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Studying The Feasibility Of Powder Composite For Mechanical Damping Purposes

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Abstract

The present work is concerned with study some of the mechanical properties (Brinell hardness, Bending strength, Damping) for a metal matrix composite (Aluminum-powder). Firstly Fabrication and characterization specimens reinforced with rice husk ash (RHA) particles are dealt in the present study. The metal matrix composites (MMC's) were prepared by addition of (0,1,2,3,4 and 5%) volume fraction of RHA particulates.

The best mechanical properties for composite metal matrix at volume fraction (3.7%) R.H.A at hardness (70.76 HB) with bending (97.88 Mpa). Secondly estimated the damping constant and damping ratio in structure which is made volume fraction of R.H.A. The main objective of this paper is to estimate the damping ratio, natural frequency, damping constant of metal matrix composite reinforcement with different volume fraction of R.H.A by forced vibration analysis experimentally and theoretically, damping ratio is determine by using half-power bandwidth method. The damping ratio, natural frequency, damping constant proportional directly with volume fraction of R.H.A, best value for damping ratio (0.012) at volume fraction of R.H.A (5%).

Keywords: powder composites, mechanical properties, mechanical damping,

دِراسَة جدوى مُركّباتِ المساحيق لغرض التخميد الاهتزازي الميكانيكي

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الخلاصة

ويهدف هذا العمل الى دراسة بعض الخواص الميكانيكية (صلادة ،قوة الانحناء و التخميد) على المواد المركبة ذات مصفوفة معدنية (مسحوق الالمنيوم). اولا تحضير المادة الداعمة (رماد قشر الارز RHA) ومن ثم تصنيع العينات مع المادة الداعمة يتم التعامل مع هذه المادة في الدراسة الحالية.

أعدت مصفوفة المعدنية المركبة (MMC) بواسطة إضافة جزء حجمي (0، 1، 2، 3، 4 و 5٪) من مادة (RHA). أفضل الخواص الميكانيكية للمعدن المركب في جزء حجمي (3.7٪) RHA لصلابة (HB 70.76) والانحناء (97.88 MPA). ثانيا تقدر نسبة التخميد المستمر والتخميد في مركب العينة في جزء حجمي مختلفة من(RHA) والهدف الرئيسي من هذا المشروع هو لتقدير نسبة التخميد، التردد الطبيعي، التخميد المستمر لتعزيز مصفوفة ذات المركب المعدني مع جزء حجمي مختلف من (RHA) بواسطة تحليل الاهتزاز القسري نظريا وعمليا. نسبة التخميد يتم تحديدها باستخدام نصف الطاقة طريقة عرض النطاق الترددي. نسبة التخميد، التردد الطبيعي، التخميد ثابت يتناسب طرديا مع نسبة (RHA) وافضل قيمة لنسبة التخميد هي (0.012) عند نسبة خلط (5%).

Nomenclature

SYMBOLS	DESCRIPITIONS	UNIT
ω	Natural frequency	Rad/s
Fn	Natural Frequency	Hz
ζ	Damping ratio	
C	Damping coefficient	
Cc	Critical damping coefficient	
E	Modulus of elasticity	Pa (Nm)
I	Moment of inertia	m^4
ρ	Mass density	Kg/m^3
A	Cross section area	m^2

1. Introduction

The damping capacity of a material is an evaluation of the energy dissipated in the material during mechanical vibration. High damping materials, which possess the ability to dissipate mechanical vibration energy, are valuable in the application fields of noise control and for stabilizing structures to suppress mechanical vibrations and attenuate wave propagation [1][2][3]. Practical applications need low density materials that simultaneously exhibit a high damping capacity and good mechanical properties. However, in metals these properties are often incompatible, due to the dependence of the microscopic mechanisms involved in strengthening and damping. Therefore, it would be of interest to develop new materials that simultaneously exhibit good mechanical properties and high damping [3][4]. This is possible only when the microscopic mechanisms responsible for dissipation of the vibration energy are independent of that of the hardening and strengthening. Such a compromise can be achieved by the development of two-phase composites, in which each phase plays a specific role: damping or providing mechanical strength. Metal matrix composites (MMCs) are good candidates because firstly, MMC processing allows the possibility of tailoring the resultant damping properties by selecting high damping reinforcements, secondly, MMC processing modifies the microstructure of metals and alloys, thus introducing energy dissipation source[3][5], and thirdly, typically hard and high strength reinforcements will improve the mechanical properties of the composites.

The uses of aluminum and its alloys have greatly increased in recent years due to the proper physical and mechanical properties of these alloys such as the low density, high strength to weight ratio and superior strength. Aluminum is the only one of the light metals in that it lends itself readily to being shaped and worked. The disadvantage of the strength and stiffness of aluminum as compared to steel is largely offset where weight is a consideration. Thus, the density of aluminum, which is about 2.7 g/cm^3 as compared with 7.8 g/cm^3 for steel and 8.8 g/cm^3 for copper, is of extreme importance. The wear resistance of aluminum, as might be suspected from its surface hardness of aluminum will broaden its applications [6].

The reinforcements in a composite can take either discontinuous (particulates, platelets, whiskers or chopped fibers) or continuous (typically long fibers) form. Continuous fiber reinforcements may provide the most effective strengthening (in a given direction), while particulate reinforced materials are more attractive owing to their cost-effectiveness, and isotropic properties.

2. Literature Survey

Hui Lu, Xian ping Wang, Tao Zhang [1] The damping mechanisms of the MMCs are the intrinsic damping of the metal matrix, the intrinsic damping of the reinforcing particulates, and the particulate/matrix interface damping. Regarding the processing of high damping MMCs, a variety of classic techniques and variants can be utilized. Due to the incompatibilityof high damping and good mechanical property, and the flexibility of damping mechanisms, most of the existing materials still cannot meet the demands.

Prasad D. [2] Was studied Fabrication and characterization of A356.2 alloy reinforced with rice husk ash (RHA) particles. Mechanical properties like density and hardness were measured for the composites. As the percentage of RHA particles increases, the density of the composites decreases and there is slight increase in the hardness.

Maher. A etc [3] An improved dynamical model for vibration damping in composite structures is introduced to investigate the stacking sequence and the degree of anisotropy as a function of the vibration modes. Extensive investigation has been carried out from the fitting of modal measurements with lowest residual errors to establish quasi-uniform mass damping models in terms of normal coordinates system. There is an existence of generalized quasi-rectangular hyperbolic relationships between the loss factor sand natural frequencies of composite structures and can be found at any selected range of frequency spectrum.

Hasan G Pasha [4] The error calculated by comparing the experimental value of the natural frequency with the standard value is as a result of the fact that any vibration is damped to some extent. In this case the Coulomb damping caused due to air was neglected. Error can also be attributed to the fact that the material in the cantilever might not be uniformly distributed in the material continuum as assumed. Layer upon a substrate is considered as the top level of the structural hierarchy.

THAER A.SHIHAB. [12] This research was a Study the Sintering Effect on the Mechanical Properties of Manufacture Parts Made from a Mixture of Copper and Graphite Powder.

ANHUSH.J.[13] The main objective of this research is to study the vibration damping characteristics of three material (aluminum ،brass and steel).To collect the data based on two parameters(excitation force،excitation frequency) using forced vibration technique and compare it theoretical results. The cantilever beams have been subjected to sine sweep test and damping ratios has been computed using half power bandwidth method. The damping ratio increase with decrease in thickness for each material, the material damping decrease with increase in natural frequency of the cantilever specimens for each material, the damping of aluminum was found to be lowest than either steel or brass.

3. Experimental procedures

3.1. Preparation of the Specimens

A Mold is designed in the Technical College - Baghdad, dies and the tools department using steel type (100Cr6).The dimensions of the punch is (200 mm X 10 mm X 38 mm) shown in **Figure (3-1).**

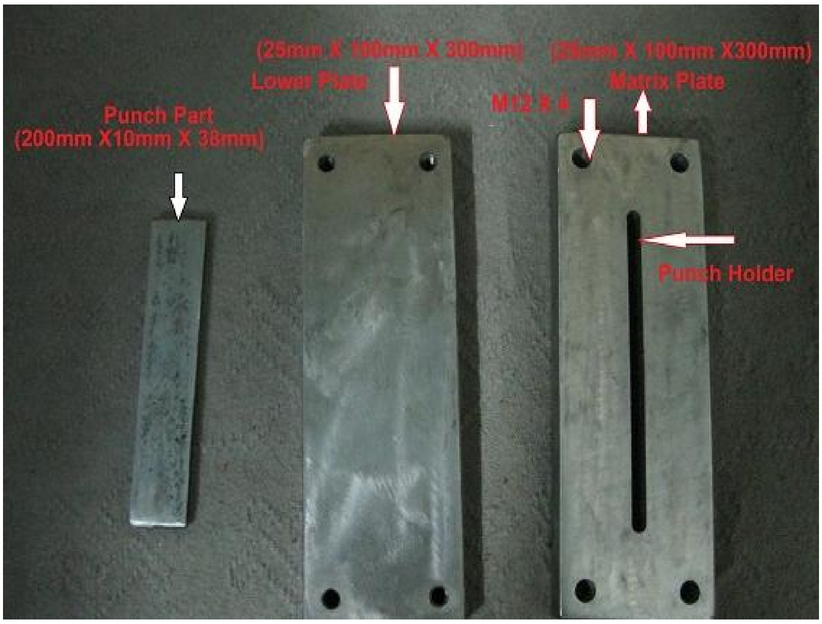


Fig. (3-1) Part of the Mold

3.2. Preparation of Rice Husk Ash

Rice husk in an agricultural waste and is available in very large quantities throughout the world. Rice husk, which essentially protects the rice grain during growth, contains approximately 50 to 60% fixed carbon, the reseeding silica and minor oxides. Rice husk was procured from local sources in Iraq and was thoroughly washed with water to remove the dust and dried at room temperature for 1 day. Washed rice husk was then heated to 200 C for 1 h in order to remove the moisture and organic matter. During this operation, the color of the husk changed from yellowish to black because of charring of organic matter. It was then heated to 700 C for 90 minute to remove the carbonaceous material .After this operation, the color changed from black to grayish white as show in **Figure (3-2).** The amount of ash produced when husks are burned is only about 20% by weight of the total husks. [7]

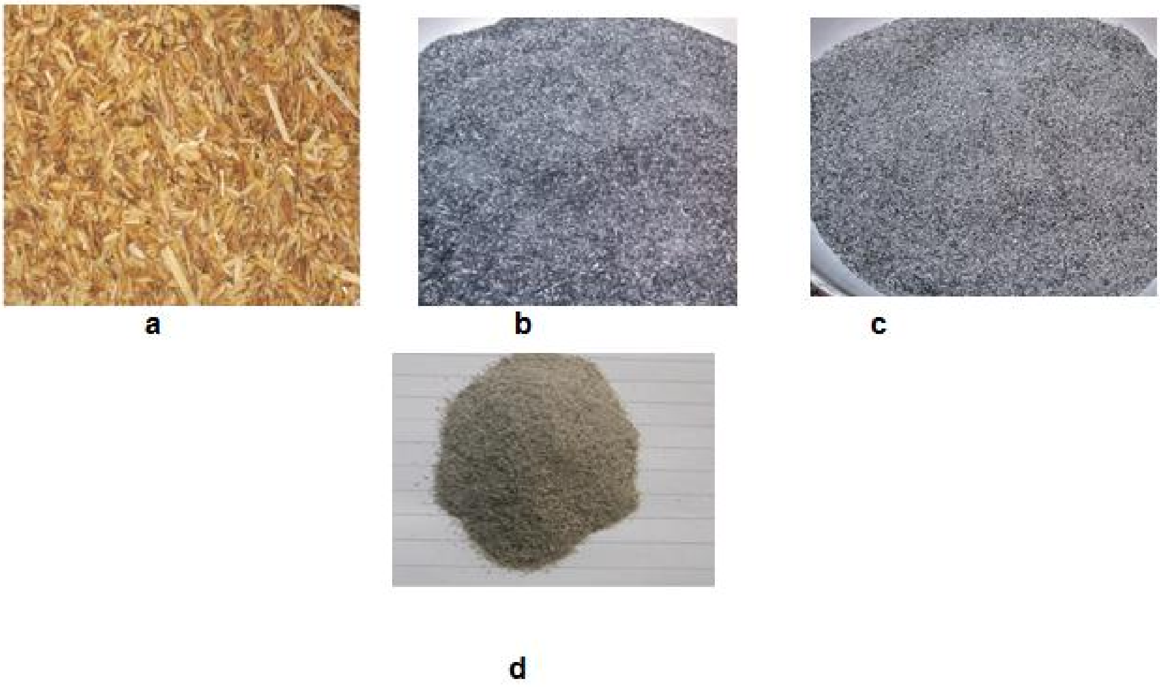


Fig. (3-2) Represents The Step of Transformation of Rice Husk

(a) Rice husk, (b) high carbon RHA, (c) optimum RHA (d) RHA with silica

The silica-rich ash, thus obtained, was used as a filler material in the preparation of composites. Chemical composition of the rice husk ash after the above treatments is shown in **Table (1).**These results analyzing a sample of the RHA in the laboratories of Ibn Sina state company.

Table(1) Chemical Composition of Rice Husk Ash

Constituent	%composition
Silica – SiO_2	**62.72**
Alumina – Al_2O_3	**0.616**
Calcium oxide – CaO	**3.65**
Magnesium oxide – MgO	**1.79**
Potassium oxide – KaO	**1.088**
Ferric oxide – Fe_2O_3	**1.25**

There are two samples of rice husk ash s prepared to measure the density as shown in **Table (2)**

Table (2) Density of Rice Husk Ash (physical properties)

Sample No.	Grain Size (Micro)	Bulk density (g/ml)	Real density (g/ml)
1	**< 180**	**0.1838**	**0.2411**
2	**< 25**	**0.346**	**0.3972**

3.3. Aluminum powder

Aluminum (Al) is a widely used non ferrous material in the manufacturing of different engineering and commercial products owing to its good strength to weight ratio. Powder metallurgy (P/M) is one such process used in processing of the Metal Matrix Composites (MMCs). The basic manufacturing steps in P/M include powder mixing, compacting and sintering of the powder mixture. In Powder metallurgy, it is important to compact the powder to a required shape to obtain sufficient strength, porosity and density **[8]**.

The main characterization of aluminum powder can be shown in the table (3). All of the data were achieved from packing label for manufacturer.

Table (3) Properties of aluminum powder [9]

Material	Company	Properties
Al	Himedia	Composition :99.47% (purity) Maximum limits of impurities a. Iron (Fe) :0.5% b. Heavy metals (as Pb): 0.03% Particle size : (25 micro) Density :(2700 Kg/m^3) Young's modulus : 0.69x10^{11} (N/m^2)

3.4. Powder compaction

Powder compaction is the process of compacting metal powder in a die through the application of high pressures at room temperature. Typically the tools are held in the vertical orientation with the punch tool forming the bottom of the cavity. The powder is then compacted into shape and then ejected from the die cavity [10][11].Pressing process is done in material laboratory at Technical College - Baghdad **Figure (3-3)** shown the hydraulic press. Through multiple tests to see how much pressure is obtained on 250 bars depending on the surface area of the sample the pressing time was about minute [11].

Fig. (3-3) Hydraulic Press

3.5. Furnace and Sintering.

Involving a process of heating the samples in a controlled oven and a temperature just below the melting point of metal powder for the purpose of establishing the bonds between the metal particles melted or pressed without distortion [5] [6].One of the factors affecting the sintering; [temperature, time of stay, Atmosphere interaction (an inert gas)].Estimated the temperature used in the sintering process by (60-90) % of the melting point metal [12].
Samples were sintered at 550 C_o for 40 minute [12] as shown in **Figure (3-4)** using a vacuum furnace under pure argon at the department of production engineering and minerals in the University of Technology As have shown **Figure (3-5).**

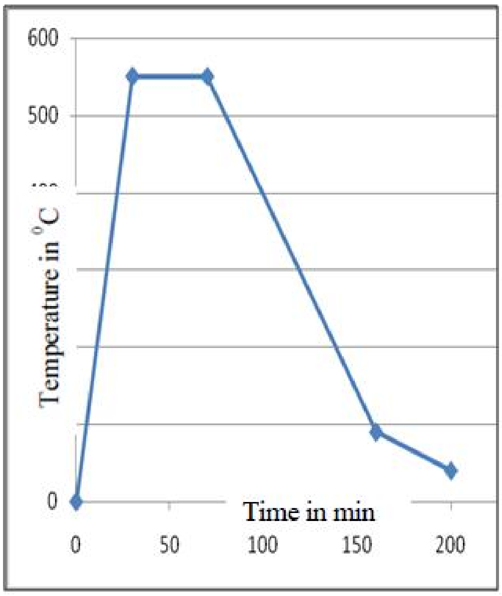


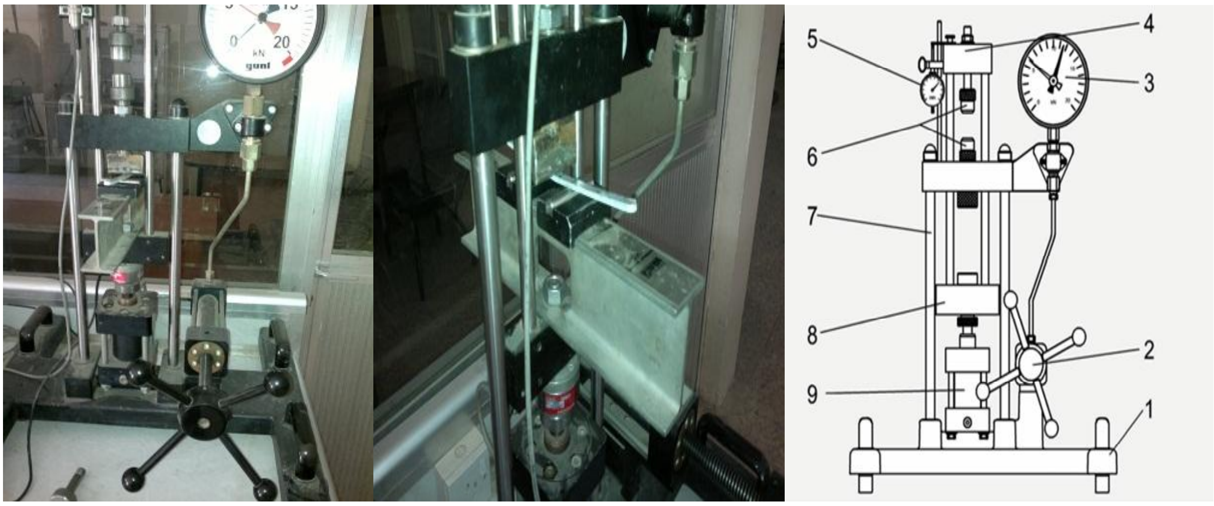
Fig. (3-4) Sintering Cycle

Fig. (3-5) Vacuum Furnace

3.6. Mechanical Properties Test

3.6.1. Bending Test

The test base on three points bending condition**.** The specimens dimensions according to ASTM E290 standardization .This test was performed on the Gunt universal tester added data acquisition card in the strength of material lab on technical collage – Baghdad, as shown in **Figure (3-6).**



1machine base with rubber feet, 2 hand wheel, 3 load gauge, 4 upper cross- member, 5 gauge for deformation displacement, 6 gripping heads, 7 frame pillars, 8 lower cross-member, 9 main hydraulic cylinder

Fig. (3-6) Gunt WP 300 Universal Tester

3.6.2. Brinell Hardness Test

Hardness of the unreinforced and RHA reinforce were measured using a standard Brinell hardness tester shown in **Figure (3-7).** A test load of 3000Kg_f is applied on the specimens for 10sec. The diameter of the steel ball indenter is 10mm. Hardness test were carried out at Mustansiriya University the college of engineering - mechanical engineering department laboratory of graduate studies, name of the device (brooks).
An average of seven readings was taken of each sample for hardness measurements.

Fig. (3-7) Brinell hardness Tester

3.6.3. Damping Test

Specimens dimensions according to ASTM E756-04E01standardization (200 mm X 10mm X 3mm) as shown in **Figure (3-8)**

Fig .(3-8) Damping Specimen

The instruments used in measuring the damping shown in **Figure (3-9)**, **Figure (3-10).** The experimental vibration system consists of six main components as shown in **Table (4).**

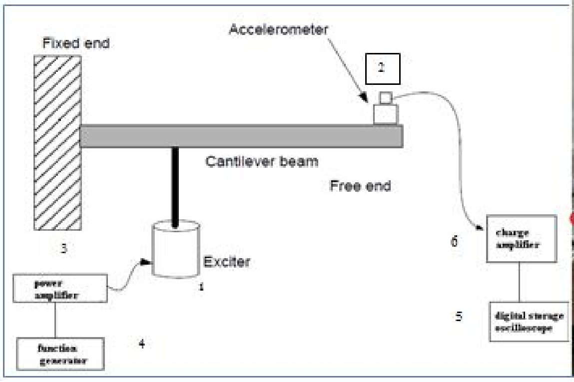


Fig .(3-9) Parts of the Damping System

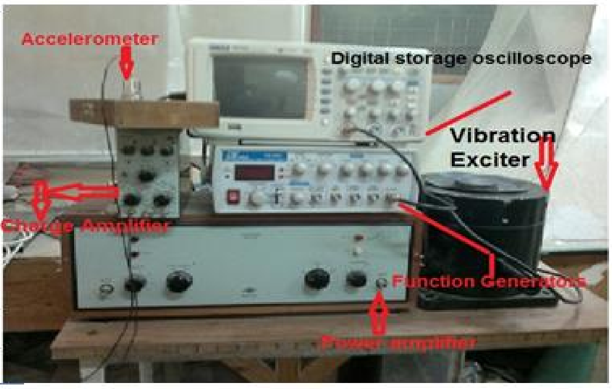


Fig .(3-10) Damping System

Table (4) main components of damping system

No.	Instrument	Note
1	Vibration exciter	(B & Kjaer type 4808)
2	Accelerometer	(B & Kjaer type 2760)
3	Power amplifier	(B & Kjaer type 2712)
4	Function generators	(Lutron FG.2003)
5	. Digital storage oscilloscope	
6	Charge amplifier	

3.6.3.1. Experimental Setup

1. A beam of composite material (aluminum & aluminum with RHA dimensions (200mm, 10mm, and 3mm) was used as cantilever beam Figure (3-8)
2. The fixed end was made by clamping on the combo base.
3. Linking parts of the system as shown in Figure (3-9).
4. Started the experimental by giving force signal to the exciter and allow the beams forced vibrate shown in Figure (3-11).
5. The FFT analyzer and the accelerometer are interface to convert the time domain data to frequency domain.
6. Begin to change the value of the frequency of power while getting a great response for the case of resonance as shown in Figure(3-12).
7. Record the values of frequency, which represents the natural frequency and is drawn through the drawing، can; calculate the value of damping ratio.

Fig .(3-11) Cantilever beam

Figure(3-12) shows acceleration data in the time domain, which in converted to the frequency domain via FFT (Fast Fourier Transform) so that the natural frequencies and damping identified.

The yellow color represents the acceleration data in X-direction in the time domain plot reads from start to stop varying of frequency in the select frequency.

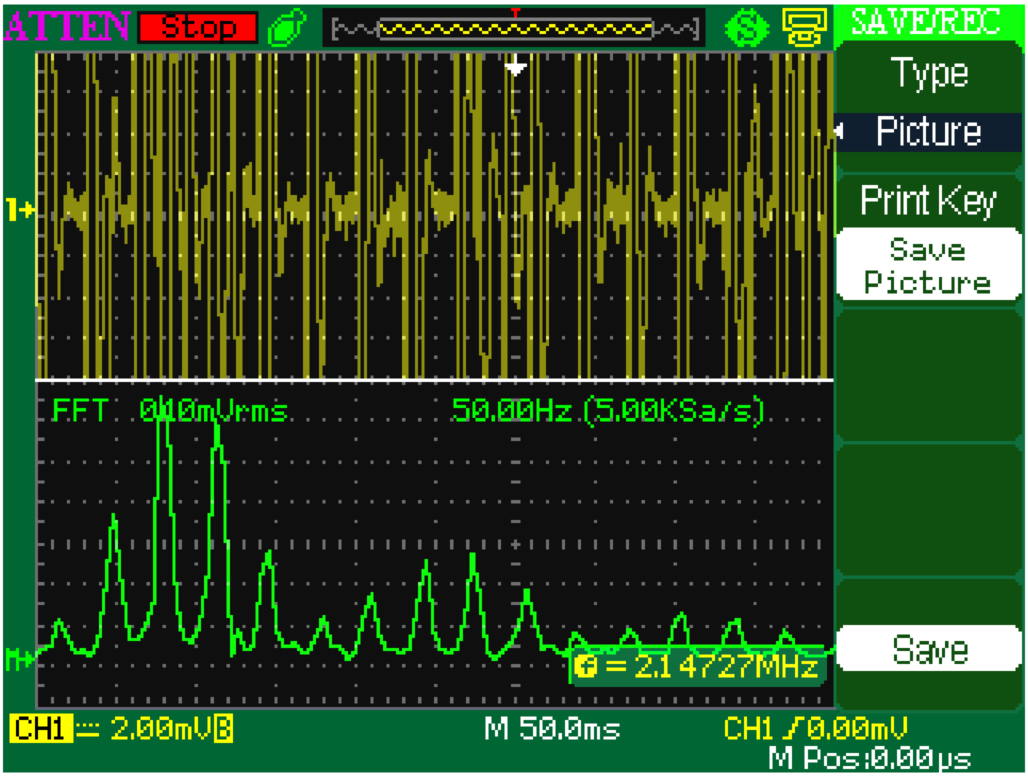


Fig .(3-12) Time - Response graph for aluminum beam

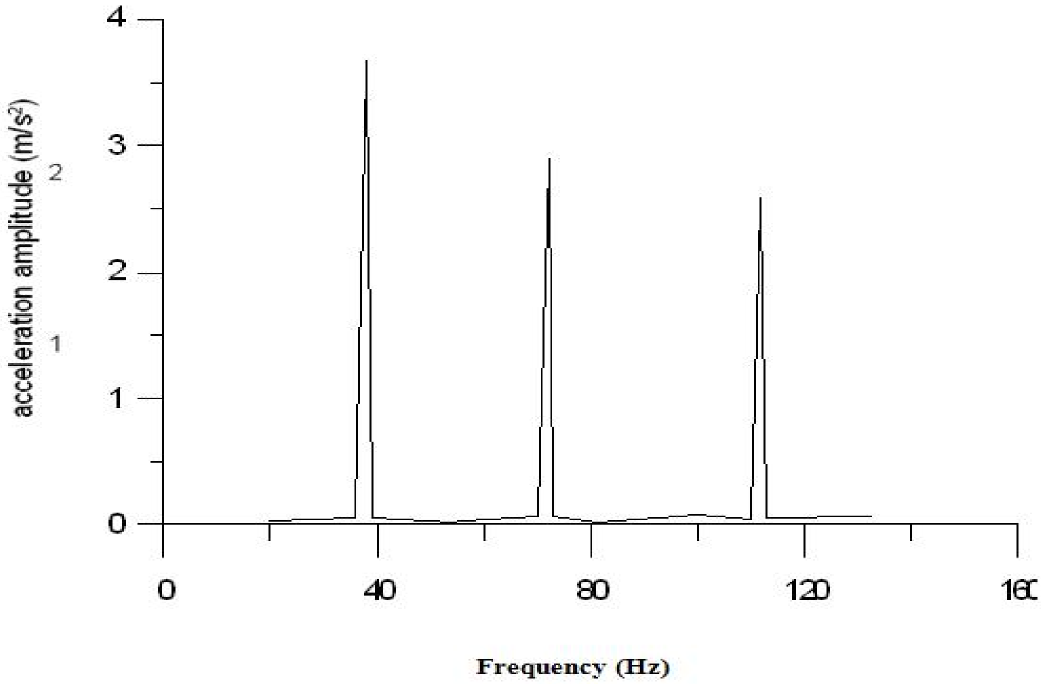


Fig .(3-13) Acceleration Vs frequency graph in X-direction

3.6.3.2. Calculation of Damping Ratio Using Half - Power bandwidth Methods

The damping ratio value is calculated as Eq (1):

$$\zeta = \frac{\omega_2 - \omega_1}{2\,\omega_n} \qquad \textbf{Eq (1)}$$

Where ω2 and ω1 are the frequencies corresponding to the half-power Points which defined at which the response amplitude is 0.707 times the resonant response amplitude and ωn is the resonant frequency as shown in Figure (3-14).

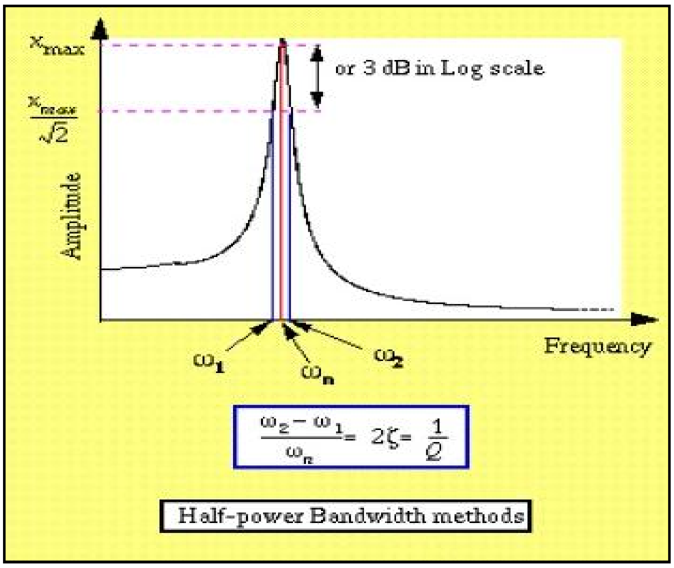


Fig .(3-14) Frequency Response

Figure (3-14) The peak value shows maximum amplitude in terms of acceleration corresponding to fundamental natural frequency i.e. resonant frequency.

From Figure (3-13) the natural frequency (mode 1) which corresponds to the peaks response can be seen to be (38 Hz). The half power points where the response amplitude is equal to 0.707 times [13].At first mode ω_n = 38 Hz corresponding to peak amplitude (3.668 m/s^2) ω_1= 37 Hz, ω_2=38.4 Hz. Hence the damping ratio corresponding to natural frequency 38 Hz is 0.018 .From analysis point of view resonant frequency response amplitude is very important. Since the input force is constant during excitation, the output can be viewed as frequency response function. Hence output response can be considered for analysis of damping for first mode in X- direction.

3.7. Microstructure analysis

Good retention of Rice hush ash particles was clearly seen in the microstructures RHA composites as shown in Figure (3-15)Good interfacial bonding can be obtained by heating of rice husk ash particulates prior to dispersion Scanning electron micrographs of a typical rice husk ash particle which has retained the original shape of the rice husk are shown in (3-16)

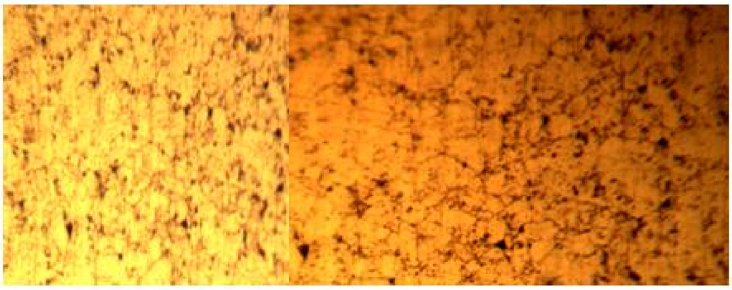


Fig .(3-15) Picture (20x) for RHA comp.mat.

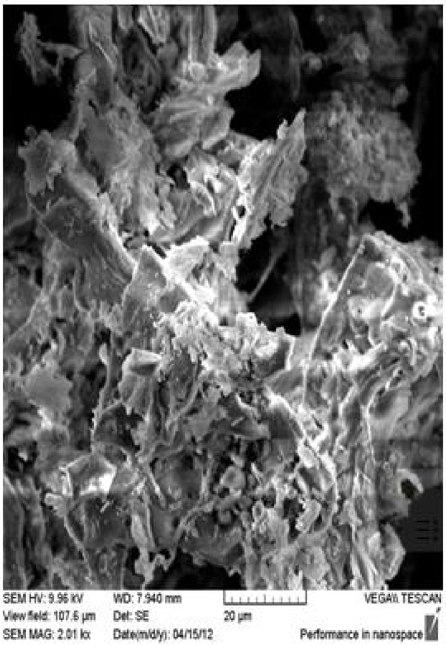


Fig .(3-16) Picture for RHA

4. Results

4.1. Density Result

Figure (4-1) illustrates the density of matrix and composite that reinforced with RHA at variable volume fraction (1, 2, 3, 4 and 5) respectively. Both calculated and measured densities are much closed to gather with my percentage of error doesn't exceed 1.3%.The results reveal that an increase in the percentage of rice husk ash particulates in MMC decreases the material density, this is due to fact rice husk ash particles are lesser denser than aluminum powder.

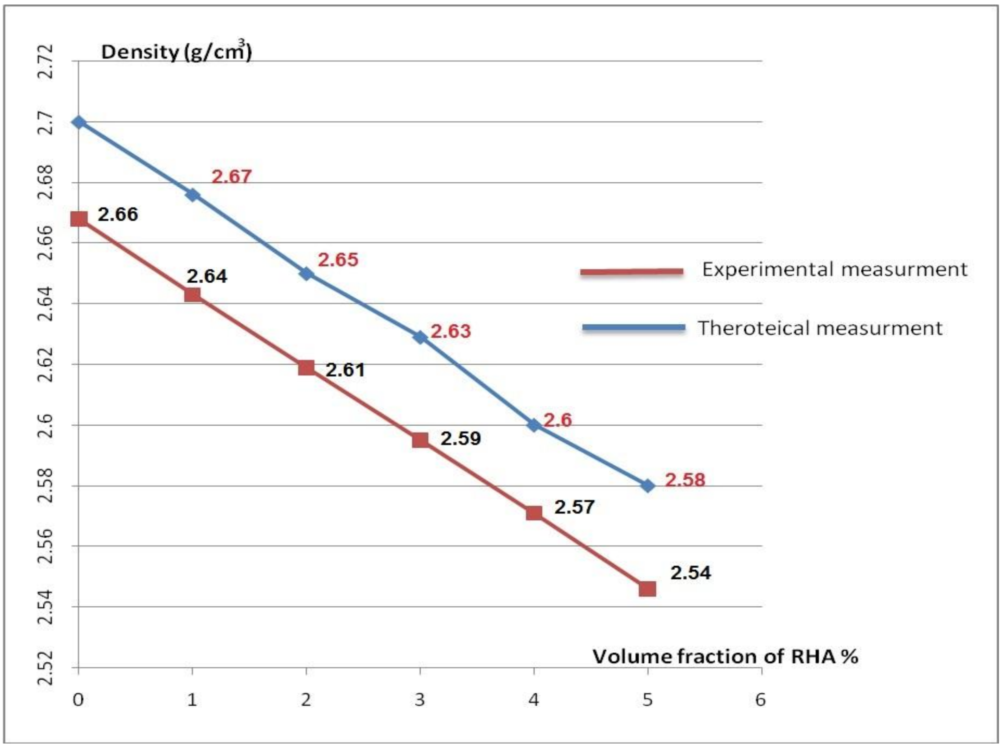


Fig .(4-1) Relation between density and volume fraction % RHA

4.2. Brinell Hardness Test Result

The hardness are proportional to the volume fraction of RHA until to approximate (4%) of RHA and then decreases as shown in **Figure (4-2)**.The increasing in hardness as a result of interface between matrix and reinforcement and the decreasing occurs as a matrix, decreases which lead to decreasing in the bonding between matrix and reinforcement. The increasing in hardness is logical because the high percentage of silica in RHA which leads this increasing.

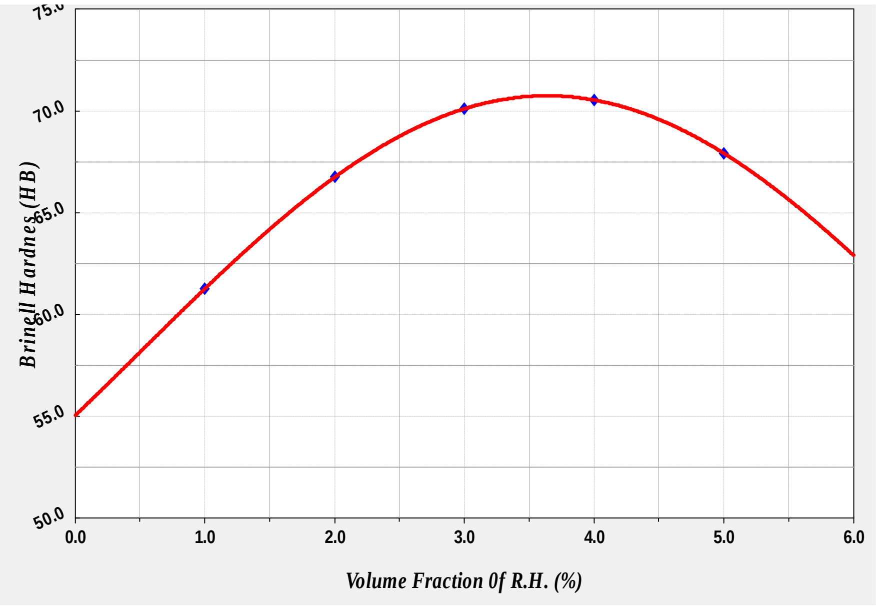


Fig .(4-2) Relation between hardness and volume fraction %

4.3. Bending Test Result

RHA will improve the value of bending strength because of the increasing of contact surface between the RHA reinforcement and matrix this lead to increase strength of the bonding between the particle and matrix until (4%). Bending strength will increase to reaches maximum value **(97.88 MPa)** at volume fraction (3.5 %) RHA (approximate4%) as shown in **Figure (4-3).**

Then the bending strength proportional inversely after (3.5%) as a result of decreasing in bending forces between matrix and reinforcement particles because the sintering temperature less than (95%) melting point and the currying time less than (3 hours).

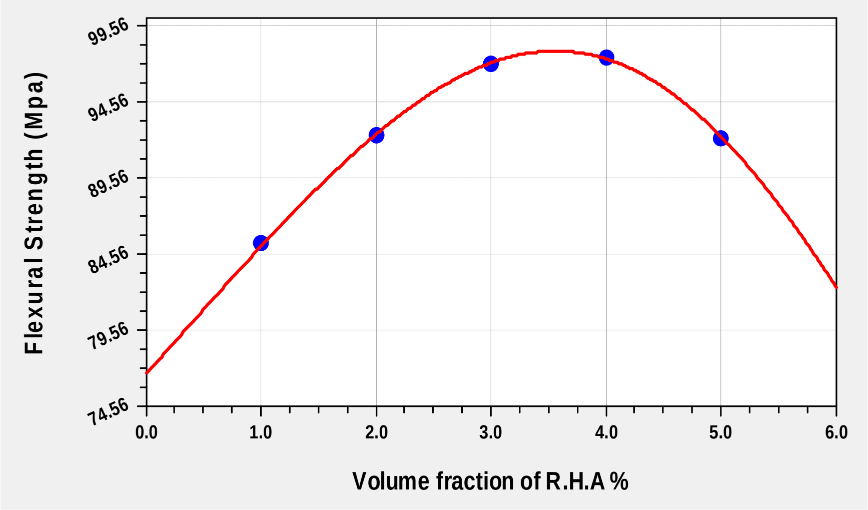


Fig .(4-3) Relation between Flexural strength and volume fraction % RHA

4.4. Damping Test Result

4.4.1. Loss Factors Damping (damping ratio) For Different Volume Fraction of R.H.A

The damping ratios are compared as below in **Table (5)** estimated damping ratio by half- power band width. The damping ratios are proportional to the volume fraction of RHA because the increase of volume fraction of R.H.A will increase distracting signal for first mode and second mode.

Table (5) Variation of Volume Fraction of R.H.A with Damping Ratio for three modes.

Volume fraction of R.H.A %	Mode	Damping ratio (ζ)
0	1	0.018
	2	0.0138
	3	0.0272
1	1	0.018
	2	0.0138
	3	0.0289
2	1	0.019
	2	0.0138
	3	0.0345
3	1	0.022
	2	0.0142
	3	0.0257
4	1	0.0354
	2	0.018
	3	0.012
5	1	0.0354
	2	0.087
	3	0.012

4.4.2. Comparison of Damping Coefficient (c) For Different Volume Fraction of R.H.A%.

The **Table (6)** shows the damping coefficient for different volume fraction of R.H.A according to Eq (2), Eq (3) and Eq (4)

$$\omega_{nf_1} = C_1^2 \sqrt{\frac{EI}{\rho A L^4}} \text{ rad/sec} \qquad \text{Eq (2)}$$

$$\omega_{nf_2} = C_2^2 \sqrt{\frac{EI}{\rho A L^4}} \text{ rad/sec} \qquad \text{Eq (3)}$$

$$\omega_{nf_3} = C_3^2 \sqrt{\frac{EI}{\rho A L^4}} \text{ rad/sec} \qquad \text{Eq (4)}$$

Table (6) the damping coefficient for different volume fraction of R.H.A%

Volume fraction RHA %	Mode	Damping coefficient by experimental method	Frequency Hz
0	1	7.614	38
1		10.2	54
2		10.48	58
3		15.47	88
4		19.53	112
5		20.24	112
	2		
0		14.43	72
1		15.12	80
2		20.61	114
3		30.94	176
4		38.36	220
5		41.24	228
0	3	22.44	112
1		24.95	132
2		30.75	170
3		48.63	266
4		57.89	332
5		60.35	334

5. Conclusion

1. R.H.A ratios (1, 2,3and 4) are directly proportional even to ratio (5%).
2. All properties change the behavior from exponential to inverse proportionality ratio after (3.7%) from R.H.A.
3. Bending strength will increase to reaches maximum value **(97.88 MPa)** at volume fraction (3.7%) RHA.
4. Change constants damping (**C**$_1$, C$_2$, C$_3$) with the volume fraction of R.H.A according to the equation (***y=(a+bx)/(1+cx+dx^2)***) from program name (Curve expert 1.3)which gave the highest correlation coefficient and the standard errors less
5. The natural frequency increases with increase the ratio of R.H.A.
6. The best mix gave the best results for all variables at the volume fraction (**3.7%**) RHA.

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