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METALLIC MATERIAL CHARACTERIZATION USING ACOUSTICS SIGNAL ANALYSIS

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Abstract

Characterization of material properties is a vital aspect in engineering structural design as it practically use as a mechanical component. Nonetheless with such application, the component is highly vulnerable to failed under active loading condition. To prevent such failure, a reliable test to characterize the in-service structural component and its material properties is highly sought by manufacturing industries. This study is based on non-destructive testing by implementing the acoustics signals to describe the relationship of metallic material properties. Experimental procedure accordance to ASTM 1876 standards was carried out by using an impact hammer within specific range of impact force and acted to the specimens. Four types of materials were used in the study, such as medium carbon steel S50C, stainless steel AISI 304, cast iron FCD 500, and brass. The measurement process involves two types of observation data signal which were acoustic signal and impact force. Subsequently, microphone and an impact hammer were used for data acquisition signals. Acoustic signals are then filtered and analyzed using two methods, namely Integrated Kurtosis based Algorithm for Z-notch filter (I-kaz™) and Mesokurtosis Zonal Nonparametric (M-Z-N). The experimental curves obtained by the determination of I-kaz™ coefficient and M-Z-N coefficient for various impact forces and metallic materials found that the results were statistically significant and can be successfully used for determining the correlation between the characteristic of the curves and the relevant elastic properties of the metallic materials. Apparently, experimental test of this analysis method on four metallic materials showed a good agreement between the quadratic coefficients with the metallic materials properties.

Keywords: Metallic material properties; Acoustic signal; I-kaz™ Method; M-Z-N method

Abstrak

Pencirian sifat bahan merupakan aspek penting dalam kejuruteraan reka bentuk struktur yang sering digunakan dalam rekabentuk komponen mekanikal. Namun begitu, komponen mekanikal terdedah kepada kegagalan di bawah keadaan beban aktif. Untuk mengelakkan kegagalan ini, pembuatan. Ujian pencirian sifat bahan adalah amat penting dijalankan di industry p. Kajian ini adalah berdasarkan kepada ujian tanpa pemusnah dengan menganalisa isyarat akustik bagi melihat hubungannya dengan sifat bahan logam. Prosedur eksperimen mengikut ASTM 1876 standard telah dijalankan dengan menggunakan tukul impak dalam julat daya impak yang tertentu dan dikenakan pada spesimen. Empat jenis bahan yang digunakan dalam kajian ini, seperti sederhana S50C keluli karbon, keluli tahan karat AISI 304, besi tuang FCD 500, dan tembaga. Proses pengukuran melibatkan dua jenis isyarat iaitu isyarat akustik dan daya impak. Mikrofon dan tukul impak digunakan untuk pemerolehan data isyarat. Isyarat akustik kemudian dituras dan dianalisis menggunakan dua kaedah, iaitu Integrated Kurtosis based Algorithm for Z-notch filter (I-kaz™) dan Mesokurtosis Zonal Nonparametric (MZN). Dari lengkung eksperimen menunjukkan penentuan pekali I-kaz™ dan pekali MZN untuk pelbagai daya impak dan bahan-bahan logam memberikan keputusan yang memberi kesan dan berjaya digunakan untuk menentukan korelasi antara ciri lengkung dengan sifat-sifat elastik bahan logam. Oleh itu, ujian eksperimen menggunakan kaedah ini terhadap empat bahan-bahan logam menunjukkan hubungan yang baik antara pekali kuadratik dengan sifat-sifat bahan logam.

Kata kunci: Sifat bahan logam; isyarat akustik; I-kaz™ Kaedah; Kaedah M-Z-N

1.0 INTRODUCTION

Material characterization is a factor to in development and quality improvement, structure enhancement, material properties and performance of materials. In material science engineering, the study of the characterization and properties of materials depend on the manufacturing process and structure of the material. In other words, there is a relationship between manufacturing process and material structures with the properties of materials that will affect the performance of the material [1]. Furthermore this relationship also will give engineers and materials new discovery. Currently, the material design problem is crucial in mechanical, civil, chemical and electrical engineering.

Among the problems in engineering is manufacturing machine components, development and construction of building structures, and design in chip electrical circuit. Conventional experimental methods can measure the properties of certain materials only for different testing machine. For example, universal testing machine can only measure the mechanical properties of certain materials such as Young's modulus, yield strength, tensile strength and maximum bending strength. Measurement of material properties such as hardness, density and impact strength cannot be tested by universal testing machine. The difference machine to operate with different performance also contributed to the inaccuracy of the results.

Impact testing on a specimen by using an impact hammer will cause the specimen to experience vibration at a certain period of time until the dynamic response is reduced after the maximum vibration occurs. In the field of materials engineering, the application of vibration and acoustic resulting from impact testing are used in characterization of materials, thickness gauge, identifying defects and typical damage such as cracks and voids, layer dated, inconsistency of material, deviation toughness, the defect in the microstructure, shrinkage cavities, fragments of material and nodular iron casting breakdown [2].

Research done by researcher [3] used alternative methods of statistical analysis M-Z-N to determine the coefficient of M-Z-N for vibration and acoustic signal obtained from experimental curve. The impact force testing conducted on several types of metal. The study found that there was a good correlation between the resulting quadratic coefficient and elastic properties of the metal materials. Integrated Kurtosis-based Algorithm for Z-Notch Filter or also known as I-kaz^{TM} analysis method is an alternative statistical analysis approach introduced by Researcher [4]. This method encompasses two important statistical characteristics of descriptive statistics and inferential statistics. The researchers [5] have used this technique to determine the relationship between the coefficients of vibration I-kaz^{TM} with polymer material properties. The study has proven is a relationship between I-kaz^{TM} coefficient of vibration signal with polymer materials properties (bulk modulus and hardness Vickers).

This study is to apply a method to characterize materials by applying I-kaz^{TM} and M-Z-N analysis of the acoustics signals obtained from this experiment. The advantage of this method is used specimens can be tested repeatedly without affecting the properties of the material.

2.0 METHODOLOGY

The experimental set-up for this study is shown in Figure 1. This set-up consists of rectangular bars, medium carbon steel S50C, stainless steel AISI 304, cast iron FCD 500 and brass with a size of 250 x 50 x 10 mm (length x width x thickness). The measurement component were an impact hammer and microphone used to pick up impact force and acoustics signal. The impact hammer was used as an impactor to measure force. The predetermined range of impact force was set 400-500N, 600-700N, 800-900N, 1000 -1100N, 1200-1300N, 1400-1500N and 1600-1700N. The microphone was used to measure an acoustic signal. Microphone was located over an antinode point and closes with the specimen. Acoustics signal was analyzed by using I-kaz^{TM} and M-Z-N method. The results of experiment was compared with the elastic properties of the specimens from CES EduPack 2011 [6] and shown in Table 1. The experiment was conducted in a semi anechoic room and the procedure was in accordance with ASTM E1876-07 [7].

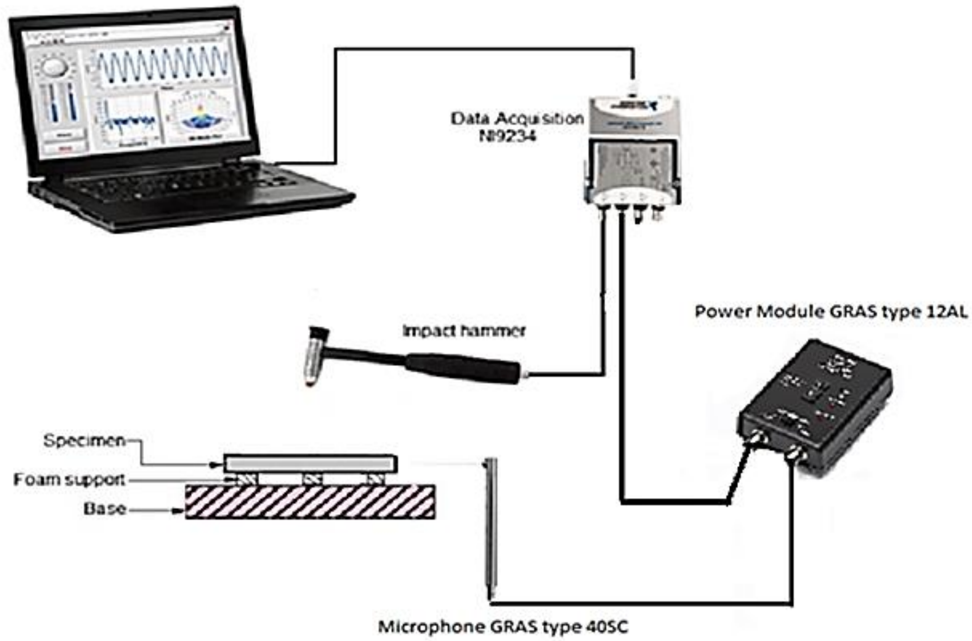

Figure 1 Schematics of experimental design

Table 1 The elastic properties of the specimens [6]

Properties Of Material	Carbon Steel S50C	Stainles Steel AISI 304	Cast iron FCD 500	Brass
Young's Modulous (Gpa)	213.9	196.31	90.5	96.95
Shear Modulus (Gpa)	82.56	77.56	35.53	35.88
Yield Strength (Mpa)	364.8	257.2	81.4	89.6
Tensile Strength (Mpa)	637.5	564.7	124.8	204.8
Rupture Modulus (Mpa)	365	257.52	95.01	89.98

3.0 RESULTS AND DISCUSSION

Impact force generating process is done by using an impact hammer. Therefore, it is very difficult to generate the impact force according to a certain value impact force. To overcome this problem, the impact experiment conducted in a certain range within a predetermined impact. The impact force range is 400-500N, 600-700N, 800-900N, 1000 -1100N, 1200-1300N, 1400-1500N and 1600-1700N. The magnitude of minimum impact force prescribed in this study was within the range of 400-500N. Acoustic signal for each type of material and the magnitude of impact force measured simultaneously in each set of experiments. Dynamic response of the specimen when subjected to the impact force is measured using microphones, and both signals are recorded in the form of an electrical signal time domain. Signal amplitude is in units of volts obtained through the use Lab View software. Figure 2 shows the acoustic signal for medium carbon steel S50C, while Figure 3 was for stainless steel AISI 304. Figure 4 shows acoustic signals for cast iron FCD 500 and Figure 5 for brass

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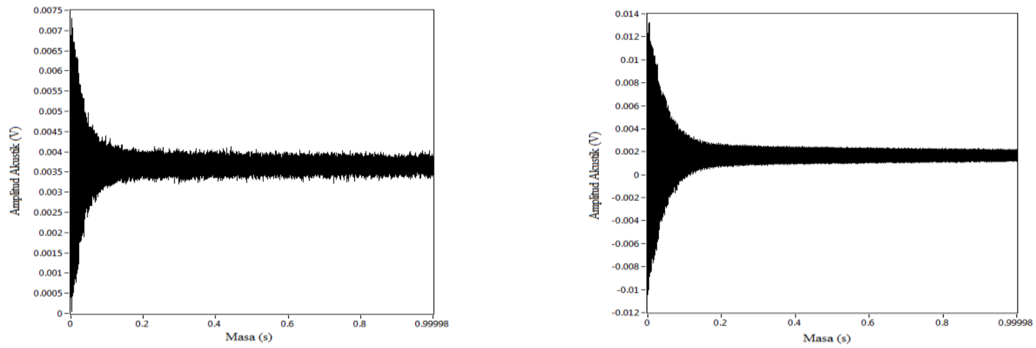
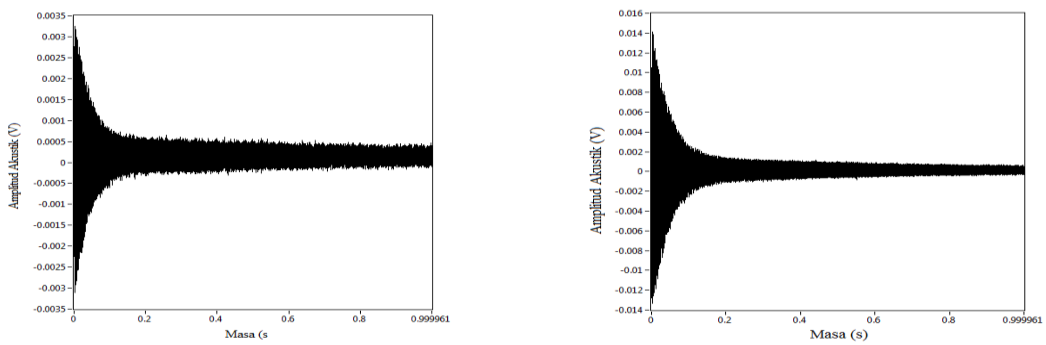


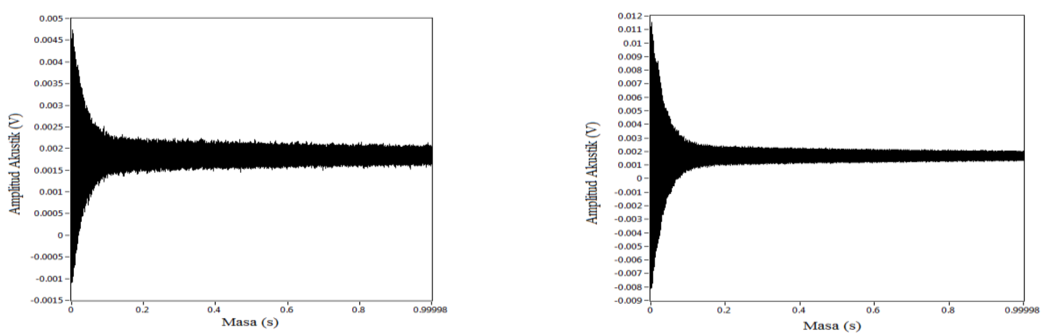
(a) (b)

Figure 2 Acoustics signal for medium carbon steel S50C (a) 456 N (b) 1610 N



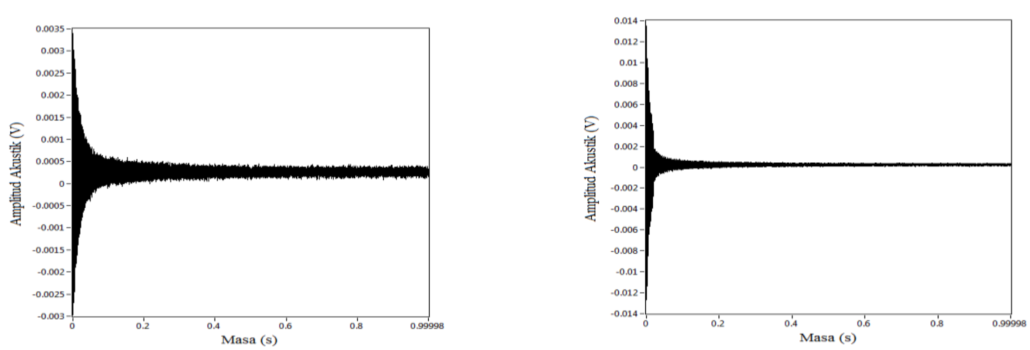
(a) (b)

Figure 3 Acoustics signal for stainless steel AISI 304 (a) 437 N (b) 1661 N



(a) (b)

Figure 4 Acoustics signal for cast iron FCD 500 (a) 476 N (b) 1645 N



(a) (b)

Figure 5 Acoustics signal for brass (a) 458 N (b) 1643 N

Based on Figure 2 to Figure 5 it can be found that the experimental impact on each type of material will produce acoustic signal in transient nature. This phenomenon happens because of the effect of dynamic response of the material after subjected to the impact force [6]. Amplitudes for acoustics signals will increase significantly than the initial amplitude when the impact force exerted on the specimen. When the maximum amplitude of the signal has been reached, the signal amplitude deteriorates rapidly. Difference in shape and height of the amplitude in vibration and acoustic signals for each type of material and the magnitude of the impact force has certain characteristics. Figure 6 show the correlation between the maximum amplitude of acoustics signal versus impact force

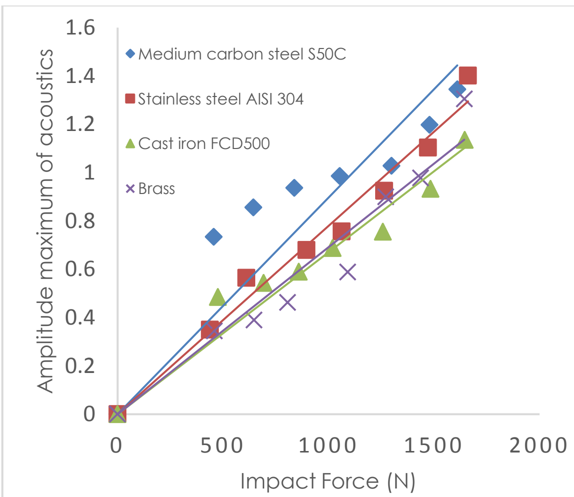


Figure 6 Maximum amplitude versus impact force

3.1 I-kaz™ Statistical Analysis

Integrated kurtosis based algorithm for Z-Notch Filter (I-kaz™) is used to analyze and filter the time domain acoustic signals. This method is also used to analyze information contained in acoustics signal. I-kaz™ analysis will produce the coefficient of I-kaz™ [4]. Value of kurtosis and standard deviation for 3 frequency range of the low frequency range, high frequency range and high frequency range. Using Equation 1, the I-kaz™ coefficient obtained.

$$Z^{\infty} = \sqrt{\frac{\sum_{i=1}^{N}\left(x_i^L - \overline{\mu_L}\right)^4}{N^2} + \frac{\sum_{i=1}^{N}\left(x_i^H - \overline{\mu_H}\right)^4}{N^2} + \frac{\sum_{i=1}^{N}\left(x_i^V - \overline{\mu_V}\right)^4}{N^2}} \qquad (1)$$

Based on experiments, it was found that the I-kaz™ coefficient was slightly lower at 10^{-6} to 10^{-9}. Figure 7 shows the I-kaz™ coefficient for acoustic signals for each type of material and the impact involved in the experiment.

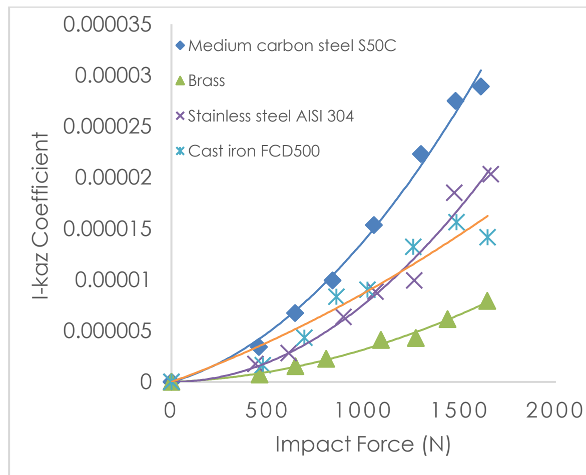


Figure 7 Variation of acoustics I-kaz™ coefficient based on impact force

Table 2 Correlation coefficient, R^2 for quadratic polynomial for I-kaz coefficient

Material	Correlation Coefficient, R^2
Carbon Steel S50C	0.988
Stainless Steel AISI 304	0.982
Cast Iron FCD500	0.975
Brass	0.968

Table 3 Equation for quadratic polynomial for acoustic signal

Material	Equation for the quadratic polynomial
Medium carbon Steel S50C	$y = 1.85\text{x}10^{-15}x^2 + 5.66\text{x}10^{-13}x$
Stainless Steel AISI 304	$y = 1.72\text{x}10^{-15}x^2 - 1.46\ \text{x}10^{-13}x$
Cast Iron FCD500	$y = 7.66\text{x}10^{-16}x^2 + 9.45\ \text{x}10^{-13}x$
Brass	$y = 5.52\ \text{x}10^{-16}x^2 + 4.27\text{x}10^{-13}x$

From the Figure 7 above, the curve form for each material is quadratic polynomial. The general equation of quadratic polynomial for the curve is $y = ax^2 + bx$. This polynomial quadratic curve is choosen due to the high correlation coefficient, R^2 value which between 0.968 until 0.988. The value of correlation coefficient, R^2 of each material is shown in Table 2.

Based on Table 3 above, the difference between the equations are influence by quadratic polynomial coefficient, *a* from the quadratic polynomial equation $y = ax^2 + bx$. This quadratic coefficient was used to get the relation between acoustic signal and modulus of rupture characteristics. Table 4 show the quadratic coefficient and modulus of rupture for each material.

Table 4 Correlation between quadatic coefficient and modulus of rupture

Material	Quadratic Coefficient	Modulus of Rupture (MPa)
Medium carbon steel S50C	1.85 x 10^{-15}	365
Stainless Steel AISI 304	1.72 x 10^{-15}	257.5
Cast Iron FCD500	7.66 x 10^{-16}	95.01
Brass	5.52x 10^{-16}	89.98

Based on the Table 4 above, the material with high modulus of rupture will produce high quadratic coefficient. The result of the experiment has proved that medium carbon steel has highest modulus of rupture which is 365 MPa that produced the highest quadratic coefficient which is 1.85 x 10^{-15} followed by Stainless Steel AISI 304, Cast Iron FCD500 and Brass.

3.2 M-Z-N statistical analysis

To expand the scope to characterize the properties of different materials involving four different types of material, acoustic signals were analyzed using statistical methods Nonparametric Zonal Mesokurtosis (M-Z-N). M-Z-N method was developed on the basis of scattering data of the root mean square (rms) of data containing the energy of the acoustics signal. The M-Z-N coefficient can be obtained from equation 2

$$^{M}Z_N = \frac{1}{M}\sum_{j=1}^{M}\left[\frac{1}{N}\sum_{j=1}^{N}(x_i - rms)^2\right] \quad (2)$$

Figure 8 shows the M-Z-N coefficient for acoustic signals for each type of material and the impact involved in the experiment.

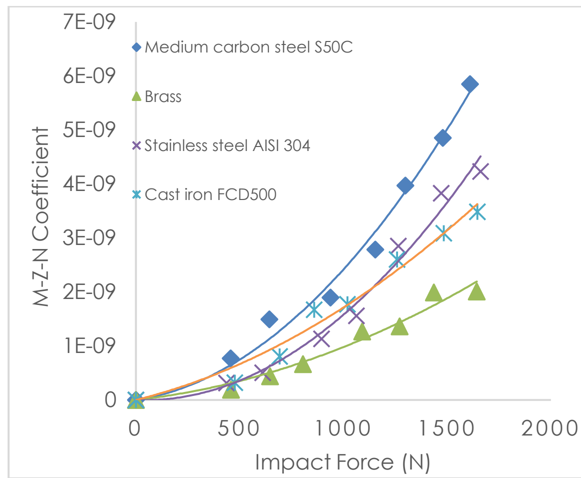


Figure 8 Variation of acoustics M-Z-N coefficient based on impact force

Based on the figure shown, the curve for each material is a quadratic polynomial and the equation is equal to $y = ax^2 + bx$. This quadratic curve is choosen due to the high correlation coefficient, R^2 value which between 0.9082 until 0.9890. The value of correlation coefficient, R^2 of each material is shown in Table 5.

Table 5 Correlation coefficient, R^2 for quadratic polynomial M-Z-N coefficient

Material	Correlation Coefficient, R^2
Medium Carbon Steel S50C	0.9400
Stainless Steel AISI 304	0.9804
Brass	0.9890
Cast Iron FD500	0.9082

Table 6 Equatian for quadratic polynomial acoustics M-Z-N coefficient

Material	Equation for the quadratic polynomial
Medium Carbon Steel S50C	y = 8.43.x $10^{-12}x^2$ + 5.37 x 10^{-09}x
Stainless Steel AISI 304	y = 7.57.x.$10^{-12}x^2$ + 6.17 x.10^{-12}x
Brass	y = 2.457 x $10^{-12}x^2$ + 7.08 x 10^{-10}x
Cast Iron FD500	y = 1.86 x.$10^{-12}x^2$ + 6.81 x.10^{-09}x

Based on Table 6 above, the difference between the equations are influence by quadratic coefficient, *a* from the linear equation $y = ax^2 + bx$ This quadratic coefficient was used to get the relation between acoustics signal and Young Modulus, Shear Modulus, Yield Strength and Tensile Strength. Table 7 show the quadratic coefficient and metallic properties for each material.

Table 7 Quadratic coefficient and Young Modulus, Shear Modulus, Yield Strength and Tensile Strength

Material	Quadratic Coefficient	Young Modulus (GPA)	Shear Modulus (Gpa)	Yield Strength (Mpa)	Tensile Strength (Mpa)
Medium Carbon Steel S50C	$8.43.x\ 10^{-12}$	213.9	82.56	364.8	637.5
Stainless Steel AISI 304	$7.57.x.10^{-12}$	196.31	77.56	257.2	564.7
Brass	2.457×10^{-12}	96.95	35.88	89.6	204.8
Cast Iron FD500	$1.86\ x.10^{-12}$	90.05	35.53	81.4	124.8

Based on the Table 7 above, the material with high Young Modulus, Shear Modulus, Yield Strength and Tensile Strength will produce higher quadratics coefficient. The experiment proved that medium carbon steel S50C has highest value of Young Modulus, Shear Modulus, Yield Strength and Tensile Strength followed by Stainless Steel AISI 304, Brass and cast iron FCD 500.

4.0 CONCLUSION

From the present study, the followings can be concluded:

(a) Applicability of the developed alternative statistical signal analysis method known as Intergrated Kurtosis based Algorithm for Z-notch filter (I-kaz™) and Mesokurtosis Zonal Nonparametric (M-Z-N) to characterize the relevant elastic properties of metallic material.
(b) the development of an alternative signal analysis method has been described in detail and the experimental curves of the I-kaz coefficient and M-Z-N coefficient for different metallic materials have been plotted
(c) correlation between the I-kaz™ coefficient and M-Z-N coefficient and elastic properties of metallic material
(d) Experimental test of this method on four metallic materials shows a good agreement between the quadratic coefficients with the elastic properties of the metallic material.

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