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Characterisation of Mechanical Properties Using I-Kaz Analysis Method under Steel Ball Excitation Technique

[1,2]Mohammed T. Jasim, [1]M.Z. Nuawi, [1]S.S. Ziyad, [3]A.R. Bahari,
[1]F.M. Nadia and [1]M.H. Mohammed
[1]Department of Mechanical and Materials Engineering,
Faculty of Engineering and Built Environment, 43600 UKM Bangi, Selangor, Malaysia
[2]Department of Mechanical Engineering, University of Technology, Baghdad, Iraq
[3]Faculty of Mechanical Engineering, UiTM (T) Kampus Bukit Besi,
23200 Bukit Besi, Dungun, Terengganu, Malaysia

Abstract: The evaluation and design of more productive and cheaper materials and products can be improved by measuring their long lasting mechanical properties. In this study, vibration signals emitted from a steel ball were measured using a regular pulsing excitation method based on ASTM E1876 and at the same time, data was obtained from the configurations of an accelerometer and a piezofilm sensor. The polymeric materials selected for the proposed design were made up of rectangular bars consisting of cross-sections of polyvinyl chloride (PVC) and cast nylon (MC), acrylic (AC) and polyethylene (PE) with the same dimensions as the sample. The time domain and the frequencies of the vibration signals that were produced during the experiment were examined by means of an alternative statistical analysis method known as the Integrated Kurtosis-Based Algorithm for Z-Filter (I-Kaz™) which was used to decipher the information that was gathered. Two correlation processes were obtained from the material properties (Compressive strength and Bulk modulus) and the I-Kaz™, Z^{∞} coefficients of the vibration signals picked up by an accelerometer and piezofilm sensor. The results prove that correlation processes can be used with the I-Kaz™ methods as standards for determining the properties of materials and that this technique is efficient, safe and cheap.

Key words: Statistical analysis, polymer, mechanical properties, vibration signal, I-Kaz

INTRODUCTION

Material is described as all matter that is used or processed by humans to generate industrial or consumer products (Meyers and Chawla, 2009). In order to fully characterize engineering materials it is absolutely necessary to know their elastic properties (Alfano and Pagnotta, 2007). The performance of an engineering material depends on its internal structure. There are generally two types of experimental methods for determining the properties of materials, i.e., destructive and non-destructive methods. In the destructive method, the behaviour of the sample material is tested using different loads until failure occurs. On the other hand, in the non-destructive method, the properties of the material are assessed without damaging the sample. This method is preferred as it is more exact, is cheaper, can be used for any size or shape of the test sample and the sample can be re-used for further tests (Zhu and Emory, 2005; Alfano and Pagnotta, 2007).

The impulse excitation method using a steel ball measures the natural frequencies of the vibrations emitted by a rectangular beam sample that has been mechanically stimulated by an impulse. Since the natural or resonant frequencies depend on the mass and shape of the object being examined, they are a measure of the rigidity of the object (Botelho *et al*., 2006). The impulse excitation method has been used by many researchers to measure the elastic properties of materials such as the Elastic modulus, Poisson's ratio and Shear modulus. The resonant frequencies of round glass plates were measured by Salem and Singh (2006). The data obtained can be examined to discover the features of the resulting frequency. The use of several different types of sensors installed on bearings can provide additional information compared to the use of single sensors. The combined information from the multiple sensors will result in better detection of faults and a more accurate analysis (Safizadeh and Latifi, 2014).

Corresponding Author: Mohammed T. Jasim, Department of Mechanical and Materials Engineering,
Faculty of Engineering and Built Environment, 43600 UKM Bangi, Selangor, Malaysia

This study presents another non-destructive method for the characterization of mechanical properties for engineering purposes. Polymeric materials were subjected to impulse excitation tests to obtain the resonant frequencies of the impulses emitted from the steel ball at various amplitudes. A different statistical signal analysis method was used to evaluate the brief response of the specimen and to examine the relationship between the vibration signals emitted by the piezofilm sensor and accelerometer and the I-Kaz™, Z^8 coefficients.

MATERIALS AND METHODS

The set-up for the current measurement experiment is shown in Fig. 1. It comprised of the sample, a steel ball, a piezofilm sensor, an accelerometer and a data acquisition and support system. The selected test samples of different polymeric materials were as follows: Polyvinyl chloride (PVC) and cast nylon (MC), acrylic (AC) and polyethylene (PE) with standard dimensions of 150 mm (length)×50 mm (width)×20 mm (thickness). The material properties of each sample are listed in Table 1 (ASTM C1548-02, 2007). When a steel ball was dropped in the centre of the polymeric material, energy was exerted on the polymer. The signal waveform that was generated was then saved in Txt using the data acquisition software. The approximate amplitudes for the same sample were measured when the steel ball was dropped from heights of 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40 and 42 cm.

The tests were carried out in the flexural direction only for the specified dimensions of the sample. The sample was mounted on the supports placed at the primary nodal points (0.224 L from each end). The excitation point (centre of the sample) was chosen so as to denote the vibration modes in the out-of-plane flexure. Two different measurement techniques were used. In this study, both sensors were fixed on the edge of the polymer sample. The output from the sensors was linked by a cable to input channels 1 and 2 of the National Instrument model (NI 9234).

I-Kaz™ analysis method: This method which was proposed by Nuawi *et al.* (2008), is an alternative statistical analysis approach consisting of two vital statistical properties, namely descriptive statistics and statistical inference. Descriptive statistics involve the calculation of the I-Kaz coefficient, Z^8 to produce a three-dimensional graphical depiction of a sample. The I-Kaz™ statistical analysis method was developed according to the idea of scattering data to a central value of dispersion known as the centroid (Nuawi *et al.*, 2008).

Table 1: Minimum value of mechanical properties of polymer according to CES Edupack 2011©

Mechanical properties	PE	Acrylic	PVC	MC blue
Minumum value				
Young modulus	0.621	2.240	2.140	2.62
Shear modulus	0.218	0.803	0.766	0.97
Bulk modulus	2.150	4.200	4.700	3.70
Poisson's ratio	0.418	0.384	0.383	0.34
Compressive strength	19.700	72.400	42.500	55.00
Maximum value				
Young modulus	0.896	3.800	4.140	3.20
Shear modulus	0.314	1.370	1.490	1.19
Bulk modulus	2.250	4.400	4.900	3.90
Poisson's ratio	0.434	0.403	0.407	0.36
Compressive strength	31.900	131.000	89.600	104.00

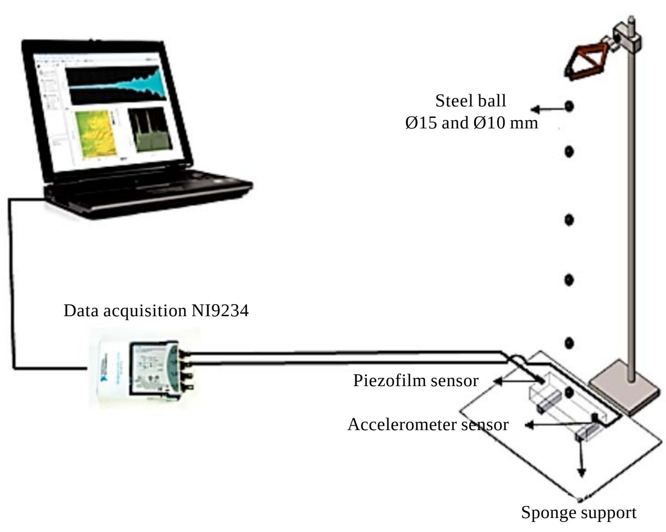

Fig. 1: Schematic of the experimental design

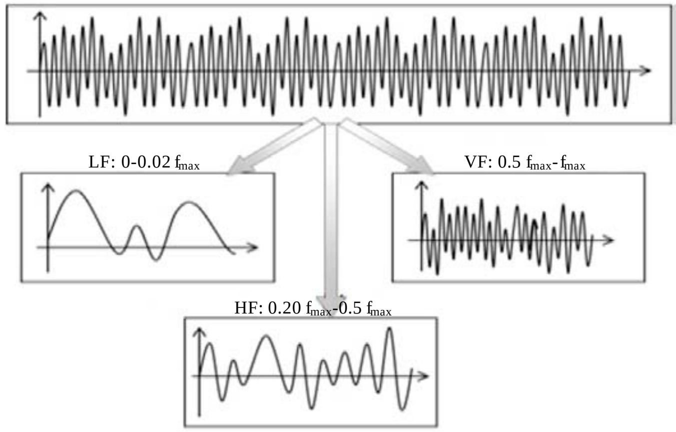

Fig. 2: Frequency range of I-Kaz™ method

Figure 2 shows a signal dynamics to help explain this concept. The time domain of the signal is divided into three frequency ranges:

- X-axis: Low frequency range (LF) of 0-0.25 f_{max}
- Y-axis: High frequency range (HF) which is 0:25 f_{max}- 0.5 f_{max}
- Z-axis: Frequency range is very high (VF) of 0.5 f_{max}-f_{max}

where, f_{max} denotes the maximum frequency set for the measurement of the signals. This value is specifically half that of the sampling frequency used during the recording of a signal. According to the sampling theorem, the signal can be described by Eq. 1:

$$f_s \geq 2f_{max} \quad (1)$$

where, f_s is the sampling frequency and f_{max} is the highest frequency measured in the signal. The factors 0:25 f_{max} and 0.5 f_{max} were selected as the lowest and highest frequencies, respectively in terms of the concept of the second stage in the breaking of the signal. Using σ^2 as the parametric variance, the degree of dispersion of the measured data is given as in Eq. 2.

$$\sigma_L^2 = \frac{\sum_{i=1}^{N}\left(x_i^L - \mu_L\right)^2}{n}; \sigma_H^2 = \frac{\sum_{i=1}^{N}\left(x_i^H - \mu_H\right)^2}{n}; \sigma_V^2 = \frac{\sum_{i=1}^{N}\left(x_i^V - \mu_V\right)^2}{n} \quad (2)$$

Equation 3 is used to calculate the I-Kaz coefficient, Z^∞ according to the concept of the scattering of data around a centroid:

$$Z^\infty = \sqrt{\frac{\sum_{i=1}^{N}(X_i^L - \mu_L)^4}{n^2} + \frac{\sum_{i=1}^{N}(X_i^H - \mu_H)^4}{n^2} + \frac{\sum_{i=1}^{N}(X_i^V - \mu_V)^4}{n^2}} \quad (3)$$

where, x_i^L, x_i^H, x_i^V are the values of the discrete data and μ_L, μ_H and μ_V denote the mean values of the discrete data in the low, high and very high frequency range, respectively at i-sample of time while N represents the number of data.

RESULTS AND DISCUSSION

It was mentioned in the earlier study that two types of plots were made for the time domain in this study, namely with an accelerometer and a piezofilm sensor. The Integrated Kurtosis-Based Algorithm for Z-Filter (I-Kaz™) method was used to analyze the data in order to detect the characteristics of the signal. (The previous study use frequencies of the vibrations to characterize types of material such as metal, stones (Dos Santos *et al*., 2013; Yoshida *et al*., 2010) for I-Kaz capability to characterise other different type of material which is polymer). The transient vibration signals emitted from acrylic (AC), polyethylene (PE), cast nylon (MC) and polyvinyl chloride (PVC) are shown in Fig. 3-6.

An analysis of the I-Kaz™ resulted in the I-Kaz coefficient (Nuawi *et al*., 2011). The kurtosis value and standard deviation were measured for the three frequency ranges of low, high and very high frequencies. Using Eq. 2, low values of 10^{-5} were obtained for the I-Kaz coefficients which were then reduced to a reference coefficient of the I-Kaz. Table 2 present the I-Kaz coefficient values from the piezofilm sensor and the accelerometer for each type of material, the energy force of the steel ball and the velocity of the steel ball when it was dropped during the experiment.

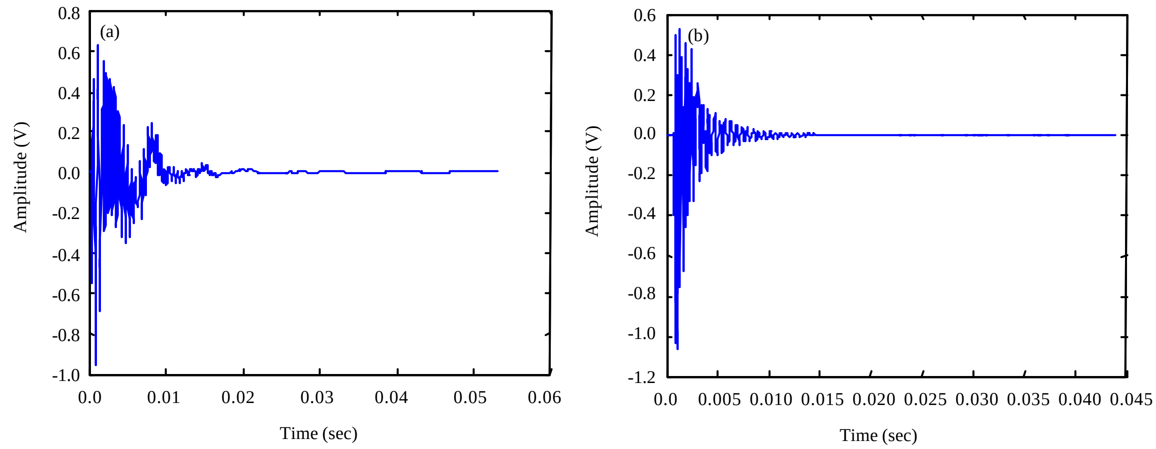

Fig. 3(a-b): Vibration signal of Acrylic (AC) at 20 cm amplitude under steel ball (a) Piezofilm sensor and (b) Accelerometer sensor

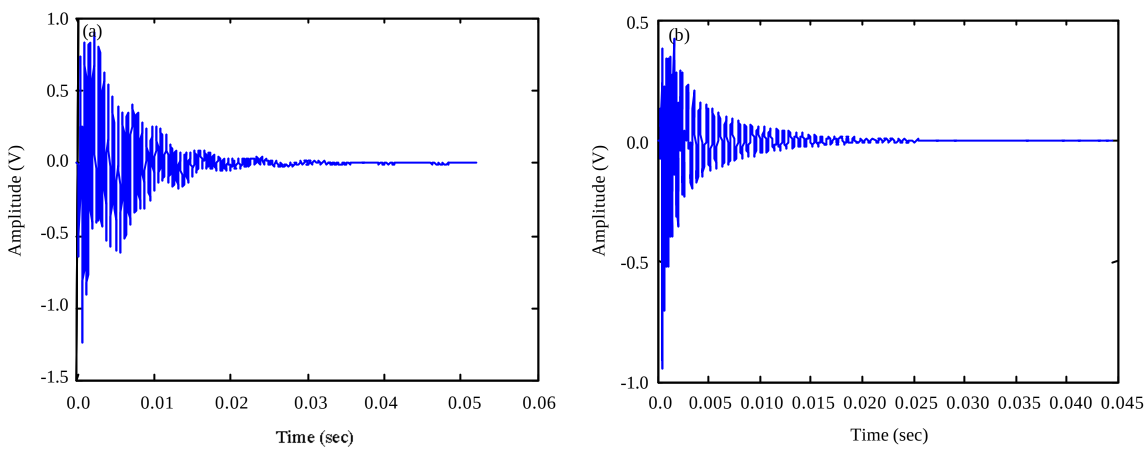

Fig. 4(a-b): Vibration signal of Nylon (MC) at 20 cm amplitude under steel ball (a) Piezofilm sensor and (b) Accelerometer sensor

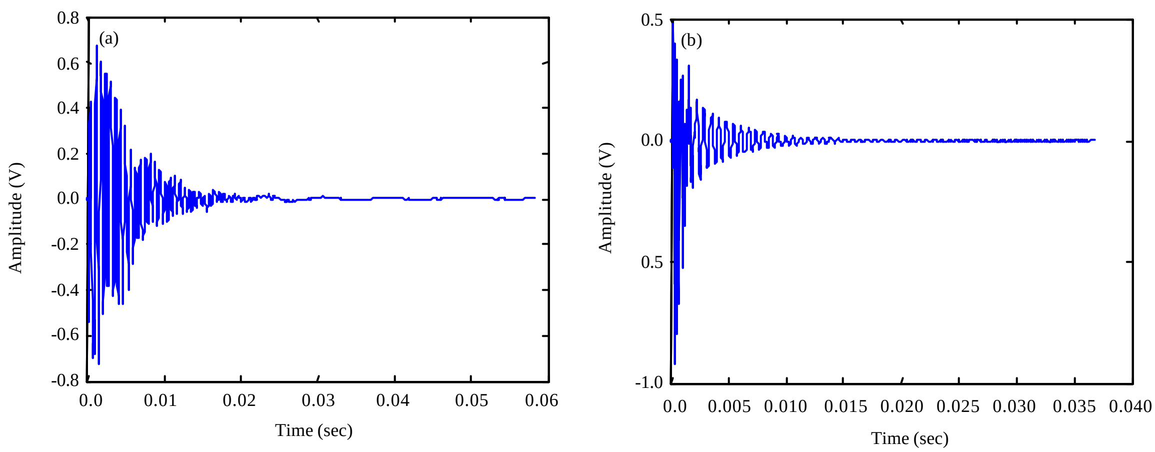

Fig. 5(a-b): Vibration signal of polyvinylchloride (PVC) at 20 cm amplitude under steel ball (a) Piezofilm sensor (b) Accelerometer sensor

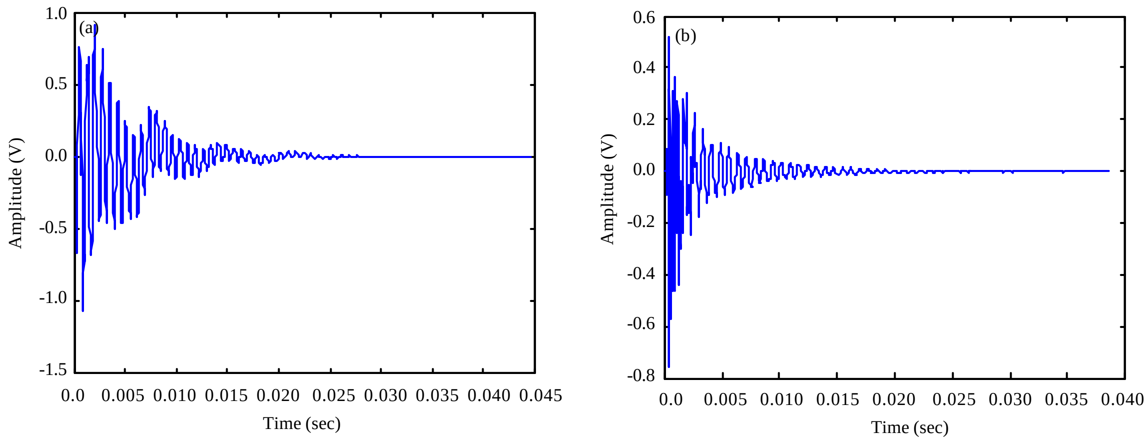

Fig. 6(a-b): Vibration signal of polyethylene (PE) at 20 cm amplitude under steel ball (a) Piezofilm sensor and (b) Accelerometer sensor

Table 2: I-Kaz coefficient of piezofilm and accelerometer sensor in polymer acrylic (AC), nylon (MC), polyethylene (PE) and Polyvinyl chloride (PVC) under energy and velocity of spherical steel ball

Amplitude cm	Energy (J)	Velocity (m sec^{-1})	I-Kaz AC coefficient×10^{-5}	I-Kaz MC coefficient×10^{-5}	I-Kaz PE coefficient×10^{-5}	I-Kaz PVC coefficient×10^{-5}
For piezofilm sensor						
0	0	0	0	0	0	0
20	8.036	1.980	1.8526	4.4493	0.315910	1.8103
22	8.843	2.077	1.9663	4.6156	0.358274	2.0658
24	9.644	2.169	1.9856	4.7098	0.378770	2.2487
26	10.45	2.258	2.7913	5.2843	0.586200	2.4377
28	11.25	2.343	4.4287	5.7058	0.474060	2.8095
30	12.06	2.426	4.5031	6.0188	0.557390	2.8877
32	12.87	2.506	5.0583	6.2176	0.581480	3.1758
34	13.66	2.582	5.2075	6.9058	0.634190	3.4961
36	14.47	2.657	5.5052	8.0561	0.665870	3.5328
38	15.27	2.730	5.6165	8.1215	0.945490	4.2274
40	16.08	2.801	6.9245	8.8701	1.000400	4.7756
42	16.88	2.870	7.6821	9.3946	1.351100	5.6246
For accelerometer sensor						
0	0	0	0	0	0	0
20	8.036	1.980	1.3427	1.0910	0.31591	1.0280
22	8.843	2.077	1.6626	1.1258	0.36076	1.2756
24	9.644	2.169	1.8659	1.2015	0.37660	1.5848
26	10.45	2.258	1.9193	1.2834	0.44559	2.2311
28	11.25	2.343	2.0983	1.5756	0.48111	2.3741
30	12.06	2.426	2.2945	1.3155	0.55597	2.5467
32	12.87	2.506	2.4185	2.3101	0.58736	3.4191
34	13.66	2.582	2.9827	2.4241	0.60593	3.6292
36	14.47	2.657	3.5052	2.6669	0.63711	4.1517
38	15.27	2.730	3.7822	2.8393	1.04010	5.4366
40	16.08	2.801	3.8631	4.0608	1.14280	5.6841
42	16.88	2.870	5.8833	4.1794	1.14310	5.8020

I-Kaz characterise only Young's modulus of metallic material (medium carbon steel S50C, stainless steel AISI 304, brass and cast iron FCD 500) (Nuawi *et al*., 2014) in this study, we can expand the capability of I-Kaz statistical analysis method to characterise other different material properties (compressive strength and bulk modulus.

The I-Kaz™ coefficient for all the polymeric materials increased when higher amplitudes of energy were applied to the samples. The amplitude of each discrete data generated by the piezofilm sensor and the accelerometer increased when the energy applied to the samples was increased. The I-Kaz™ scattering data method of statistical analysis is based on the idea of a scattering centre known as the centroid (Nuawi *et al*., 2008). When the value for each discrete data signal to the centroid is increased, the scattering of the data will be extended, thus enhancing the I-Kaz™ coefficients of the piezofilm sensor and the accelerometer.

Table 3: Quadratic equation and quadratic coefficients (R^2) of piezofilm sensor under velocity, accelerometer sensor under energy and accelerometer sensor under velocity

Material	Quadratic equation	Correlation coefficients (R^2)
Piezofilm sensor under velocity		
Acrylic (AC)	$y = 1.969332x^2-3.066195x$	0.965282
Nylon (MC)	$y = 1.341276x^2-0.664504x$	0.985559
Polyvinylchloride (PVC)	$y = 1.058389x^2-1.297699x$	0.963226
Polyethylene (PE)	$y = 0.294528x^2-0.464257x$	0.887355
Accelerometer sensor under energy		
Polyvinylchloride (PVC)	$y = 0.026804x^2-0.088560x$	0.984535
Acrylic (AC)	$y = 0.017098x^2+0.000349x$	0.925852
Nylon (MC)	$y = 0.016734x^2-0.045145x$	0.945888
Polyethylene (PE)	$y = 0.004115x^2-0.002544x$	0.931588
Accelerometer sensor under velocity		
Polyvinylchloride (PVC)	$y = 1.874824x^2-3.320927x$	0.980174
Acrylic (AC)	$y = 1.251048x^2-1.962499x$	0.902217
Nylon (MC)	$y = 1.145117x^2-1.956055x$	0.919954
Polyethylene (PE)	$y = 0.298152x^2-0.478549x$	0.909915

In another previous study they use the frequencies of the vibration signals to determine young's modulus, shear modulus and Poisson's ratio (ASTM E1876-09, 2007; Radovic *et al*., 2004; Dos Santos *et al*., 2013; Zhu and Emory, 2005; Alfano and Pagnotta, 2007). In this study, we can expand the functionality of the frequencies of the vibration signals of the materials to characterise the other type of material properties which are compressive strength and bulk modulus.

From the data obtained from Table 3 on the four types of polymer materials, the I-Kaz™ coefficients of the piezofilm sensor and the accelerometer at the velocity and energy applied were plotted.

From Fig. 7-9 it can be seen that a matching quadratic polynomial curve was obtained for each type of polymer. The quadratic equation fits the curve:

$$y = ax^2+bx$$

A quadratic polynomial shape was selected because the resultant curve had good values for the correlation coefficient (R^2), ranging from 0.887355 to 0.985559. The quadratic equation and the values of the correlation coefficient (R^2), for the piezofilm sensor and the accelerometer are shown in Table 3.

From the quadratic equation ($y = ax^2+bx$) for each material, as given in Table 3, the quadratic coefficients (a) for the quadratic equations of the I-Kaz™ curves were obtained and arranged in ascending order. This sequence was then compared with the arranged sequence of the material properties from Table 1 and 2 based on the CES Edupack 2011©. It was discovered that the sequence for the quadratic coefficient of the I-Kaz™ for the piezofilm sensor under velocity matched the sequence of the compressive strength (minimum value) of the materials. Meanwhile, the sequence for the quadratic coefficient of the I-Kaz™ for the accelerometer under energy matched

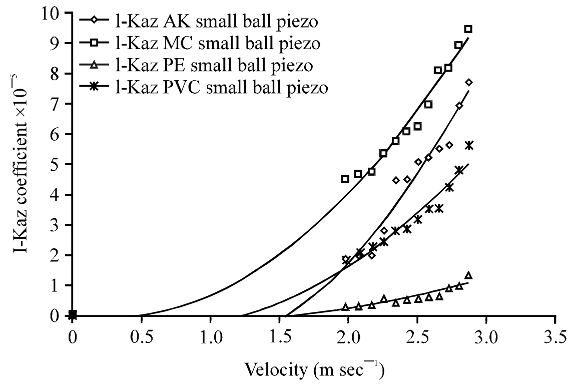

Fig. 7: I-Kaz coefficient of piezofilm sensor vs. velocity of drop the steel ball

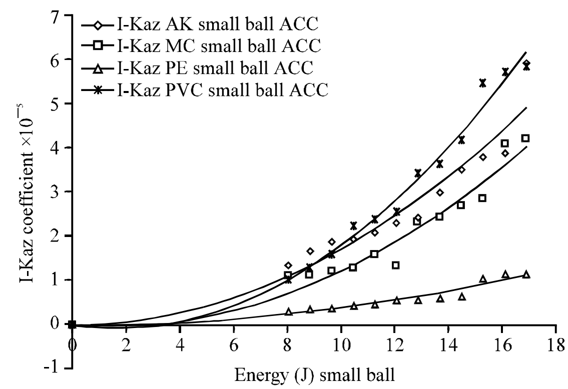

Fig. 8: I-Kaz coefficient of accelerometer sensor vs. energy of drop the steel ball

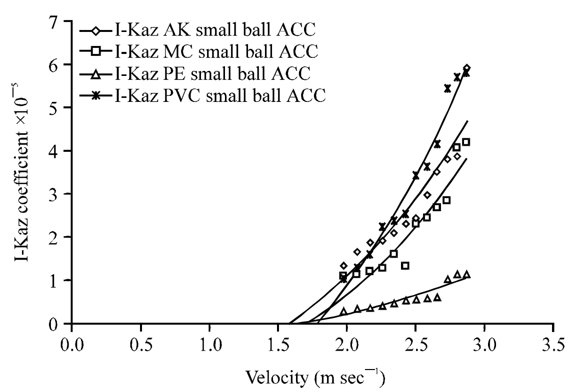

Fig. 9: I-Kaz coefficient of accelerometer sensor vs. velocity of drop the steel ball

the sequence of the bulk modulus (minimum value) and that of the quadratic coefficient of the I-Kaz™ of the accelerometer under velocity was similar to the sequence of the bulk modulus (maximum value) of the materials.

Table 4: Quadratic coefficients (a) and compressive strength of materials for piezofilm sensor under velocity

Material	Quadratic Coefficients (a)	Compressive strength (MPa) from CES (min)
Acrylic (AC)	1.969332	72.4
Nylon (MC)	1.341276	55.0
Polyvinylchloride (PVC)	1.058389	42.5
Polyethylene (PE)	0.294528	19.7

Table 5: Quadratic coefficients (a) and bulk modulus of materials for accelerometer sensor under energy

Material	Quadratic Coefficients (a)	Bulk modulus (GPa) from CES (min)
Polyvinylchloride (PVC)	0.026804	4.70
Acrylic (AC)	0.017098	4.20
Nylon (MC)	0.016734	3.70
Polyethylene (PE)	0.004115	2.15

Table 6: Quadratic coefficients (a) and bulk modulus of materials for accelerometer sensor under velocity

Material	Quadratic Coefficients (a)	Bulk modulus (GPa) from CES (max)
Polyvinylchloride (PVC)	1.874824	4.90
Acrylic (AC)	1.251048	4.40
Nylon (MC)	1.145117	3.90
Polyethylene (PE)	0.298152	2.25

The quadratic coefficient of the I-Kaz of vibration for the piezofilm sensors under velocity and the accelerometer under energy and velocity, together with the compressive strength and bulk modulus for each polymeric material, respectively are presented in Table 4-6.

It is obvious from Table 4-6 that the I-Kaz™ coefficient of the vibration signal for the piezofilm sensor and the accelerometer under velocity and energy was related to the compressive strength and bulk modulus of the polymeric material in that the polymer with the highest compressive strength and bulk modulus had the highest I-Kaz™ quadratic coefficient of the vibration signal for both sensors under velocity and energy. In order to represent this relationship by a mathematical equation, it was necessary to scatter the data of the quadratic coefficient of the I-Kaz vibration on the four types of polymers, namely polyethylene (PE), cast nylon (MC), acrylic (AC) and polyvinyl chloride (PVC) against the compressive strength and bulk modulus as indicated in Fig. 10-12.

The linear equation (y = 31.845 x +10.273), obtained from the linear trend line as shown in Fig. 10, had a good correlation coefficient value of 0.9955:

$$\text{Compressive strength} = 31.845\ (\text{quadratic coefficient of I-Kaz of piezofilm}) + 10.273 \quad (4)$$

The correlation between the vibration signal of the piezofilm sensor and the compressive strength was expressed by the mathematical equation given in Eq. 4.

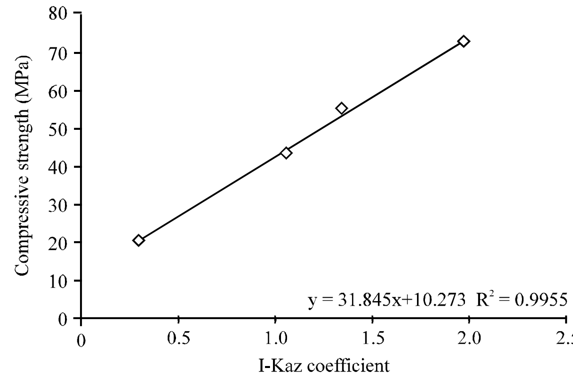

Fig. 10: Compressive strength vs. I-Kaz quadratic coefficient (piezofilm sensor) under velocity of drop the steel ball

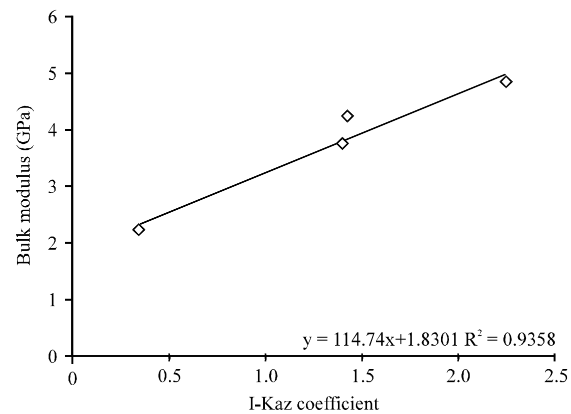

Fig. 11: Bulk modulus vs. I-Kaz quadratic coefficient (accelerometer sensor) under energy of drop the steel ball

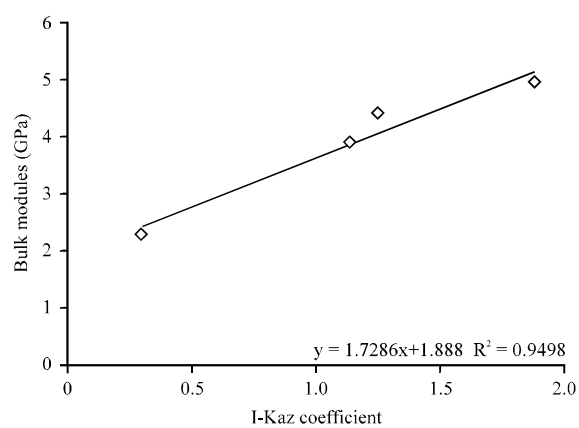

Fig. 12: Bulk modulus vs. I-Kaz quadratic coefficient (accelerometer sensor) under velocity of drop the steel ball

Table 7: Compressive strength under velocity of steel ball and CES (minimum value) of compressive strength of tested polymer materials

Material	Compressive strength (MPa) from correlation	Compressive strength (MPa) from CES	Error (%)
Acrylic (AC)	72.90	72.4	0.8
Nylon (MC)	53.00	55.0	3.6
Polyvinylchloride (PVC)	43.90	42.5	3.4
Polyethylene (PE)	19.65	19.7	0.2

Table 8: Bulk modules under energy of steel ball and CES (minimum value) of bulk modules of tested polymer materials

Material	Bulk modulus (GPa) from correlation	Bulk modulus (GPa) from CES	Error (%)
Polyvinylchloride (PVC)	4.90	4.70	4.30
Acrylic (AC)	3.80	4.20	9.50
Nylon (MC)	3.75	3.70	1.30
Polyethylene (PE)	2.30	2.15	7.08

Table 9: Bulk modules under velocity of steel ball and CES (maximum value) of bulk modules of tested polymer materials

Material	Bulk modulus (GPa) from correlation	Bulk bodulus (GPa) from CES	Error (%)
Polyvinylchloride (PVC)	5.10	4.90	4.60
Acrylic (AC)	4.05	4.40	7.90
Nylon (MC)	3.86	3.90	1.02
Polyethylene (PE)	2.40	2.25	6.60

The linear equation (y = 114.74 x +1.8301), obtained from the linear trend line as shown in Fig. 11, had a good correlation coefficient value of 0.9358:

$$\text{Bulk modulus (B)} = 114.74\ (\text{quadratic coefficient of I-Kaz of accelerometer}) + 1.8301 \quad (5)$$

The correlation between the vibration signal of the accelerometer and the bulk modulus (minimum value from CES®) was expressed by the mathematical equation given in Eq. 5.

Finally, the linear equation (y = 1.7286 x+1.888), obtained from the linear trend line as shown in Fig. 12, had a good correlation coefficient value of 0.9498:

$$\text{Bulk modulus (B)} = 1.7286\ (\text{quadratic coefficient of I-Kaz of accelerometer}) + 1.888 \quad (6)$$

The correlation between the vibration signal of the accelerometer and the bulk modulus (maximum value from CES©) was expressed by the mathematical equation given in Eq. 6. The compressive strength under velocity and the bulk modulus under velocity and energy that were calculated for all the polymeric materials using the correlation Eq. 4-6 are shown in Table 7-9, respectively. The percentage error of these properties were calculated by comparing the maximum and minimum values of the bulk modulus and the compressive strength with the maximum and minimum values obtained from the Cambridge Engineering Selector software CES Edupack 2011©. The difference between the two values ranged from 0.2-9.5% which was an acceptable percentage error particularly for engineering matters.

CONCLUSION

This study has achieved its objective of developing a method to characterize the material properties of polymers by using vibration signals from a piezofilm sensor and an accelerometer. The correlation between the vibration signals produced by the impact of a steel ball dropped at various amplitudes and the properties of certain materials in the test samples was obtained by means of a mathematical equation. Another statistical analysis method known as the Integrated Kurtosis-Based Algorithm for Z-Filter (I-Kaz™) was used to determine the relevance. According to the statistical analysis method employed in this study, these findings indicate there is a connection between the vibration signals and the properties of certain materials. When a higher impact due to a higher amplitude was exerted on the sample, the I-Kaz coefficient increased in the form of a quadratic polynomial curve, $y = ax^2+bx$. By characterizing the quadratic curves and the properties of the sample materials, it was discovered that there is a correlation between the I-Kaz coefficient of the vibration signals recorded by the piezofilm sensor and the compressive strength and between the I-Kaz coefficient of the vibration signals recorded by the accelerometer and the bulk modulus of sample materials. The correlation between the I-Kaz coefficient of the piezofilm vibration signal and the compressive strength (C) is represented by the mathematical equation, C = 31.845 (quadratic coefficient of I-Kaz of piezofilm)+10.273 (under velocity of the steel ball). The correlation between the I-Kaz coefficient of the accelerometer vibration signal and the bulk modulus, B, is represented by the mathematical equation, B = 114.74 (quadratic coefficient of I-Kaz of accelerometer)+1.8301 (under energy of the steel ball). Meanwhile, the correlation between the I-Kaz coefficient of the accelerometer vibration signal and the bulk modulus, B, is represented by the mathematical equation, B = 1.7286 (quadratic coefficient of I-Kaz of accelerometer)+1.888 (under velocity of the steel ball). The correlation equations for the various processes can be used as standard equations for ascertaining the properties of materials through an I-Kaz™ analysis of the vibration signals.

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REFERENCES

ASTM C1548-02, 2007. Standard test method for dynamic Young's modulus, shear modulus and poisson's ratio of refractory materials by impulse excitation of vibration. ASTM International. http://www.astm.org/DATABASE.CART/HISTORICAL/C1548-02R07.htm

ASTM E1876-09, 2007. Standard test Method for Dynamic Young's Modulus, Shear Modulus and Poisson's Ratio by Impulse Excitation of Vibration. American Standard of Testing Materials, Wasghinton, DC., USA.

Alfano, M. and L. Pagnotta, 2007. A non-destructive technique for the elastic characterization of thin isotropic plates. NDT and E Int., 40: 112-120.

Botelho, E.C., A.N. Campos, E. de Barros, L.C. Pardini and M.C. Rezende, 2006. Damping behavior of continuous fiber/metal composite materials by the free vibration method. Compos. Part B: Eng., 37: 255-263.

Dos Santos, J.P.L., P.M. Amaral, A.C. Diogo and L.G. Rosa, 2013. Comparison of Young's moduli of engineered stones using different test methods. Key Eng. Mater., 548: 220-230.

Meyers, M.A. and K.K. Chawla, 2009. Mechanical Behavior of Materials. University Press, Cambridge, ISBN-13: 9780521866750, Pages: 856.

Nuawi, M.Z., A.R. Bahari and S. Abdullah, 2011. Impact test on steel structures-an experimental investigation. Adv. Mater. Res., 146-147: 1514-1518.

Nuawi, M.Z., M.J.M. Nor, N. Jamaludin, S. Abdullah, F. Lamin and C.K.E. Nizwan, 2008. Development of integrated kurtosis-based algorithm for z-filter technique. J. Applied Sci., 8: 1541-1547.

Nuawi, M.Z., A.R. Bahari, S. Abdullah and A.K. Ariffin, 2014. Comparison of Young's modulus property determination of metallic materials under two statistical analysis methods. Adv. Mater. Res., 894: 186-191.

Radovic, M., E. Lara-Curzio and L. Riester, 2004. Comparison of different experimental techniques for determination of elastic properties of solids. Mater. Sci. Eng. A, 368: 56-70.

Safizadeh, M.S. and S.K. Latifi, 2014. Using multi-sensor data fusion for vibration fault diagnosis of rolling element bearings by accelerometer and load cell. Inform. Fusion, 18: 1-8.

Salem, J.A. and A. Singh, 2006. Polynomial expressions for estimating elastic constants from the resonance of circular plates. Mater. Sci. Eng., 422: 292-297.

Yoshida, T., K. Sakurada and M. Hoshino, 2010. Measurement of static stress in round bar by impact sound. Proceedings of the 14th International Conference on Experimental Mechanics, July 4-9, 2010, Poitiers, France, pp: 1-2.

Zhu, W.D. and B.H. Emory, 2005. On a simple impact test method for accurate measurement of material properties. J. Sound Vibr., 287: 637-643.