DAMPING BEHAVIOUR OF CAST AND SINTERED ALUMINIUM

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ABSTRACT

Estimating damping in structures made of different materials and processes still remains as one of the biggest challenges. Aluminium is one such pioneer material which is being used extensively in aerospace, automotive and the manufacturing industry. Aluminium components are mainly manufactured by traditional casting and powder metallurgy process. The main objective of this paper is to estimate the damping ratio of aluminium manufactured through powder metallurgy (P/M) process and compare it with the commercially available Cast aluminium. Aluminium powder is compacted, sintered and then it is extruded to the required geometry. Cantilever beams of required size and shape are prepared for experimental purpose and the damping ratio is investigated. Damping ratio is determined by sweep sine test using half power bandwidth method. Free vibration tests also confirmed the damping ratios obtained by sweep sine method. It is observed that damping ratio is higher for sintered aluminium than cast aluminium which may be attributed to increased porosity.

Keywords: aluminium, damping ratio, sweep sine, bandwidth method, natural frequency, sintered.

INTRODUCTION

Aluminium (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. It is only about one-third the weight of steel. Significant weight savings and good mechanical properties can make Aluminium a potential material for most of the mechanical applications especially in automobile and aeronautical industries [Sharma, 2004, Chunlei, 2007]. Progress in the metallurgy of Aluminium and its alloys alongside the manufacturing processes has shown a significant land mark in the process of development of new materials and as a possible replacement for steel family [Neubing, 2002]. Powder metallurgy (P/M) is one such process used in processing of the Metal Matrix Composites (MMCs) [O'Donnell, 2001]. The process offers homogeneity in both composition and microstructure and also good yield of the matrix [Hennessey, 2005]. This technique requires less energy input than the conventional ingot metallurgy processes. 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.

All materials possess certain amount of internal damping, which is manifested as dissipation of energy under vibration [Jeary, 1997]. Its effect is to remove the vibration energy from the system [Dinarogonas, 1976]. This energy in a vibratory system is either dissipated into heat or radiated away from the system. Material damping or internal damping contributes to about 10-15% of total system damping [Rao, 1990]. In vibration analysis, the damping of the system is generally observed in terms of the system response. The loss of energy from the oscillatory system results in the decay of amplitude of free vibration [Riviere, 2003]. In Forced vibration, the energy supplied by the excitation balances the energy loss. This is significant when the system is close to its resonating frequency under self excitation or external excitation. Hence it is really necessary to predict the damping behaviour of such systems under operating conditions to prevent catastrophes occurring due to resonance.

DAMPING MEASUREMENT

The two most popular techniques to evaluate damping are time domain approach and frequency domain approach [Bert, 1973]. Time domain approach, the fundamental principle is energy lost from the oscillatory system which results in decay of amplitude of oscillation. Free vibration technique is the most popular method used to evaluate damping ratio in time domain analysis. But unlike time domain analysis, frequency domain analysis is not based on any time history data. Time domain analysis does not contain any multiple frequency based information which may be important to characterize the dynamic response of a system. Forced vibration is the main concept behind frequency domain analysis. The solution of the vibration problem can be represented as an input/output relation where the force (F (ω)) is the input and vibration amplitude (X (ω)) is the output. If force and vibration are represented in the frequency domain, then the transfer function can be viewed as

$$X(\omega) = H(\omega) * F(\omega) \tag{1}$$

$$H(\omega) = \frac{X(\omega)}{F(\omega)} \tag{2}$$

Where H (ω) is called the Frequency Response Function (FRF). It has both phase and magnitude component. The frequency response function can be determined experimentally. By applying a constant force and sweeping the frequency one can measure the resulting vibration and calculate the frequency response function, and hence characterize the system. Some of the popular experiments in the frequency domain analysis are impulse test method and sweep sine method. The name sweep sine arises due to the fact that the system is made to respond between 2 frequency limits. The suspected natural frequency may lie in between these two frequency limits. At a particular instance of time, the input frequency approaches the natural frequency of the system the amplitude level increases significantly. This is the resonance peak and can be clearly distinguished in the response curve. As soon as the input frequency crosses the resonant frequency, system amplitude keeps on reducing. From analysis point of view, resonant frequency response amplitude is very important. Since the input force is constant during excitation, the output can be still viewed as Frequency Response Function (FRF). Hence output response itself can be considered for analysis of damping. The FRF for a typical single degree of freedom (SDOF) system is shown in Figure-1.

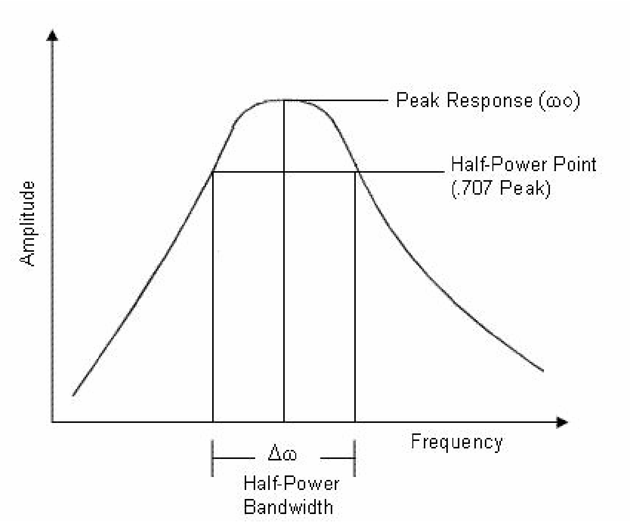

Figure-1. FRF Plot for a SDOF.

For quantitative measurement of damping, the half-power bandwidth method [Clarance, 2007] can be employed. The damping of the structure can be determined from the ratio of Δω and ωo, where Δω is determined from the half-power point below the resonant peak value. On a decibel scale, this corresponds to a–3 dB drop from the peak of the response curve. For this reason, the damping measurement technique is also referred to as the 3 dB method. In bandwidth method damping ratio is given by ratio of half power bandwidth frequency at -3dB drop to the resonant frequency, which is shown in Eq (3)

$$\xi = \Delta\omega / 2\omega_0 \qquad (3)$$

Where ξ is the damping ratio, ω_0 is resonant frequency and Δω is frequency difference at 3dB drop.

In case of free vibrations the damping ratio is evaluated by logarithmic decrement. A typical free vibration response for a SDOF system is shown in Figure-2.

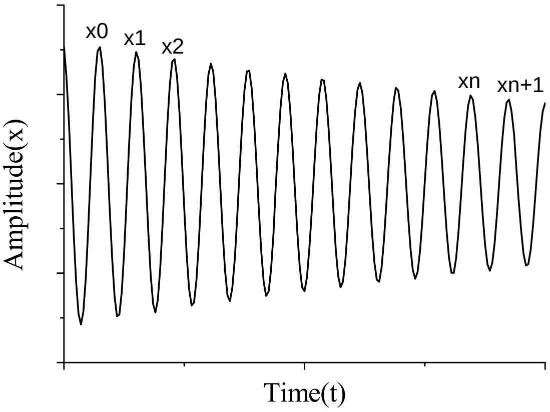

Figure-2. Free vibration response of a SDOF system.

In Figure-1 x0, x1, x 2 etc. are successive amplitudes. Logarithmic decrement [Clarance, 2007] is computed from these amplitudes which is shown in Eq (4)
Logarithmic decrement,

$$\delta = \ln\frac{x_1}{x_2} = \frac{1}{n}\ln\left(\frac{x_1}{x_{n+1}}\right) = \xi\omega_n T \qquad (4)$$

Where x_1, x_2 are firs two successive amplitudes, n is no of cycles, T is period, ω_n is natural frequency, ξ is damping ratio

$$\delta = \frac{2\pi\xi}{\sqrt{1-\xi^2}} \qquad (5)$$

Since, $\omega_d = \omega_n\sqrt{1-\xi^2}$ is damped natural frequency (6)

Hence the equations could be solved to obtain damping ratio

Damping ratio, $\xi = \frac{\delta}{\sqrt{4\pi^2+\delta^2}}$ (7)

SPECIMEN PREPARATIONS

Compaction was done at room temperature (cold pressing). Initially Al powder of 200 mesh size was pressed and its densification behaviour was studied. A die of 25.4mm diameter was designed to obtain cylindrical specimen as per ASTM standard B-925 03. Suitable amount of powder was weighed before pressing. A coating of zinc stearate on the die surface was used to minimise friction during the compaction process. 35 grams of Al powder was taken for compaction. The load was applied through Universal Testing Machine (UTM) of 40 tons capacity at the rate of 2 ton/min. Densification behaviour of nanocrystalline Titania powder under cold compaction has been studied and reported [Lee, 2008]. The compaction unit is shown in Figure-3.

Figure-3. Compaction setup.

After compaction density of the specimen was determined by measuring its mass and volume. The procedure was repeated for varying compaction loads. Figure-4 shows aluminium compact densities for increasing loads.

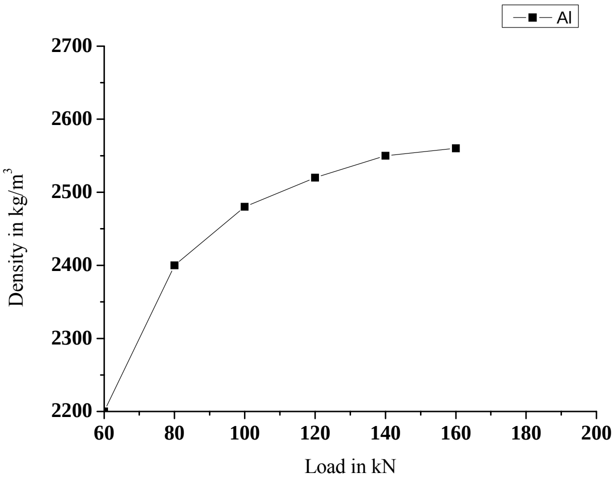

Figure-4. Compaction density for aluminium.

In case of Al it is found that optimal load for compaction is around 120 kN. The microstructures of the specimens were observed under Scanning Electron Microscope (SEM) shown in Figure-5.

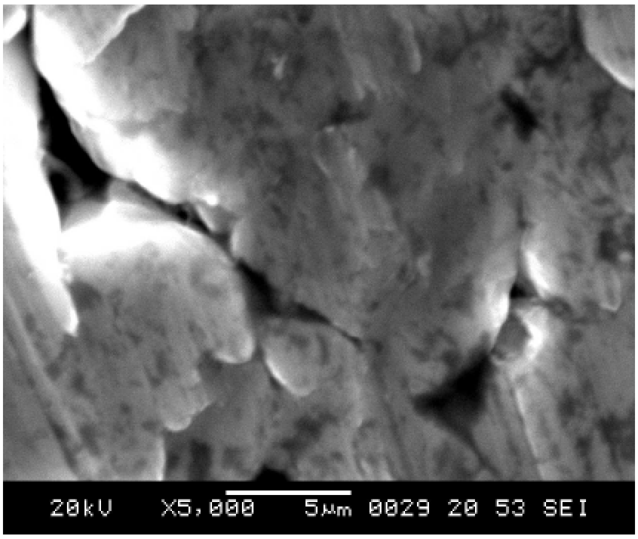

Figure-5. SEM image of compact aluminium.

The SEM image indicates the presence of pores present in the compacted specimen. The sintering setup is shown in Figure-6 and sintering cycle adopted in Figure-7.

Figure-6. Vacuum furnace used for sintering.

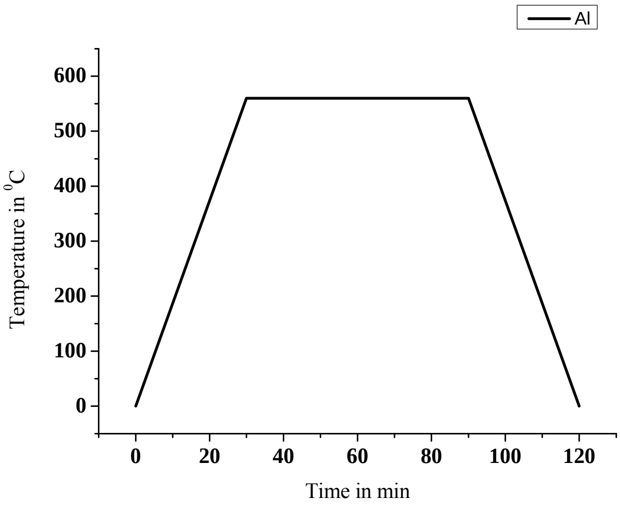

Figure-7. Sintering cycle for aluminium.

The sintered cylindrical Al specimen of diameter 25.4 mm was hot extruded at 400^{0}C into rectangular beam of 15 mm in width and 5mm in depth. The constituent of the sintered Al specimen was investigated under Energy Dispersive Spectroscopy (EDS) shown in Figure-8.

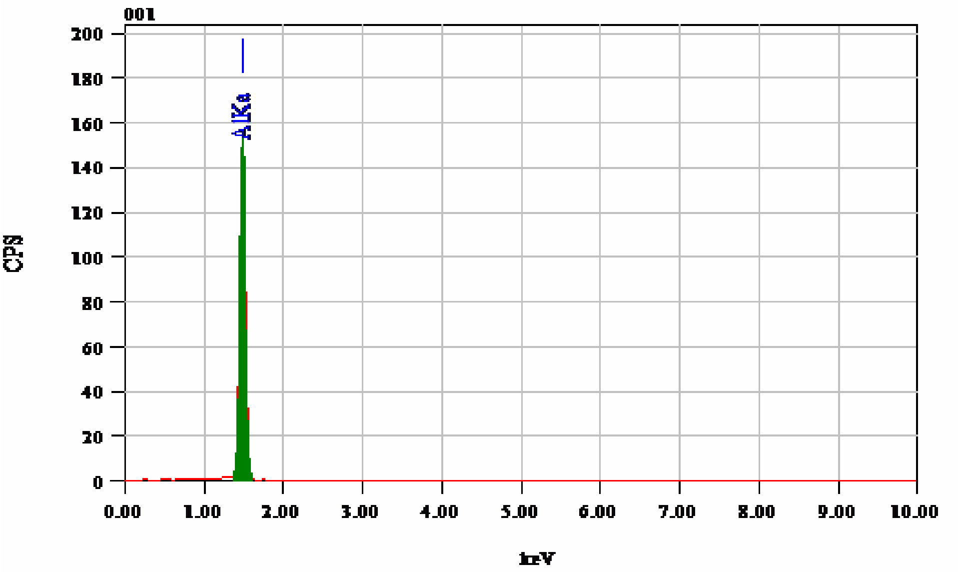

Figure-8. EDS result of compact aluminium.

ED's results confirmed the purity of Al. Cast Al specimen was also machined to the required dimension from commercially available ingots. The hardness of the green compacts and sintered compacts were determined by Rockwell hardness testing machine and compared with conventional cast aluminium and found to be satisfactory.

EXPERIMENTAL SETUP

Sweep Sine tests and free vibration tests was conducted for cast and sintered Al beams of span length 100mm. Electrodynamic shaker of 25kgf was used as an external exciter. Agilent Function generator 3322A was used to generate the required sine function to excite the shaker. Accelerometers A and D 1221 with sensitivity 10mV/g was used to measure the base response or input response. Accelerometer A and D 3101 with sensitivity 9.8mV/g was used to measure the beam response. For data acquisition National Instruments SCXI 1000 chassis with SCXI 1531 Integrated Electronic Piezoelectric acceleration measurement module was used. The data was analysed through MATLAB 7.0. Figure-9 and Figure-10 show the sweep sine experimental setup and LabVIEW block diagram for vibration measurement, respectively.

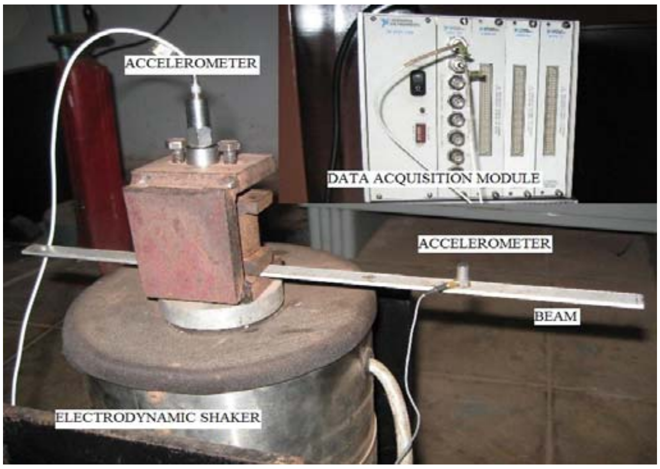

Figure-9. Experimental setup.

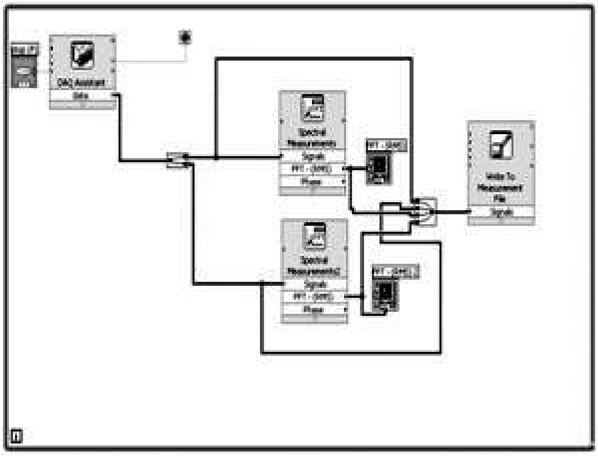

Figure-10. LabVIEW block diagram.

RESULTS AND DISCUSSIONS

Figure-11 and Figure-12 show the FRF for cast and sintered Al of beam length 100 mm obtained through sweep sine test.

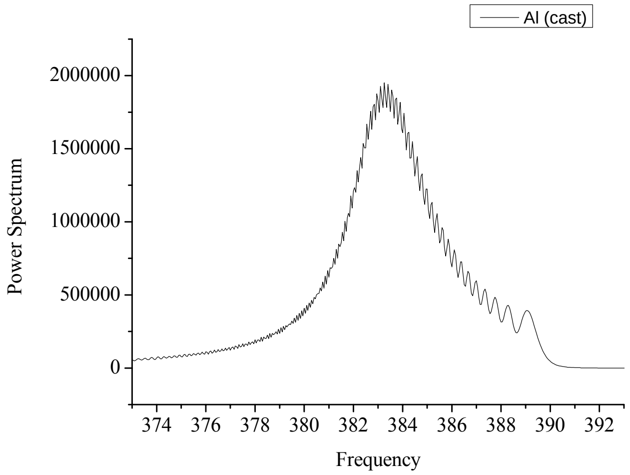

Figure-11. FRF for cast al beam of length 100 mm.

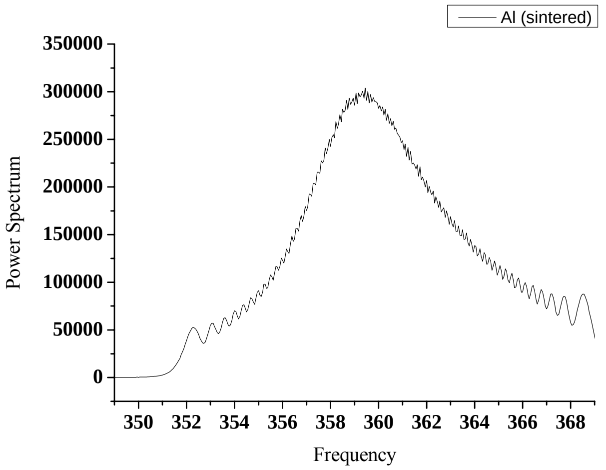

Figure-12. FRF for sintered Al beam of length 100 mm.

Table-2. Natural frequency obtained by experiments for cast and sintered Al for different beam lengths.

Material	Natural frequency
Cast Al	383 Hz
Sintered Al	359 Hz

From Table-2 it can be seen that sintered Al has lower natural frequency compared to cast specimen. This can be accounted to the presence of pores which results in lower stiffness hence in turn lower elastic modulus. Figure-13 compares natural frequencies of the 2 specimens for a span length of 100 mm.

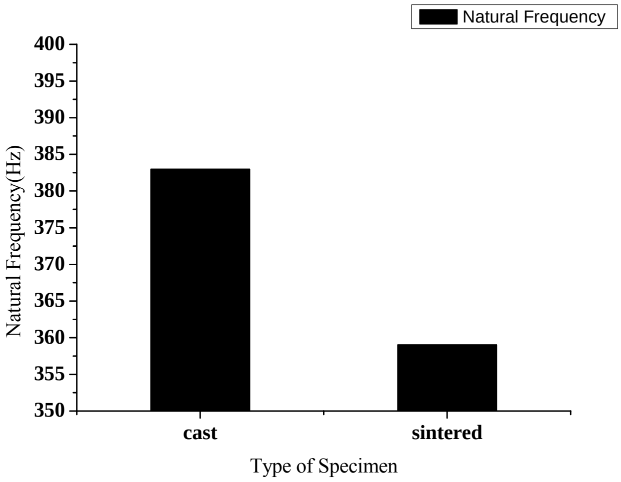

Figure-13. Comparison of natural frequencies.

Figure-14 and Figure-15 shows free vibration response of cast and sintered Al respectively. The time interval has been normalised for comparison with interval being 0.05 seconds. Free vibration test was conducted on rigid support with same sensors and data acquisition system.

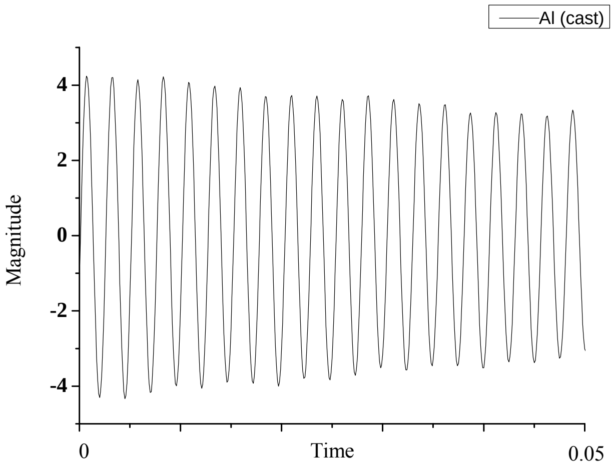

Figure-14. Free vibration response of cast Al of beam length 100 mm.

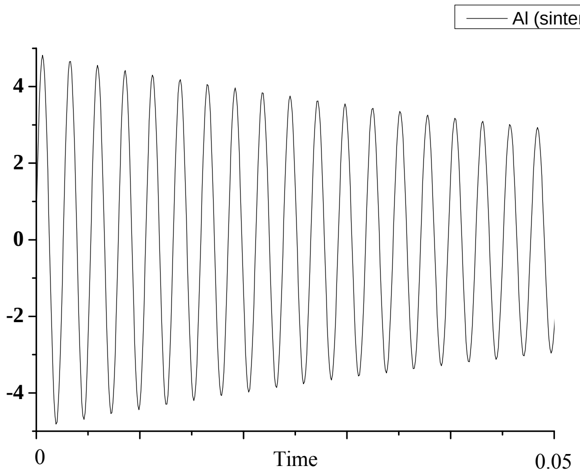

Figure-15. Free vibration response of sintered Al of beam length 100 mm.

The results obtained by sweep sine method were consistent with free vibration results.

Table-3. Comparison of damping ratio for cast and sintered al beams.

Span length	Damping ratio of cast Al beam	Damping ratio of sintered Al beam
100 mm	0.0025	0.0040

From Table-3 it is evident that damping ratio is higher for sintered Al in comparison with cast Al. The reason for increased damping could be the presence of voids and pores incorporated during the powder metallurgy process. The SEM image also had indicated the presence of pores. Figure-16 compares damping ratios of the 2 specimens.

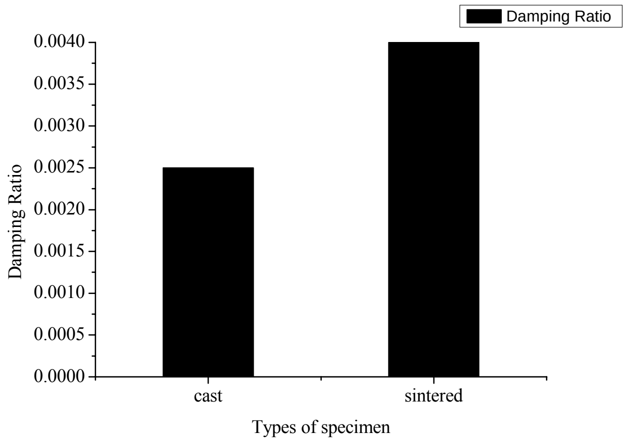

Figure-16. Comparison of damping ratios.

CONCLUSIONS

The main objective of the current paper was to study the damping characteristics of cast and sintered aluminium. Optimal compaction was achieved for powdered Al. The compacted specimen was examined under SEM and also to check the constituents. After compaction, the specimen was sintered in vacuum furnace and its hardness was measured. The sintered Al was extruded into cantilever beams of rectangular geometry. These beams along with the cast Al beams were subjected to sine sweep test and damping ratio was computed using half power Bandwidth method. From the experiments it was evident that damping ratio is higher for sintered aluminium in comparison with cast aluminium. The increase in damping could be correlated to the presence of voids or pores in powder metallurgy specimens.

REFERENCES

Bert C W. 1973. Material Damping: An introductory review of mathematical measures and experimental techniques. J. of Sound and Vibration. 29(2):179-153.

Chunlei jia. 2007. Study on damping behaviour of FeAl3 reinforced commercial purity aluminium. Materials and Design. 28: 1711-1713.

Clarance W. De Silva. 2007. Vibration Damping, Control, and Design. CRC Press.

Dinarogonas AD. 1976. Vibration Engineering. New York, USA: West Publishing.

Hennessey Caley C.H, Kipouros W.F, Bishop D.P. 2005. On Enhancing the Development of Al-Si Based Powder Metallurgy Alloys. Intl. J. Powder Met. 41(1): 50-63.

Jeary AP. 1997. Damping in structures. J wind Eng Ind Aerodyn. 72: 345-55.

Lee S C, Kim K T. 2008. Densification behaviour of nanocrystalline Titania powder under cold compaction. Powder Technology. 186: 99-106.

Neubing C C, Gradl J, Danninger H. 2002. Advances in Powder Metallurgy and Particulate Materials, Part 13, Metal Powder Industries Federation (MPIF). pp. 128-138.

O’Donnell G, Looney L. 2001. Production of Aluminium matrix composite components using conventional PM Technology. Materials Science and Engineering. A303: 292-301.

Rao SS. 1990. Mechanical vibrations. New York: Addison Wesleg Publishing.

Riviere A. 2003. Measurement of high Damping: techniques and analysis. Journal of Alloys and Compounds. 355: 201-206.

Sharma S C, Krishna M, Shashishankar A., Paul Vizhian S. 2004. Damping behaviour of aluminium/short glass fibre composites. Materials Science and Engineering. A364: 109-116.