

Defining and comparing vibration attributes of AlSi10 foam and CFRP coated AlSi10 foam materials

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Abstract. Now, Aluminum materials have begun being manufactured as porous structures and being used with additive composite materials through emerging manufacturing technologies. These materials those porous structures have also begun being used in many areas such as automotive and aerospace due to light-weighted structures. In addition to examining mechanical behavior of porous metallic structures, examining vibration behavior is important for defining characteristic specifications. In this study, vibration attributes belong to %80 porous AlSi10 foam and CFRP coated %80 porous AlSi10 foam are determined with modal analysis. Modal parameters such as natural frequencies and damping coefficient from frequency response functions at the end of hammer impact tests. It is found that natural frequency of CFRP coated AlSi10 foam's is 1,14 times bigger than AlSi10 foam and damping coefficient of CFRP coated AlSi10 foam is 5 times bigger than AlSi10 foam's with tests. Dynamic response of materials in various conditions is simulated by evaluating modal parameters with FEM. According to results of the study, CFRP coating on AlSi10 foam effect vibration damping and resonance avoidance ability positively.

1. Introduction

While designing mechanical systems, Physical attributes of materials that generate parts should be known well. Modal analysis is one of the most effective methods for defining physical attributes and it is used commonly. Natural frequencies, damping coefficient and mode shapes could be found by modal analysis [1]. Frequency interval without resonance could also be found by natural frequencies. Additionally, when Effects of force on materials will wither could be determined by damping coefficient. Materials that used in the study could be produced by several methods. In this study, Powder metallurgy (PM) method is used. PM method works with metal powders such as aluminum and TiH₂ and also utilizes high pressure and heat effects. After pressure implementation and heating processes, TiH₂ powders are vaporized. So materials get porous structure [2]. Interest on using aluminum foam increases because of high energy absorption capacity and low density attributes with in automotive, aerospace and railways where need safety and lightness. Because of porous structures, metallic foams have also good impact absorption ability. Under low stress, metallic foams have energy absorption ability more than non-porous metals [3]. Despite all these good attributes, aluminum foams isn't suitable directly uses due to low stress resistance. They should be supported with composite materials at using areas. Those composite materials bear supportive and protective purposes. Some



composite component materials such as GFRP and CFRP materials are used for coating metallic foams. In previous studies, GFRP coated aluminum foams' attributes have examined [4]. In this study, CFRP coated aluminum foams' vibration responses have defined.

2. Experimental study

2.1 Materials properties

In experimental study, two parts of AlSi10 foam and two parts of CFRP coated AlSi10 foam specimens were tested for modal measurements. Ingredients, pore structures, specimen dimensions belong to specimens is shown at Table 1.

Table 1. Properties of specimens.

Specimens No	Specimens Name	Ingredient	Coating	Dimensions	Pore
1	AlSi10 foam	%82,3Al,%17Si,%0,14Ti,%0,56O	None	50×125×10	%80
2	CFRP coated AlSi10 foam	%82,3Al,%17Si,%0,14Ti,%0,56O	CFRP	50×125×12	%80

Aluminum foam materials could be manufactured by various methods. Aluminum foam component's percentages could be regulated in those methods. These specimens are named as "Alulight GmbH" by the company that invents this material. Additionally, There are some another types of aluminum foams invented such as "Shunk GmbH AlSi7" [5].

Powder metallurgy method is used for manufacturing Alulight. In this method, two kind of powder is mixed. This mixture should be homogeneous as possible. Mixed metal powders consist of aluminum alloy powders and porous maker powders. TiH₂ powders are used for getting porous structure. In this mixture, H₂ elements remove from the material when heat interacts the mixture. Main materials percentages are defined depending on wanted porous amount. These materials are manufactured at five main steps. Firstly, all powders is mixed. Turbula mixer is used for mixing process. Mixed powders could be compressed in two ways as hot or cold. Then, heat treatment is implemented on compressed parts. Heat effect begins at 380°C and the optimum temperature is 450°C. Finally, porous structure is got when porous maker powders are vaporized. Whole processes are showed at Figure 1 [6,7].

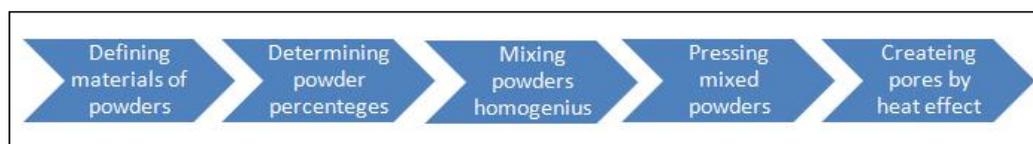


Figure 1. Alulight foam material manufacturing process.

Two numbers of CFRP coated and non-coated foams have been provided and tests were repeated on each specimen. So, determined natural frequencies damping coefficients after experiments are evaluated together and materials characteristic specifications were examined more accurate. In addition, to get more data from each specimen, data was achieved from two points on each specimen. Characteristic natural frequencies and damping factors were examined by averaging data got from tests.

In this study, either porous AlSi10 foams or CFRP coated porous AlSi10 foams attributes such as natural frequencies and damping factor were defined. Vibration damping capacities of porous structure materials are higher than non-porous structure materials. But also, the more pore amounts rise, the lower mechanical strength on porous structure materials are [8]. Besides, how natural frequencies and damping factors are effected coating foams with CFRP materials were observed by experiments. Specimens which used in experiments are showed at Figure 2.



Figure 2. AISi10 foam (left) and CFRP coated AISi10 foam (right) materials specimens.

2.2 The experimental setup

To obtain natural frequencies and vibration damping factors belong to specimens controlled experimental facilities that testing materials are needed. Therefore, the experimental setup which system output gets when the defined inputs are implemented was prepared. Designed experimental setup operates with converts analog data to digital data to show natural frequencies and damping factors on computer interface.

Experimental setup consists of main five components: Such as; 1) Material and fixing tools 2) Impact Hammer 3) Acceleration Sensor 4) DAQ/Amplifier system and 5) MalDAQ Cutpro™ Modal Analysis software.

3. Results evaluation

3.1 Experimental data evaluation

In experiments, achieved data from specimen had the same distances between each other. So specimens surfaces were made grid. In each specimen, two different positions of sensor were defined and then data were achieved from surface. Mean value of achieved data were calculated to define general characteristic natural frequencies and damping factors. 5 measurement points of specimens tested in experiments.

Natural frequency numbers were calculated in range of 100-5000 Hz. In this range, frequency of maximum (peak) amplitude value is the natural frequency. Obtained measurements were analyzed by using two different methods. It was found that both results of methods were the same. Firstly, half power method was used [9].

From the FRF measurement, value of f_n was found as 417 Hz. Equation 1 is applied to measure natural frequency.

$$\begin{aligned}\omega_n &= 2.\pi.f_n \\ \omega_n &= 2622 \text{ rad / s}\end{aligned}\quad (1)$$

In addition, damping factor is found applying half power method. In half power method, frequency numbers of $0,707 \cdot \text{Amplitude}$ is calculated for peak amplitude. Calculated numbers and natural frequency were evaluated together to find damping factor.

$$\xi = \frac{f_2 - f_1}{2.f_n} \quad (2)$$

$$A = 2.8187.10^{-4} \text{ [N/m]}$$

Frequencies of corresponding amplitude for $0,707A = 1,99.10^{-4} \text{ [N/m]}$ were found :
 $f_1 = 413\text{Hz}$, $f_2 = 419\text{Hz}$, $\xi = 7,2.10^{-3}$

Second method operates with extreme values. In this method, the ranges between extreme points are examined on real part graph of FRF [10].

Natural frequency is found by intersection point of x axis and the curve .

$$f_n = 417\text{Hz} , \omega_n = 2622 \text{ rad/s} \quad \xi = \frac{f_{\text{maksreal}} - f_{\text{minreal}}}{2 \cdot f_n} \quad (3)$$

Measurements achieved on each specimen's surface were examined and natural frequency and damping factor were calculated. Average values of natural frequency and damping factor was gotten to attain characteristic vibration response. Calculation results are showed on Table 2 as detailed.

Table 2. Test and the calculation results of AlSi10 foam materials and CFRP coated AlSi10 foam materials.

Material	Specimen and Exp. Number	Natural Frequency f_n	Damping Factor ξ	Average Natural Frequency f_n	Average Damping Factor ξ
AlSi10 Foam	Spec.1, point 2	417	$7,2 \times 10^{-3}$	513	$1,1 \times 10^{-2}$
	Spec.1, point 4	503	$16,1 \times 10^{-3}$		
	Spec.2, point 2	407	$12,3 \times 10^{-3}$		
	Spec.2, point 4	475	$8,42 \times 10^{-3}$		
CFRP coated AlSi10 Foam	Spec.3, point 2	551	$43,4 \times 10^{-3}$	450	$4,1 \times 10^{-2}$
	Spec.3, point 4	608	$35,2 \times 10^{-3}$		
	Spec.4, point 2	426	$40,0 \times 10^{-3}$		
	Spec.4, point 4	467	$43,9 \times 10^{-3}$		

3.2. Finite element method analysis of experimental data

Obtained results with the study were controlled by various ways to reinforce results. Data of experiments are showed at Table 2. Making use of that data and mechanical material specifications, digital simulations were executed on computer. These simulations consist of fundamental modal analysis and FEM. Modal analysis were executed by using average test results of AlSi10 foam materials on "Ansys Workbench program".

Fastening surface of specimens were modeled according to press jaws in CAD design. In addition, because of pressing pressure, specimen's fastening surfaces were dented 1 mm inward. Specimens were modeled similar to test conditions.

Mechanical, vibration, and general material specifications were defined on "Ansys Workbench". Only enough specifications were entered for modal analysis. Entered specifications are showed at Table 3.

Table 3. AlSi10 material specifications

Temperatures °C	Young Modulus Pa	Poisson Ratio	Bulk Modulus Pa	Shear Modulus Pa
22	5,333e+008	0,3325	5,3065e+008	2,0011e+008
Constant Damping Ratio				
7,2e-003				
Density				
53 kg/m ³				

After study of FEM (finite element method), results that are showed on Table 4 was found as the same as result as experiments. Natural frequency value of one side fixed specimens found after FEM analysis on 450,97 Hz in Mode Shape 1.

3.3. Achieving mathematical model for first mode

Various results were found with experiment specimens. In this chapter, vibration transfer functions and system response were created as mathematically with test results. So according to results of experimental tests, how the material vibrates time dependent was found under outer effects.

By virtue of results from the tests, modal matrix, stiffness matrix, modal masses and frequency transfer functions of system responses were found. An application for specimen 1 and point 2 was explained [10].

$$k_1 = \frac{-1}{2 \cdot \xi \cdot h_{11}} \quad (4)$$

$$m_1 = \frac{k_1}{\omega_{n1}^2} \quad (5)$$

$$u_{11} = \sqrt{-2 \cdot \xi \cdot \omega_{n1}^2 \cdot h_{11}} \quad (6)$$

$$s = j \cdot \omega_n \quad (7)$$

$$\frac{x_1}{F_1} = \frac{u_{11} u_{11}}{s^2 + 2 \cdot \xi \cdot \omega_n \cdot s + \omega_n^2} \quad (8)$$

Equation 4,5,6,7 and 8 were implemented step by step. Then results were gained.

$$h_{11} = -3,76 \cdot 10^{-11} \text{ m / N} \quad \xi_1 = 7,2 \cdot 10^{-3} \quad k_1 = 1,85 \cdot 10^{12} \text{ N / m} \quad m_1 = 269058 \text{ kg}$$

$$u_{11} = 1,93 \cdot 10^{-3} \quad \frac{x_1}{F_1} = \frac{3,7 \cdot 10^{-6}}{s^2 + 2,7,2 + 10^{-3} \cdot \omega_n \cdot s}$$

FRF of the system was found [9].

$$c = 2 \cdot \xi \cdot \sqrt{k \cdot m} \left[\frac{\text{N} \cdot \text{s}}{\text{m}} \right] \quad (9)$$

$$\varnothing = \tan^{-1} \left(\frac{\text{Im}G(r=1)}{\text{Re}G(r=1)} \right) \quad (10)$$

$$r = \frac{\omega}{\omega_n} \quad (11)$$

In case of damping factor "ξ" is between 0-1 and the system is second order delayed, time-amplitude correlation (system response) was created in Equation 6.

$$x_{(t)} = \frac{v_0}{\sqrt{1 - \xi^2} \cdot \omega_n} \cdot e^{-t \cdot \xi \cdot \omega_n} \cdot \sin \left(\omega_n \cdot \sqrt{1 - \xi^2} \cdot t + \varnothing \right) \text{ [m]} \quad (12)$$

$$v_0 = \frac{F \cdot \Delta t}{m} \text{ [N.s/m]} \quad (13)$$

$$T_0 = \frac{1}{f_n}, \Delta t = \frac{T_0}{20} \quad (14)$$

When unknown phrases put in the equation 12;

$$x_{(t)} = F \cdot 1,7 \cdot 10^{-13} \cdot e^{-17,24 \cdot t} \cdot \sin(2620 \cdot t - 90) \text{ [m]}$$

System response was found depend on impulse force magnitude (F) and time (t). The system response provides to calculate vibration amplitude which is occurred due to impulse force effect ranging between 100-1000 Hz frequencies.

4. Results and discussions

- The end of the result of tests on AlSi10 foam materials and CFRP coated AlSi10 foam materials, natural frequency of AlSi10 foam was found as 2830 rad/s and also natural frequency of CFRP coated AlSi10 foam was found as 3223 rad/s. According to natural frequencies of materials, natural frequency of CFRP coated AlSi10 foam is higher than natural frequency of AlSi10 foam. According to results, CFRP coated AlSi10 foam materials can operate up to higher frequencies without going into resonance. So using areas of the material is widen.
- As a result of the experiment, damping factor of AlSi10 foam materials found as $1,1 \times 10^{-2}$, damping factor of carbon-fiber coated AlSi10 foam material found as $4,1 \times 10^{-2}$. According to results, damping factor of carbon-fiber coated AlSi10 foam is almost 3,7 times higher than AlSi10 foam material's damping factor. So, it is understood that if AlSi10 foam is coated by CFRP, damping factor of material increases about 3,7 times. After the evaluation, it can be indicated that CFRP coated AlSi10 foams could be used under vibrated environments.
- Because of mechanical properties and vibration damping capacity of AlSi10 foam materials, they can't be used without coated by other materials [11]. They can only be used where properties of lightness and good vibration damping, when they are supported by some kind of materials. Especially, excess vehicle weight which one of the biggest problem of aircraft could be fixed by using these coated AlSi10 foams.
- Natural frequency values are found also vibration damping factors. Only one natural frequency value is found range between 0-1000 Hz. According to this result, it could be easy to avoid catching resonance.
- Utilizing equations given at section 3.3, mathematical model and vibration response of the material is identified. Examining vibration response, how the material vibrates can be predicted under impulse forces.

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