outcome reveals that the heat treatment process alters the material microstructure and mechanical properties, whereas in this study the impact energy responses are influenced by these circumstances. Moreover, the chemical composition of the aluminium alloy distinguishes these two grades from one another, thus resulting in different impact responses.

Keywords: charpy impact, energy absorbed, AL 6061, AL 7075.

Manuscript Received 29 February 2024; Revised 14 May 2024; Published 30 June 2024

INTRODUCTION

Over the years, the study on the impact of energy-absorbing material has been extensive to help engineers come up with the best material to be used in their productions, particularly in automotive and aerospace industries where the application of impact-absorbing structure is mostly used. Impact energy absorption ability depends on many factors for example the material thickness [1], the material properties and the impact velocity [2, 3]. Impact loading can be categorised as low, intermediate, high/ballistic and hypervelocity impact [4]. The Charpy impact test has various impact velocities in the range of below 10 m/s determined by the Charpy machine, and this method is recognized as a low-impact loading test. The usage of instrumented Charpy impact test not only provides the energy absorbed, deformation and failure, other information such as force, displacement [5], time and energies [2]. This information is crucial in evaluating the impact resistance and can correlate the response/behaviour with the mechanical properties of the material. Aluminium alloy is the second most popular metallic material after steel because of its good workability, good castability, ease of joining, excellent corrosion resistance and low density which can help in energy saving specifically in transportation applications [6]. In automotive applications, 25 to 30 % of vehicle weight is due to the aluminium parts installed, most are made up of 5000 series and 6000 series aluminium alloy. Meantime, the 7000 series, especially the 7050 and 7075 are extensively used in the aircraft industry as they have the optimum strength-to-weight ratio that fits for security crash components, together with having the most cost-effective per kilogramme saved [7].

A previous study of impact analysis on aircraft engine rotor blade by Sudhir Sastry et al. (2019) on 2024-T4, 6061-T6 and 7075-T6 found that the 7075-T6 was able to withstand the granite stone impact even though it may lead to plastic deformation. The study recommended the 7075-T6 as a suitable material for the rotor blade since it has higher fatigue strength and fracture toughness than the other materials. Yildiz (2022) investigated the correlation of fracture toughness calculated with the impact energy from the Charpy V-notch test, for 6061-T6, 2024-T4 and 7075-T6 aluminium alloy. His results reveal that among the aluminium alloys, 6061-T6 has the greatest impact energy value and highest fracture toughness too. Despite that AL 7075-T6 possesses higher yield strength than the AL 6061-T6, the impact energy and impact strength gained are lower compared to the AL 6061-T6 [10].

In recent years, 7000 series aluminium alloy has had the potential to be fabricated as automotive components that need high strength [11], specifically the aluminium alloy 7075 throughout the hot stamping process during the manufacturing process [12, 13]. Aluminium alloy is composed of various alloying elements at different

ARPN Journal of Engineering and Applied Sciences

chemical compositions and processing conditions, which produce distinct material properties and characteristics. This study chose aluminium alloy 6061 (AL 6061) and 7075 (AL 7075) under two different heat treatment conditions; O-anneal and T6 temper conditions. Most automotive components are made up of 6000 series aluminium rather than the 7000 series which is commonly used in the aerospace industry. The AL 6061 is typically designed as the automotive components such as the crash box, suspension components and impact bumper. In addition to the automotive component, the AL 7075 is frequently used to fabricate aircraft components like the landing gear, fuselages and wing structure. The objective of the study is to observe and analyse the impact response of the AL 6061 and AL 7075 at O-anneal and T6 temper conditions. In order to fulfil the objective, the Charpy impact test is conducted at room temperature to determine the impact response of the material, referring to the impact energy absorbed value and impact strain signal recorded. The expected result of this study is that O-anneal condition and T6 temper material show different impact energy absorbed ever since they undergo different processes of heat treated process. Moreover, the AL 7075 and AL 6061 shall behave dissimilarly since they are made from different portions of chemical composition/ alloying elements.

MATERIALS AND METHODS

Material and Specimen

The material selected for this study is the aluminium alloy 6061 and aluminium alloy 7075, at heat-treated O-anneal and T6 conditions. These alloys were chosen because of their distinct composition and mechanical properties, which play a major role in determining their performance and suitability in various applications. Table-1 presents the chemical composition of the alloys, showing the concentration of the alloying elements such as zinc, silicon, magnesium and others. The concentration of the alloying element and the microstructure controls the mechanical, physical and chemical properties of the aluminium [14]. The major alloying element of AL 6061 is magnesium and silicon, whereas AL 7075 is zinc. Generally, the 7000 series aluminium alloy possesses high strength with lower extrudability which contrasts with the 6000 series aluminium alloy that has moderate strength and good extrudability [15-17].

Table-1. Chemical composition of the material (wt %) [18].

Element	Al	Mg	Si	Cu	Mn	Fe	Cr	Zn	Ti
AL 6061	Bal.	0.8-1.2	0.4-0.8	0.15-0.40	0.15	0.7	0.04-0.35	0.25	0.15
AL 7075	Bal.	2.1-2.9	0.40	1.2-2.0	0.30	0.5	0.18-0.28	5.1-6.1	0.20

Before conducting the Charpy impact, a tensile test is made to obtain the mechanical properties of the material. The tensile experiment is based on the ASTM E8 / E8M-16, Standard Test Methods for Tension Testing of Metallic Materials, ASTM International. The tensile specimen selected is plate type, with a specimen thickness of 5mm. Subsequently, for the Charpy impact test, the experiment tested the V-notch type specimen as Figure-1. The specimen fabricated complies with the standard in ASTM E23-18, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials.

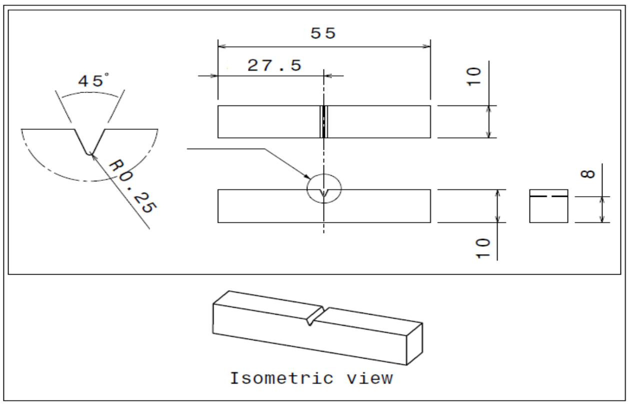


Figure-1. Standard Charpy V-notch impact specimen with dimension.

Experimental Setup

The equipment and instrument for the experiment comprise the Charpy machine, connected to a computer equipped with WinImpact software. The strain gauges are used for strain impact measurement, a data acquisition system, and a laptop for impact signal display. The experimental setup is shown in Figure-2.

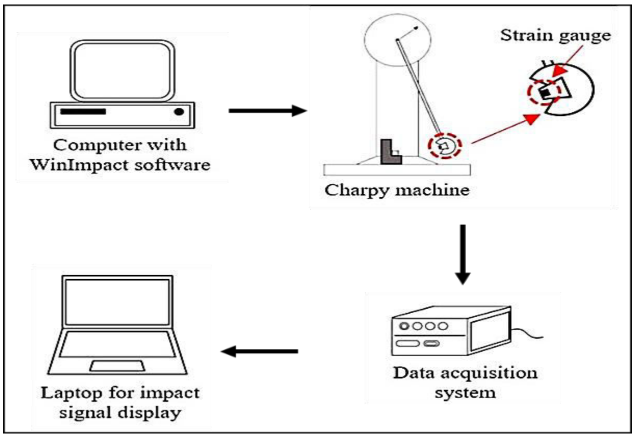


Figure-2. Instrumented Charpy impact arrangement.

The WinImpact software provides valuable information for the Charpy impact test; sufficient for the calculation of theoretical impact energy values. This

VOL. 19, NO. 8, APRIL 2024 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

includes the pendulum weight, pendulum length to the centre, angle before impact and angle after impact. The illustration in Figure-2 shows that the strain gauges are glued onto the impactor of the pendulum swing, while at the same time connected to the data acquisition system (eDAQ). The eDAQ collects processes and presents the data in the form of an impact strain signal and displays it through the laptop.

RESULTS AND DISCUSSIONS

The tensile tests were carried out to gather the mechanical properties of the material for instance the tensile strength, yield strength and ductility. These are essential characteristics to understand the material behaviour under impact response as well. Figure-3 shows the stress-strain curve for the aluminium alloy. The stress-strain curves provide the mechanical properties where the AL 7075-T6 and AL 7075-O have tensile strength values of 575 MPa and 565 MPa respectively. Meanwhile, the tensile strength for AL 6061-T6 and AL 6061-O are 324 MPa and 322 MPa. These properties reflect the difference in the alloy composition and microstructure configurations of each alloy series.

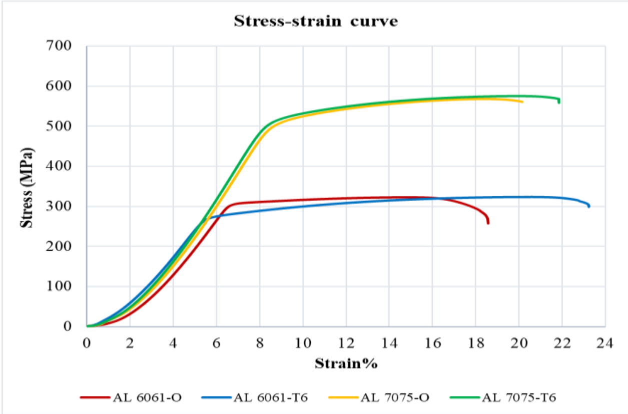
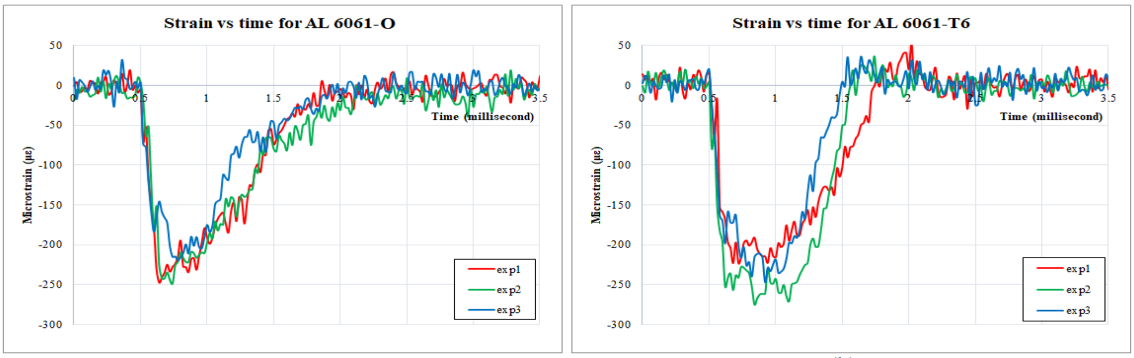


Figure-3. Stress-strain curve for each material.

The curve illustrates that the Al 6061 is more ductile than the AL 7075. The aluminium alloy 6000 series are known as the Al-Mg-Si alloy, whilst the 7000 series aluminium alloy known as Al-Zn-Mg has more contains of Zinc element that leads to an insignificant increase in strength [6]. Theoretically, the Al-Zn-Mg alloy has greater strength relative to the Al-Mg-Si alloy [21].

The result of the instrumented Charpy impact for every material is shown in Figure-4 and Figure-5. These graphs are referred to as the impact strain signal and are presented in strain versus time. The strain unit in microstrain (με) emphasizes the minuscule deformation experienced by the material and the time recorded is in millisecond (ms), highlights that the impact phenomenon happens in a very short time. Looking at Figure-4, it appears that the (a) and (b) graph have quite similar shapes, which indicates the value of the area under the curve as recorded in Table-2, clarifying the impact behaviour for each material and insight into a comprehensive understanding of the material behaviour. Dissimilar to Figure-5, the graph in (a) and (b) shows a slimmer or more narrow shape compared to the graph of the Aluminium 6061. The slimmer the graph shape, the smaller the area under the curve. Conversely, a broader graph shape corresponds to a larger area under the curve. This portrays that the AL 7075 possess a lower ability to absorb impact energy compared to the AL 6061.

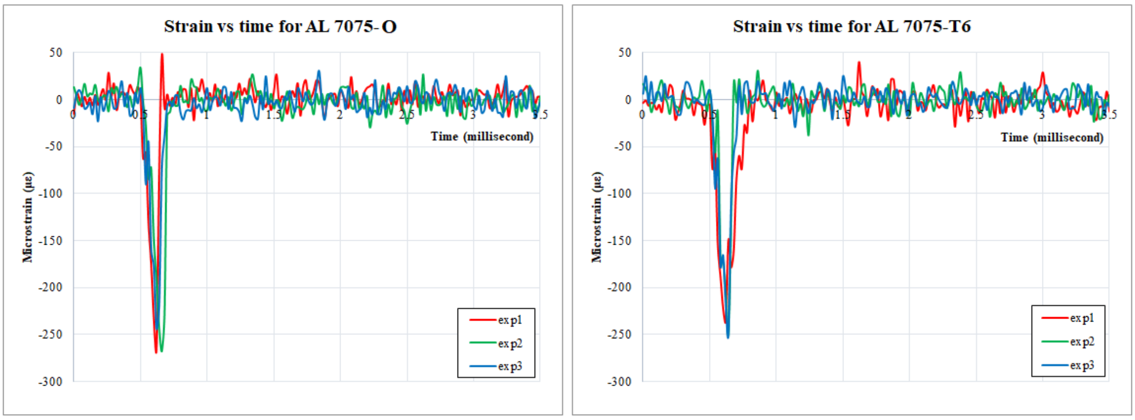


(a) (b)

Figure-4. Graph of strain-time for Aluminium 6061 at O-anneal and T6 condition.

VOL. 19, NO. 8, APRIL 2024 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com



(a) (b)

Figure-5. Graph of strain-time for Aluminium 7075 at O-anneal and T6 condition.

The energy absorbed value from the experiment is taken from the displayed scale of the Charpy machine. The experimental energy absorbed, calculated theoretical energy absorbed and area under the curve are recorded in Table-2. The result reveals that the AL 6061 experienced higher impact energy absorbed and a greater area under the curve than the AL 7075, suggesting that AL 6061 is superior in resistance to fracture and deformation. The increase in Magnesium content of 6000 series aluminium alloy contributes to the increase in strength of notch impact toughness [6]. Identically, the impact energy absorbed studied by Muhammad Said *et al*., (2018) found that the area under the curve depends on the impact energy absorbed; the increase the energy absorbed value, the larger the area under the curve. Furthermore, a previous study of fracture toughness on aluminium alloy reported that the AL 7075-T6 exhibits lesser impact energy than the AL 6061-T6 [9, 10]. AL 7075 is high in strength but is less ductile than the AL 6061 as a result of different alloying elements and its microstructure [23]. According to the mechanical properties of the AL 6061 and AL 7075, impact resistance is not solely determined by the tensile strength and yield strength, yet the ductility and the percentage elongation are important too since these allow more deformation before fracture.

Table-2. The data of energy absorbed and area under the curve for every material.

Material	Sample	Energy Absorbed (J)	Theoretical Energy Absorbed (J)	The area under Curve (με.ms)
AL 6061-O	1	33.13	27.81	183.21
	2	33.13	29.22	191.90
	3	31.25	28.51	187.71
	Average	32.50	28.51	187.60
AL 6061-T6	1	38.75	35.03	239.98
	2	35.00	32.27	212.92
	3	34.28	30.82	299.81
	Average	36.01	32.71	250.90
AL 7075-O	1	5.63	3.77	22.69
	2	6.25	2.27	31.01
	3	6.25	3.77	23.55
	Average	6.04	3.27	25.75
AL 7075-T6	1	8.75	7.60	36.71
	2	6.25	4.67	26.27
	3	6.25	5.58	27.76
	Average	7.08	5.95	30.25

From the data in Table-2, it is highlighted that for both AL 6061 and AL 7075, the material under the T6 temper condition has a better capability of absorbing the impact energy compared to the O-anneal material. Comparing the experimental energy absorbed value, AL 6061-O and AL 6061-T6 have a percentage difference of 9.74%, meanwhile calculated percentage difference for the AL 7075-O and AL 7075-T6 is 14.68%. In consequence, the area under the curve of the O-anneal material is smaller than the T6 heat-treated material. Generally, the heat treatment process involves the material heating, holding at the temperature and cooling process. However, the differences are at the heating temperature and cooling rate, where these stages determine the material properties [24]. Each stage plays an important role in determining the resulting material properties. Referring to the heat-treated process, the O-anneal condition (known as the annealing process), the material is subjected to elevated temperatures to relieve internal stresses and promote recrystallization, making the material softer while T6 tempering enhances its hardness, and therefore the heat-treatment process alters the material microstructure as well as the mechanical properties [16, 25]. Therefore, the softer nature of the O-annealed material allows for greater deformation and energy absorption before fracture, whereas the harder T6-tempered material exhibits improved resistance to deformation and fracture, resulting in a larger area under the curve in the impact test.

The theoretical energy absorbed value follows the pattern of the experimental energy absorbed value; despite that the value for the calculated energy absorbed is slightly lower than the experimental results. The percentage difference between the experimental energy absorbed and theoretical energy absorbed is 12.27% and 9.17% for AL 6061-O and AL 6061-T6 respectively. On the other hand, the percentage difference between the experimental and theoretical values of the energy absorbed for AL 7075-O and AL 7075-T6 is 45.85% and 16.00%. The difference between the theoretical and experimental values is because of the energy loss throughout the impact test, caused by friction and air drag (ASTM E23-18). Despite these discrepancies, impact testing remains a valuable tool for evaluating material performance under dynamic loading conditions.

CONCLUSIONS

This study has measured and assessed the impact response of aluminium alloys 6061 and 7075 at different heat-treated conditions; O-anneal and T6. The impact energy absorbed recorded shows that the AL 6061-T6 has the highest value of impact energy absorbed compared to the other material. Different alloying elements influence the behaviour of the material under impact test. AL 6061 has moderate strength with high ductility and better percentage elongation, while the AL 7075 possesses high strength with less ductility and lower percentage elongation. These are the reasons the AL 6061 is a better energy-absorbing material than the AL 7075. Furthermore, it was observed that for both material grades, 6061 and 7075, the O-anneal material has a lower impact energy absorbed and a smaller value under the curve than the T6 temper material. The area under the curve is dependent on the impact energy absorbed value, as the energy absorbed increases, the area under the curve gets larger. In fact, the microstructure also influences the impact response. Heat-treated conditions have modified the microstructure and mechanical properties of the material. It is noted the impact response not only depends on the tensile strength and yield strength, the ductility and percentage elongation are also the main factors in determining the impact behaviour. For future studies, it is recommended for further research, specifically on the microscopic level to gain a better understanding of the grain structure of the same material at different heat treatment conditions.

ACKNOWLEDGEMENT

The authors wish to express their gratitude and thanks to Universiti Teknikal Malaysia Melaka (UTeM) for funding this research under the Fundamental Research Grant (FRGS/1/2020/TK0/UTEM/02/36). The work has been partially presented at The 9th International Conference and Exhibition on Sustainable Energy and Advanced Material (ICE-SEAM 2023).

REFERENCES

[1] Rassiah K, Megat Ahmad MM, Ali A. 2015. Ballistic impact performance of the layered and laminated composites: A reviews. Pertanika J Sci. Technol. 23: 177-185.

[2] Ali MB, Zakaria KA, Abdullah S, Alkhari MR. 2015. Correlation of Impact Energy from Instrumented Charpy Impact. Appl Mech. Mater 815: 221-226. https://doi.org/10.4028/www.scientific.net/AMM.815.221

[3] Abdullah NAZ, Sani MSM, Salwani MS, Husain NA. 2020. A Review on Crashworthiness Studies of Crash Box Structure. Thin-Walled Struct. 153: https://doi.org/10.1016/j.tws.2020.106795

[4] Azrie S. SN, H. S. MT, C. F. 2017. Impact Characterisation of Glass Fibre-Reinforced Polymer (GFRP) Type C-600 and E-800 Using a Single Stage Gas Gun (SSGG). Pertanika J Sci Technol. 25: 303-316.

[5] Alar Ž, Mandić D. 2018. Comparasion of Impact and Tensile Properties of High-Strength Steel. Metals (Basel). 8: 1-7. https://doi.org/10.3390/met8070511

[6] Kammer C. 2018. Aluminum and Aluminum Alloys. In: Springer Handbook of Materials Data. Springer Nature Switzerland AG. pp. 157-193.

[7] Ng C-H, Yahaya SN, Majid AA. 2017. Reviews on aluminum alloy series and its applications. Acad J Sci. Res. 5: 708-716. https://doi.org/10.15413/ajsr.2017.0724

[8] Sudhir Sastry YB, Kiros BG, Hailu F, Budarapu PR. 2019. Impact analysis of compressor rotor blades of an aircraft engine. Front Struct Civ Eng. 13: 505-514. https://doi.org/10.1007/s11709-018-0493-3

[9] Yildiz RA. 2022. Evaluation of fracture toughness and Charpy V-notch test correlations for selected Al alloys. Eur. Mech. Sci. 6: 1-8. https://doi.org/10.26701/ems.913428

[10] Sunil Kumar S, Londe N V., Dilip Kumar K, Ibrahim Kittur M. 2021. Estimation of fracture toughness (KIC) using Charpy impact test for Al6061T6 and Al7075T6 alloys subjected to corrosion. Mater Today Proc. 46: 2414-2420. https://doi.org/10.1016/j.matpr.2021.01.298

[11] Wu C, Yuan Y, Kamat R. 2020. A New Approach to Implement High Strength 7075 Aluminum for Automotive Application. MATEC Web Conf. 326: 03004. https://doi.org/10.1051/matecconf/202032603004

[12] Harrison NR, Luckey SG. 2014. Hot Stamping of a B-Pillar Outer from High Strength Aluminum Sheet AA7075. SAE Int J Mater Manuf. 7: 567-573. https://doi.org/10.4271/2014-01-0981

[13] Tisza M, Czinege I. 2018. Comparative study of the application of steels and aluminium in lightweight production of automotive parts. Int. J Light Mater Manuf. 1: 229-238. https://doi.org/10.1016/j.ijlmm.2018.09.001

[14] Davis JR. 2001. Aluminum and Aluminum Alloys. In: Alloying: Understanding the Basics. pp. 351-416.

[15] Poznak A, Freiberg D, Sanders P. 2018. Automotive Wrought Aluminium Alloys. Elsevier Ltd.

[16] Starke EA, Rashed HMMA. 2017. Alloys: Aluminum. In: Reference Module in Materials Science and Materials Engineering.

[17] Mallick PK. 2012. Advanced materials for automotive applications: an overview. Adv. Mater Automot Eng. 5-27. https://doi.org/10.1533/9780857095466.5

[18] Zakaria KA, Idris MIF, Dharmalingam S, *et al*. 2018. Fatigue Strain Signal Characteristic and Damage of Automobile Suspension System. ARPN J Eng. Appl. Sci. 13: 221-225.

[19] ASTM E8 / E8M-16, Standard Test Methods for Tension Testing of Metallic Materials, ASTM International.

[20] ASTM E23-18, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials, ASTM International.

[21] Benedyk JC. 2010. Aluminum Alloys for Lightweight Automotive Structures. In: Materials, Design and Manufacturing for Lightweight Vehicles. Woodhead Publishing Limited. pp. 79-113.

[22] Muhammad Said N, Ali MB, Zakaria KA. 2018. Correlation of absorb energy with PSD energy and area under strain-time graph. J Adv Res Fluid Mech Therm Sci. 49: 126-137.

[23] Zakaria KA, Abdullah S, Ghazali MJ. 2013. Comparative study of fatigue life behaviour of AA6061 and AA7075 alloys under spectrum loadings. Mater Des. 49: 48-57. https://doi.org/10.1016/j.matdes.2013.01.020

[24] Callister WDJ, Rethwisch DG. 2018. Materials Science and Engineering: An Introduction, 10th Edition. Wiley.

[25] Shanmughasundaram P, Dahle AK. 2018. Heat Treatment of Aluminum Alloys. In: Reference Module in Materials Science and Materials Engineering. Elsevier Inc. pp. 1-8.