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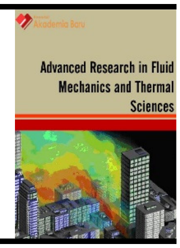

Correlation of Absorb Energy with PSD Energy and Area under Strain-Time Graph

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ABSTRACT

This paper reviews the relationship of energy absorption with power spectrum density (PSD) energy and area under strain-time graph at different parameters (material, impact speed, thickness). In automotive industry, lightweight material with high toughness and strength for wheel production is required in order to minimize fuel consumption. Impact test often performed to determine impact energy and toughness of material by calculate amount of energy absorb. However, most of material toughness measurement is not accurate and it is calculated as an estimation value. This scenario brings an idea to correlate the absorbed energy with PSD energy and area under strain-time graph from Charpy impact test. Absorbed energy and impact strain signal acquired by installing strain gauge to striker hammer that connected to data acquisition system (SOMAT eDAQ). Obtained strain signal is then analysed by plotted strain-time and PSD graphs. Results indicate a great correlation observed between absorbed energy with PSD energy and area under strain-time graph. As thickness of material increased, absorbed energy, PSD energy and area under strain-time graph increased were increased. In terms of speed, the amount of absorbed energy decreased as the speed of impact increased.

Keywords:
Impact test, Absorb energy, PSD energy, Impact strain

1. Introduction

Wheel is an important part in vehicle to enables an efficient movement. Nowadays, most of wheel is made from aluminium or magnesium alloys. Alloy materials are widely used as wheel because of ductile, lightweight and corrosion resistance. The development on vehicle industry has strongly affected the material selection, design and manufacturing process of wheels [1].

Rotating bending test, radial fatigue test and impact test are obligatory test in design and manufacturing of wheel before production process is made and the wheel has to meets safety requirements. Maximum impact force and maximum energy absorption are two important factors that need to be considered in safety evaluation [2,3]. According to Muhammad Nasiruddin *et al.*, [4] the energy absorption capability is very important in enhance the passengers' safety as vehicles are

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used broadly. Measurement of absorbed energy becomes a main concern in impact test to determine the material toughness or whether a material is ductile or brittle. A good and high quality of energy absorber should be designed to dissipate the impact energy irreversibly via plastic deformation of metallic structure. Most of the energy absorbers were developed using metallic thin-walled structure since they tends to deform plastically due to elasticplastic behavior [5].

Charpy, Izod and drop impact test are commonly used to measure absorbed energy due to impact force. However, in many years ago Charpy test is often used because of reliability, low cost and easy to conduct. In Charpy impact test, energy absorbed is the amount of energy required to fracture a test specimen. Energy absorption (EA) performance can be determined from integration of a load-displacement curve as shown in Equation 1 [6].

$$\mathrm{EA} = \int_0^{\delta b} P.\,d\delta = \mathrm{P_m}\,(\delta b - \delta l) \quad (1)$$

where P is an instantaneous crushing load, δb is the length of crushing specimen, P_m is the mean crushing load and δl is the initial length of the crushing specimen.

Factors that may influence the results of energy absorption during impact test are impact condition, thickness, rib, material and shape [4]. Numerical study by Graciano *et al.,* [7] claimed that an increasing impact speed leads to a delay in the load-displacement responses, thus the amount of energy absorbed is decreased. Therefore, different impact speed (3.35 m/s and 5.18 m/s) is applied in this study to investigate the effect of speed to material toughness and strain signal responses.

Kruger has compared the toughness of metallic material reads from dial gauge on Charpy machine with the toughness calculated from load-displacement by using signal acquisition architecture obtained through strain gauge that attached on striker contact point [8]. Previous study by Chang and Yang used rosette strain gages that attached on the wheel disc to observe the strain response of the wheel during impact test [9]. The same concept is implemented in this study where strain gauge is installed to striker that connected to data acquisition system to capture the strain signal response during impact occurs. Obtained signals are analysed in strain-time and PSD graphs. Area under graph is determined for correlation purpose with the amount of absorbed energy at different parameters (type of material, thickness of material, speed of impact).

Correlation of impact energy is studied by Ali *et al.,* [10] and the result shows that type of material, thickness of material and impact speed are strongly influence the absorbed energy, PSD peak and strain energy [10]. Ali and co-authors found that higher amount of the absorbed energy yields a higher PSD peak and strain energy. Murali *et al.,* [11] has studied the relationship between the impact energy and compressive strength from drop weight test on fiber reinforced concrete at different volume fraction of fiber. Empirical correlation obtained from regression analysis is accurate and preferable to evaluate the impact energy by using compressive strength of fiber reinforced concrete.

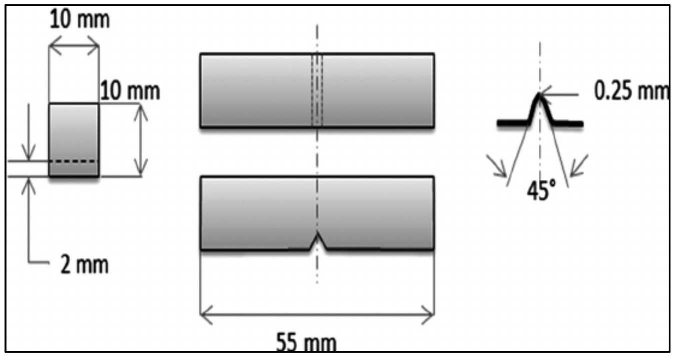
2. Methodology

2.1 Material and Specimen

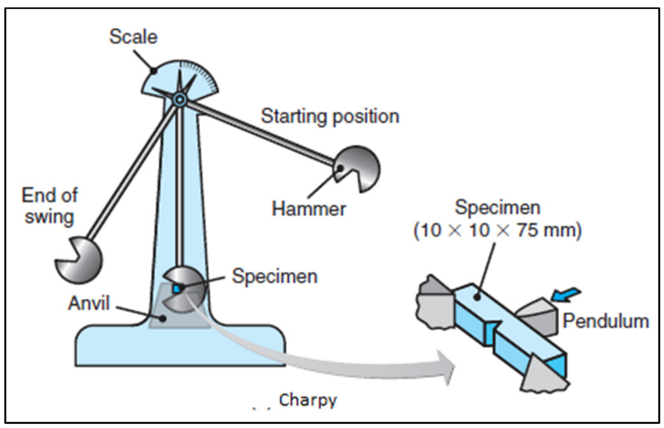
The test specimens were manufactured from Aluminium 6061-T6 and Magnesium AM60. Properties of both materials are shown in Table 1 below. The specimen is designed according to standard stated in ISO 148 where the size is 55mm X 10mm X 10mm with a notch of 45º as shown in Figure 1(a). Specimen is prepared with three different thicknesses which are 10 mm, 7.5 mm and 5 mm. Specimen is placed on the anvil of Charpy machine before testing is starts as shown in Figure 1(b).

Table 1
Material properties of impact specimen

Material	Young's Modulus, E (GPa)	Density, ρ (kg/m^3)
Aluminium 6061-T6	67.6	2694.5
Magnesium AM60	6.6	1804.6



(a)



(b)

Fig. 1. Material and equipment used: (a) Dimension of Charpy specimen, (b) Position of specimen on anvil

2.2 Charpy Impact Test

V-notch Charpy impact test was conducted by using Charpy machine with capacity of 406 J (shown in Figure 2) at speed of 3.35m/s (lower latch) and 5.18 m/s (upper latch) with different thicknesses. Test repeated for many times and test is carried out at room temperature. Strain gauge is installed to the striker surface of impact machine and connected to the data acquisition system to collect strain signal due to impact force. The strain gauge was installed properly to avoid short circuit. Figure 3 shows the equipment arrangement used to acquire required data for analysis. Set up to eDAQ software should be done in advance before hammer is released for every single test pieces. Rate of eDAQ in captured strain signal data is set to 50 000 Hz, which means in one millisecond there are 50 data is collected. Obtained data from SOMAT eDAQ is converted to INFIELD software before transferred to excel. Reading of absorbed energy is directly obtained by refers to the machine scale.

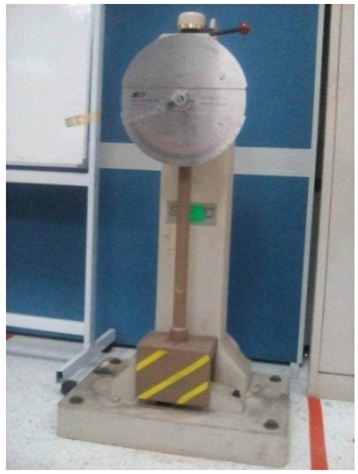


Fig. 2. Charpy impact machine

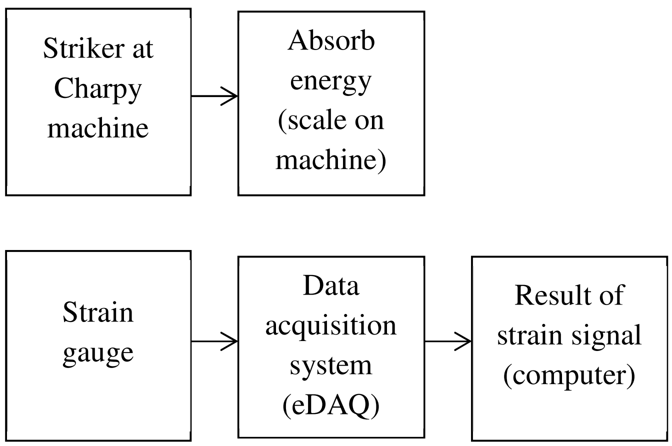


Fig. 3. Apparatus connection for data collection

From collected data, a graph of strain-time and Power Spectrum Density (PSD) graphs is plotted. Impact duration and maximum deformation of material due to impact force can be determined by referring to strain-time graph. PSD is a representation of magnitude of signal at various frequency components. It shows at which frequencies variations are strong and at which frequencies variations are weak. In this study, PSD is used to determine power contains in frequency components of impact strain signal. PSD graph is plotted by converts the strain-time data from Charpy experiment into Matlab software. Then, area under PSD and strain-time graph is calculated by using excel and OriginPro software respectively.

3. Results and Discussion

Figure 4 shows the impact specimen before and after test was conducted and the amount of average absorbed energy by each material at different speed of impact and thickness is shown in Table 2. Specimen with a thickness of 10 mm at low impact speed shows the highest absorbed energy while specimen of 5 mm at high impact speed shows lowest absorbed energy when impact load is exerted. Both materials show that impact energy increased as the thickness of material increased but decreased at high speed of impact.

In order to attain the objectives of this study, PSD and strain-time graphs are plotted to measures the area under graph for correlation to absorbed energy. Figure 5, Figure 6, Figure 7 and Figure 8 shows PSD graph while Figure 9, Figure 10, Figure 11 and Figure 12 shows strain-time graph for both materials at different speed of impact. Only one line for all thickness is presented in strain-time graph for magnesium. It is to observe clearly the strain signal at different thickness of magnesium which has small deformation due to impact. Table 3 and Table 4 represents the average amount of PSD energy and average area under strain-time graph respectively.

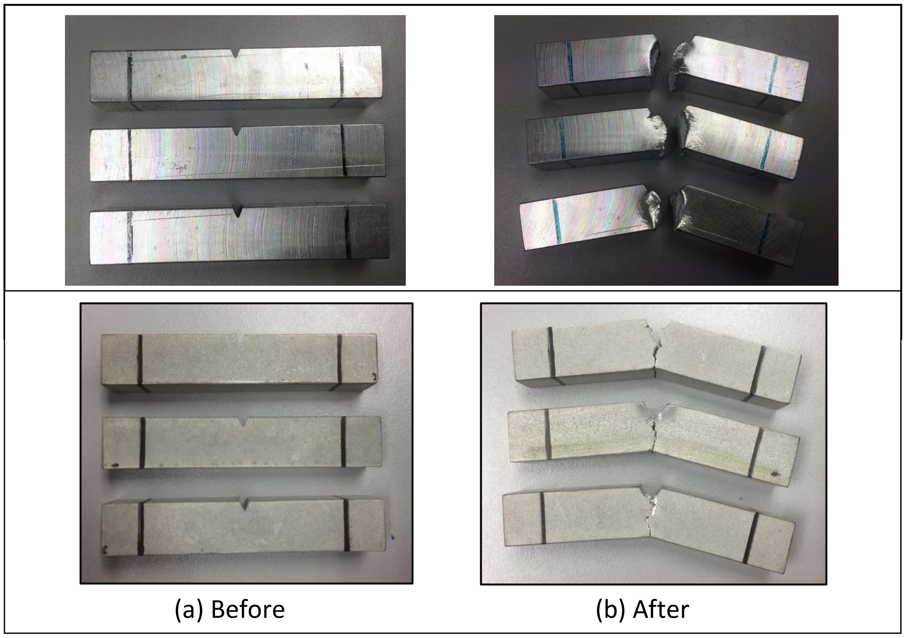


Fig. 4. Specimens of Magnesium AM60 before and after impact test

Table 2
Average absorbed energy at different parameters

Impact Speed (m/s)	Material thickness (mm)	Average Absorbed Energy (J)	
		Aluminium 6061-T6	Magnesium AM60
3.35	5	15.33	6.33
	7.5	20.33	8.00
	10	26.00	9.67
5.18	5	8.67	1.67
	7.5	13.33	2.67
	10	20.00	4.00

Table 3 indicates Aluminium 6061-T6 has more power of strain energy compared to Magnesium AM60 for every case. PSD energy increased as thickness of material increased. However, the signal power decreased when high speed of impact is applied. For both materials, highest PSD energy is shown by specimen of 10 mm imposed with low speed of impact and the lowest PSD energy shown by thinner material hits by large speed. During collision, material with high thickness tends to absorbs more kinetic energy transfer from impactor to specimen. Hence, less plastic strain energy is dissipated [4]. By referring to result, high absorbed energy caused high PSD energy since the energy is directly proportional to each other.

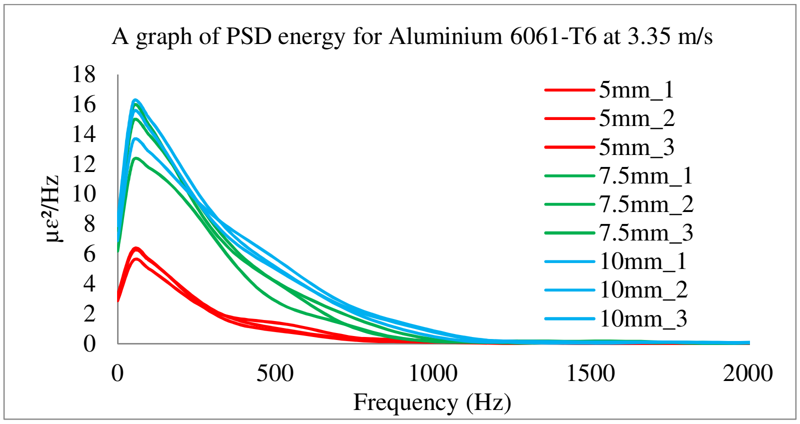


Fig. 5. PSD Energy Graph for Aluminium 6061-T6 at Impact Speed of 3.35 m/s for Different Thicknesses

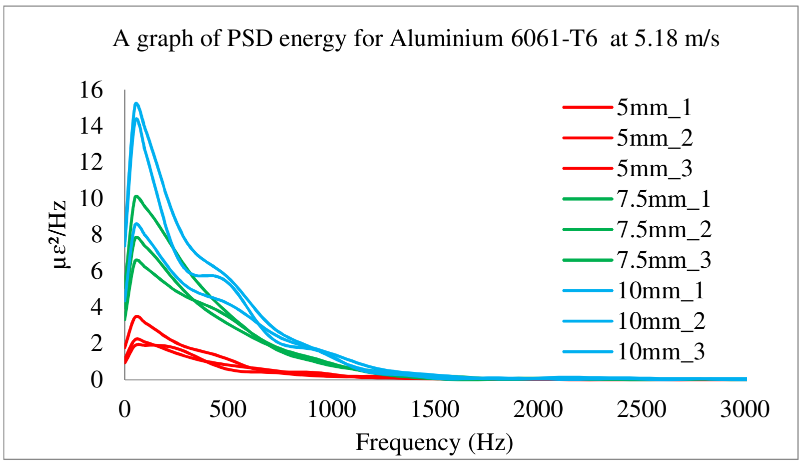


Fig. 6. PSD Energy Graph for Aluminium 6061-T6 at Impact Speed of 5.18 m/s for Different Thicknesses

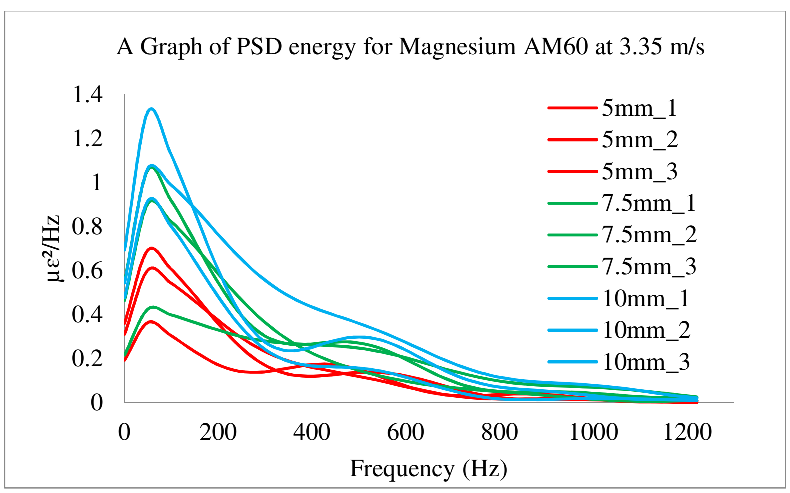


Fig. 7. PSD Energy Graph for Magnesium AM60 at Impact Speed of 3.35 m/s for Different Thicknesses

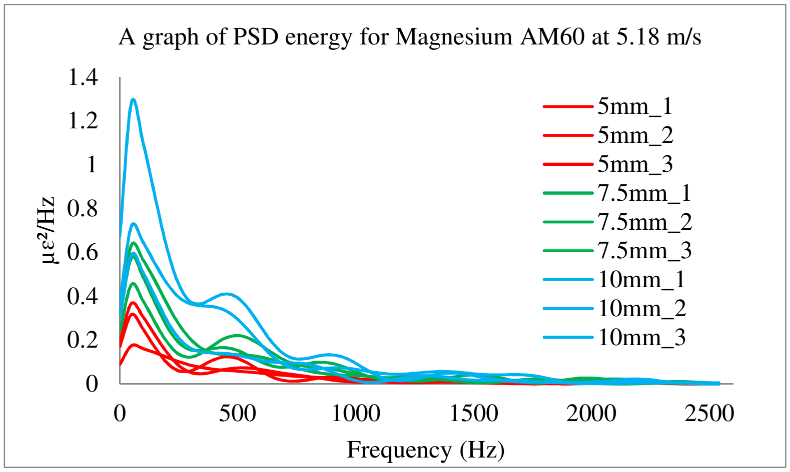


Fig. 8. PSD Energy Graph for Magnesium AM60 at Impact Speed of 5.18 m/s for Different Thicknesses

Table 3
Average PSD energy at different parameters

Impact Speed (m/s)	Material thickness (mm)	Average PSD Energy (με²/Hz)	
		Aluminium 6061-T6	Magnesium AM60
3.35	5	1900.28	256.06
	7.5	5405.90	334.48
	10	7896.19	424.45
5.18	5	1248.04	145.35
	7.5	4107.50	258.57
	10	5742.89	379.53

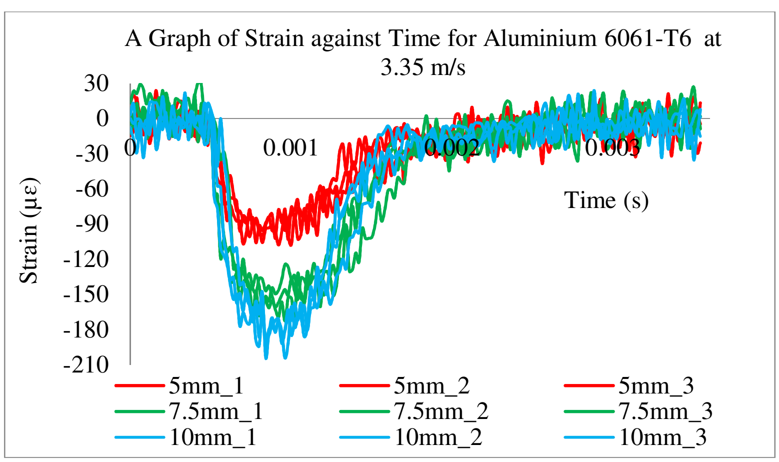


Fig. 9. A Graph of Strain-Time Graph of Aluminium 6061-T6 at 3.35 m/s for Different Thickness

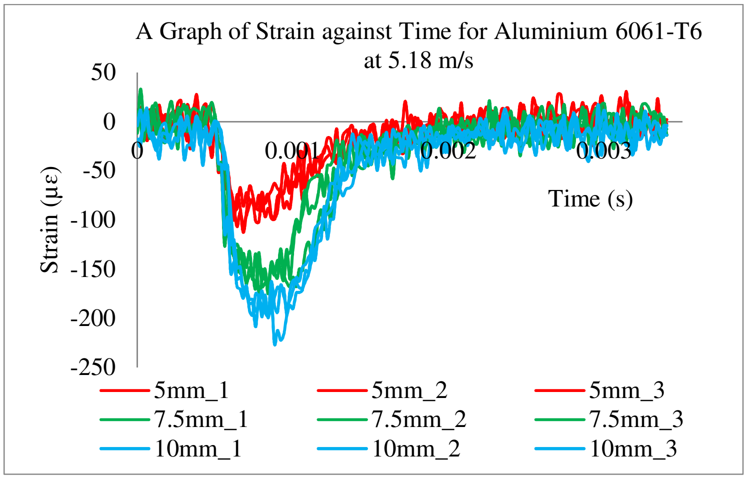


Fig. 10. A Graph of Strain-Time Graph of Aluminium 6061-T6 at 5.18 m/s for Different Thickness

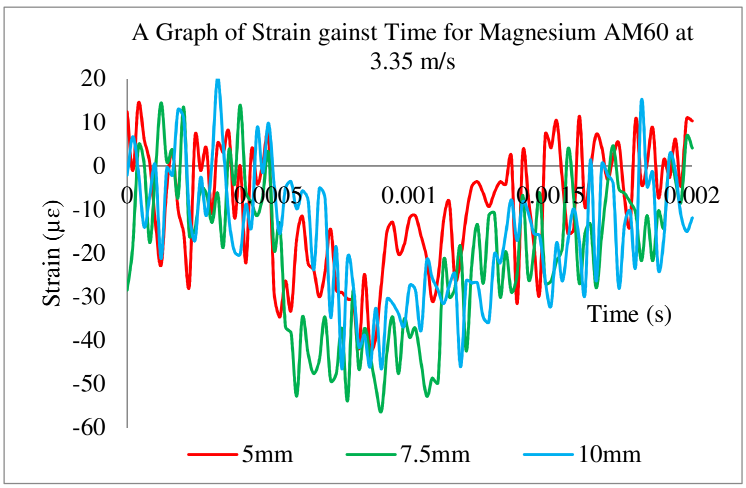


Fig. 11. A Graph of Strain-Time Graph of Magnesium AM60 at 3.35 m/s for Different Thickness

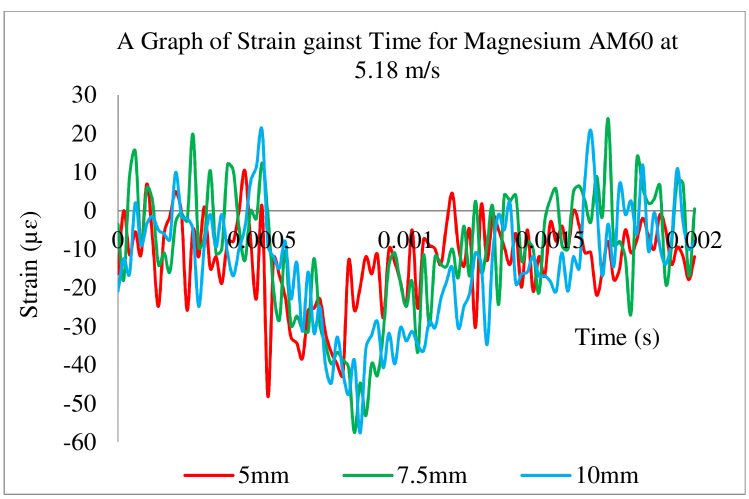


Fig. 12. A Graph of Strain-Time Graph of Magnesium AM60 at 5.18 m/s for Different Thickness

Table 4
Average area under ε-t graph at different parameters

Impact Speed (m/s)	Material thickness (mm)	Average Area Under ε-t Graph (με.s)	
		Aluminium 6061-T6	Magnesium AM60
3.35	5	0.0845	0.0227
	7.5	0.1436	0.0271
	10	0.1779	0.0314
5.18	5	0.0518	0.0115
	7.5	0.1066	0.012
	10	0.1255	0.0248

Based on strain-time graph for both materials, it shows that high duration of impact is found at the low impact speed while maximum strain is found at high speed of impact. Value of impact duration and maximum strain affects the measurement on area under strain-time graph. Results in Table IV exhibits that area under graph increased as thickness of material was increased and decreased when impact speed is increased. Specimen of 10 mm with low speed of impact shows the highest value of area under graph compared to the others. It is because low impact velocity will provide sufficient time for material to absorb more energy in deformation process before fracture occurs.

3.1 Correlation of Absorbed Energy with PSD Energy

Correlation of absorbed energy and PSD energy is shown in Figures 13 and 14. Based on the figure, PSD energy increased as the absorbed energy increased. Both energies were directly proportional to the thickness of material but inversely proportional to the impact speed. High speed of impact is determined as a factor that leads in declination of absorbed and PSD energies. By referring to Figure 13, at 50% reduction in thickness of material, the amount of energy absorbed and PSD energy for Aluminium 6061-T6 were reduced about 21.81% and 31.54% while 17.27% and 21.20% for Magnesium AM60. Amount of energy absorbed and PSD energy decreased for both materials when applied speed is increased from 3.35 m/s to 5.18 m/s. Material is easily damaged and fractured when high speed of impact is exerted compared to low speed [12].

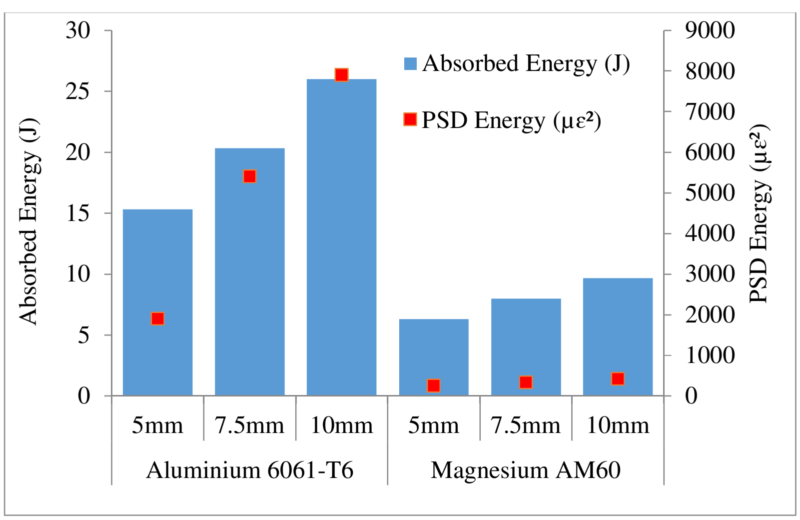


Fig. 13. Correlation of Absorbed Energy and PSD Energy at Speed of 3.35 m/s

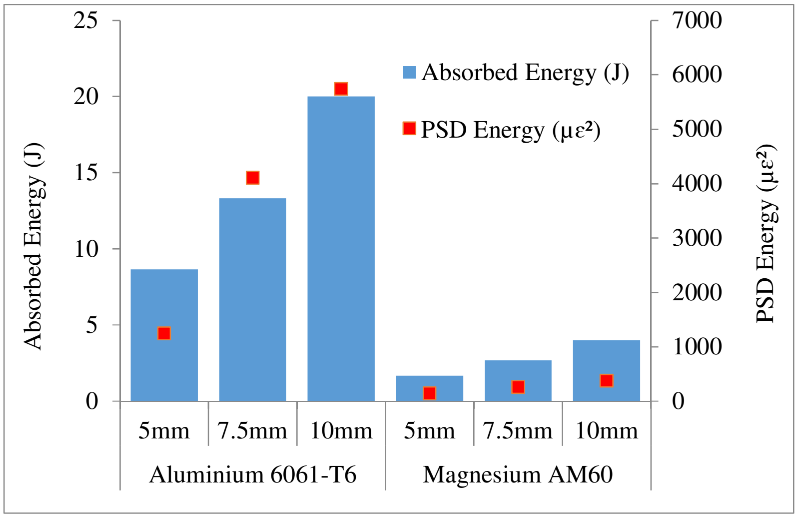


Fig. 14. Correlation of Absorbed Energy and PSD Energy at Speed of 5.18 m/s

3.2 Correlation of Absorbed Energy with Area under Strain-Time Graph

Figure 15 and Figure 16 show the correlation of absorbed energy and area under strain-time graph. Correlation of absorbed energy with area under ε-t graph has same pattern with correlation of absorbed energy with PSD energy where area under graph and PSD energy were increased as the absorbed energy increased. Besides that, in term of thickness and impact speed, Aluminium 6061-T6 shows higher absorbed energy and area under graph compared to Magnesium AM60. In Figure 15, thickness reduction from 10 mm to 5 mm caused declination to the energy absorbed and area under strain-time graph which are 41.04% and 52.50% for Aluminium 6061-T6 while 34.54% and 27.71% for Magnesium AM60. Increment to the applied impact speed leads decrements to the absorbed energy and area under strain-time graph for all thickness. High velocity of impact does not provide enough time for material to absorb more kinetic energy during collision via deformation and vibration process.

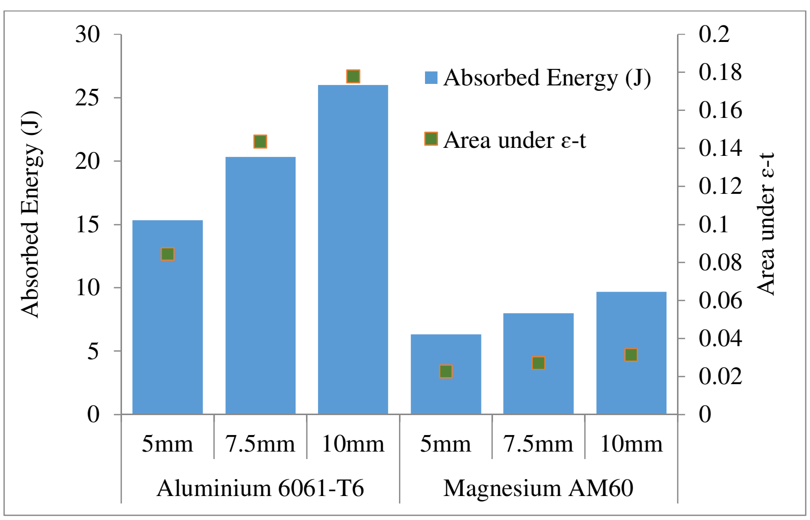


Fig. 15. Correlation of Absorbed Energy and Area under Strain-Time Graph at Speed of 3.35 m/s

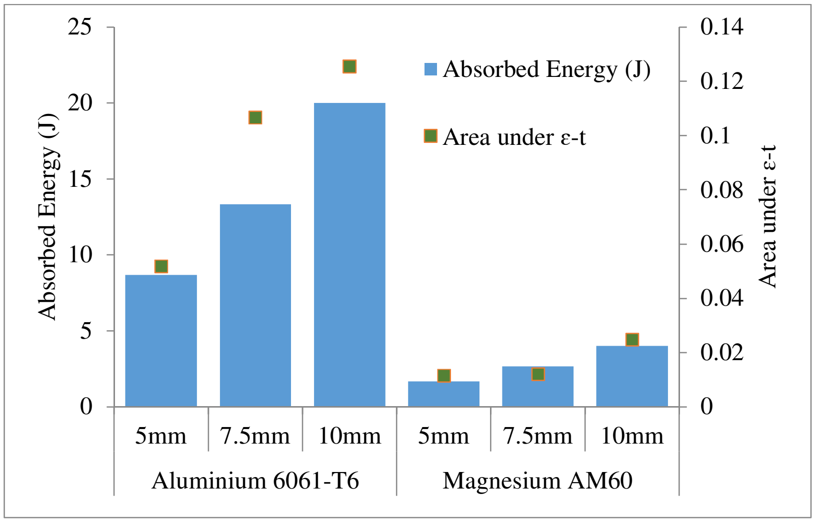


Fig. 16. Correlation of Absorbed Energy and Area under Strain-Time Graph at Speed of 5.18m/s

4. Conclusion

In this paper, the correlation of energy absorbed with PSD energy and area under strain-time graph was successfully demonstrated. This correlation is an alternative to calculate or measure the energy absorbed in order to solve problem of material toughness measurement that is not accurate/estimation value. Thicker material has a capability to absorbed more energy from impact force at lowest impact speed. The absorbed energy, PSD energy and area under strain-time graph were considerably affected by thickness of material and speed of impact. Aluminium 6061-T6 shows a great material as energy absorber compared to Magnesium AM60. It is because aluminium is more ductile than magnesium thus aluminium has more elastic and plastic region curve before fracture. Material with less plastic deformation absorbs less fracture energy.

References

[1] H. N. Parmar and A. J. Modi, “Fatigue and Static Structural Analysis of Car Wheel using Finite Element Method - A review,” *Int. J. Adv. Eng. Res. Dev.*, vol. 2, no. 1, pp. 97–102, 2015.

[2] Kim, Dong-Kuk, and Sunghak Lee. "Impact energy absorption of 6061 aluminum extruded tubes with different cross-sectional shapes." *Materials & design* 20, no. 1 (1999): 41-49.

[3] Chen, Hao, Yali Yang, and Liangjie Wang. "Vehicle front structure energy absorbing optimization in frontal impact." *The Open Mechanical Engineering Journal* 9, no. 1 (2015).

[4] Muhammad Nasiruddin, S., A. Hambali, J. Rosidah, W. S. Widodo, and M. N. Ahmad. "A Review of Energy Absorption of Automotive Bumper Beam." *International Journal of Applied Engineering Research* 12, no. 2 (2017): 238-245.

[5] Jang, Y. C., J. K. Hong, J. H. Park, D. W. Kim, and Y. Lee. "Effects of notch position of the Charpy impact specimen on the failure behavior in heat affected zone." *Journal of materials processing technology* 201, no. 1-3 (2008): 419-424.

[6] Tarlochan, F., and F. Samer. "Design of thin wall structures for energy absorption applications: design for crash injuries mitigation using magnesium alloy." *International Journal of Research in Engineering and Technology* 2, no. 7 (2013): 24-36.

[7] Graciano, Carlos, Gabriela Martínez, and Edwar Saavedra. "Effect of elastoplastic behavior on the impact response of expanded metal tubes." *Dyna* 83, no. 198 (2016): 102-109.

[8] Kruger, Eduardo Leira, and Ruís Camargo Tokimatsu. "INSTRUMENTED CHARPY TEST-EVALUATION OF THE FORCE SIGNAL CAPTURED IN THE MEASURE DYNAMIC FRACTURE TOUGHNESS OF METALLIC MATERIALS."

[9] Chang, C. L., and S. H. Yang. "Finite element simulation of wheel impact test." *Journal of Achievements in Materials and Manufacturing Engineering* 28, no. 2 (2008): 167-170.

[10] Ali, M. B., Kamarul Ariffin Zakaria, Shahrum Abdullah, and M. R. Alkhari. "Correlation of Impact Energy from Instrumented Charpy Impact." *Applied Mechanics & Materials* 815 (2015).

[11] Murali, G., A. S. Santhi, and G. Mohan Ganesh. "Empirical relationship between the impact energy and compressive strength for fiber reinforced concrete." (2014).

[12] Ali, M. B., Shahrum Abdullah, Mohd Zaki Nuawi, and A. K. Ariffin. "Correlation of absorbed impact with calculated strain energy using an instrumented Charpy impact test." (2013).