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Acoustic Performance of a Damaged Araldite Plate: Experimental and Numerical Solutions

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Abstract: While Araldite adhesives are extensively used in aerospace, maritime, and construction applications and have been well studied for their mechanical properties, their acoustic behavior remains largely unexplored. This study investigates the sound absorption of 4 mm and 6 mm Araldite plates under undamaged and damaged conditions (circular, square, triangular damages). Measurements were performed using an ASTM E2611-09 impedance tube in the 100–1000 Hz and 1000–20000 Hz ranges, and results were validated with FEM simulations in COMSOL Multiphysics. Results show that damage has little to no effect on the sound absorption coefficient, with maximum values below 0.26. FEM predictions agreed well with experiments, achieving over 90% accuracy in the mid-frequency range. These findings indicate that Araldite plates' acoustic performance is largely insensitive to small geometrical damage, providing baseline data for marine and structural applications.

Key words: Araldite, sound absorption coefficient, damage geometry, COMSOL.

1. Introduction

In marine construction, especially in luxury yachts and boats, Araldite epoxy adhesives are frequently preferred for joining structural components. Due to their high bonding capacity, resistance to dynamic loads, high stiffness, and lightweight nature, the use of these adhesives has significantly increased in recent years [1]. Studies have shown that Araldite performs strongly in terms of mechanical properties. For instance, Chikmath et al. investigated parameters such as tensile strength, flexural strength, and elastic modulus of Araldite components and concluded that the material exhibits high strength and excellent resistance to deformation under loading [2]. Faleh et al. also demonstrated that Araldite has high impact resistance and maintains solid mechanical performance under dynamic loading conditions. Moreover, Araldite provides strong adhesion not only on homogeneous but also heterogeneous material surfaces [3].

Acoustics is defined as the scientific study of reflection, refraction, absorption, and interference of sound waves [4]. Sound and noise control are critically important for comfort in many industries such as marine, aviation, and construction. In luxury yachts and boats, minimizing noise levels is essential to ensure user comfort. In marine environments, external noises such as wave impacts on the hull and wind sounds can cause discomfort inside the vessel [5]. Therefore, evaluating the acoustic properties of materials used in the maritime sector is of great importance. This study aims to determine the sound absorption coefficient of Araldite epoxy adhesives used in maritime applications. Additionally, it investigates how damage caused by minor marine accidents may affect the acoustic performance of these adhesives. In order to determine the sound absorption coefficient (SAC), the reflection coefficient must be known. In Eq. (1), the reflection coefficient R is defined as the ratio of the sound energy at the output to that at the input. The sound absorption coefficient, denoted by α\alpha, is expressed in Eq. (2) [14].

$$R=E\_out/E\_in \quad (1)$$

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$$\alpha=1-|R|^2 \quad (2)$$

The impedance tube method is widely used for acoustic measurements due to its suitability for normal incidence conditions across a range of frequencies [6]. In this study, acoustic measurements were conducted using the three-microphone impedance tube method developed by Salissou et al. [7]. This method, proposed as an alternative to the four-microphone technique, has been validated to produce similarly accurate results.

The accuracy of sound absorption coefficient (SAC) measurements obtained using the impedance tube method has been verified in various studies, and this method is widely recognized as a fast and reliable technique for the characterization of acoustic materials [8]. The impedance tube employed in the present study was developed in accordance with the ASTM E2611-09 standard. The actual impedance tube is shown in Fig. 1a, while its schematic representation is presented in Fig. 1b [9, 10, 14].

Finite element analysis (FEA) is a powerful method for solving complex problems in many fields of engineering. COMSOL Multiphysics software is particularly effective in simulating acoustic phenomena. Gaafer, demonstrated that the acoustic properties of a hexagonal honeycomb structure can be efficiently analyzed by modeling it with COMSOL [11]. Similarly, Chen et al. modeled micro-perforated double-layered materials using COMSOL and examined the effect of perforation on the sound absorption coefficient [8]. Yuvaraj et al. compared experimental and COMSOL based SAC results for a bio-based foam material and found a high level of agreement between them [12]. Additionally, Astrauskas et al. used COMSOL for the acoustic performance analysis of sustainable acoustic panels they developed [13].

Crack and defect analyses have also been extensively studied in the context of mechanical performance. The effect of cracks and discontinuities on the behavior of engineering materials has been extensively investigated in the literature through analytical and numerical approaches. For instance, Yetmez et al. analyzed a finite strip containing a central transverse crack under axial loading using the Fourier transform technique and calculated the stress intensity factors and stress distributions around the crack region. Their study provides valuable insights into the influence of cracks on the mechanical performance of isotropic materials. In a similar context, the present work examines the impact of different defect geometries (circular, triangular, and square) on the acoustic performance of Araldite plates. While Yetmez et al. focused on mechanical stress fields in cracked structures, the current research extends the investigation of damage effects into the acoustic domain through a combined experimental and FEM- based numerical approach [15].

2. Materials and Methods

2.1 Materials

In this study, Araldite plates—a type of epoxy resin commonly preferred in sectors such as aerospace and maritime due to their light weight and high strength were fabricated in two different thicknesses, 4 mm and 6 mm, and cut to a diameter of 64 mm, suitable for use in an impedance tube. The undamaged Araldite plates are presented at the top of Fig. 1, while at the bottom of the figure, respectively, plates with damages in circular, square and triangular geometries are illustrated. These prepared specimens were subsequently used to evaluate the effect of damage geometry and plate thickness on the sound absorption coefficient.

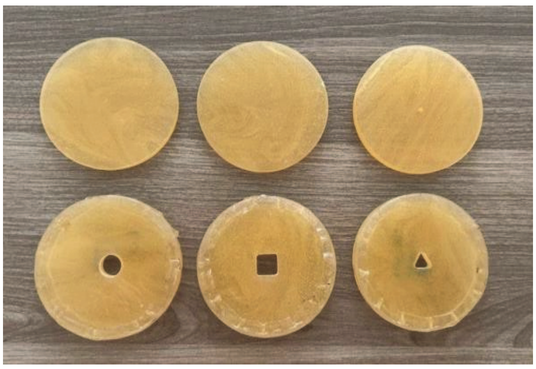


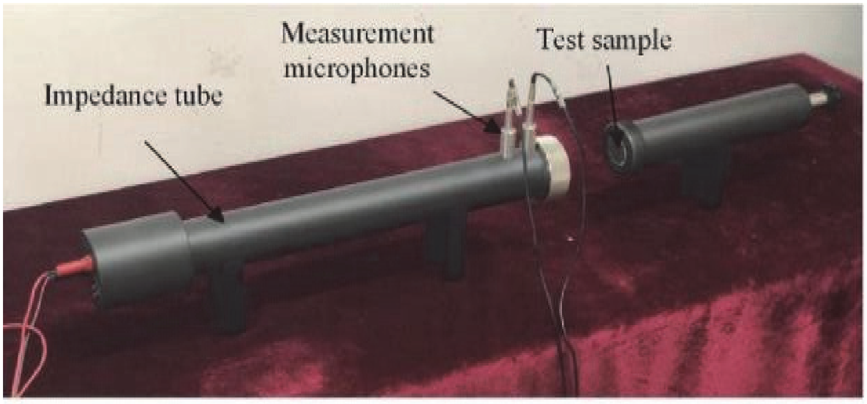
Fig. 1 At the top, undamaged Araldite plates; at the bottom, damaged plates with triangular, square, and circular geometries.

2.2 Test Methods

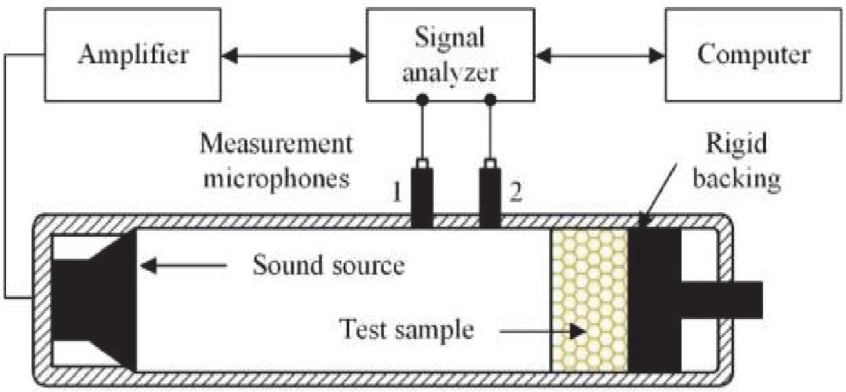
In Fig. 2, our impedance tube is shown schematically. To prevent leaks and obtain accurate results, the undamaged and damaged test samples we prepared were sealed with adhesive tape before being placed in the tube. Initially, experiments were conducted on two different thicknesses of undamaged plates, with three samples for each type, and each test was repeated twice. The same procedure was then applied to the three different damage types. First, the acoustic performance of the Araldite plates was examined at low frequencies (0–1,000 Hz), and any changes in performance due to damage were observed. Subsequently, the same tests were repeated for high frequencies (0–20,000 Hz). This allowed us to determine the optimal thickness, frequency range, and damage condition for the best performance of the material. Environmental conditions were kept constants for all experiments to eliminate the influence of other parameters on the results.

2.3 Modeling with COMSOL Multiphysics

To investigate how the sound absorption coefficient of the Araldite plate changes under damaged and undamaged conditions, a COMSOL model was developed to validate the experiments conducted with our impedance tube, and approximate results were obtained. Initially, the laboratory impedance tube dimensions were used as a reference for model creation. A cylindrical tube with a diameter of 64 mm and a length of 50 mm was designed. The COMSOL model consists of two parts. The first part (left side) is defined as an air domain, where the sound pressure is measured. The second part (right side) is defined as a poroacoustic domain, representing the Araldite plate.



(a)



(b)

Fig. 2 (a) Impedance tube; (b) Schematic diagram of the experimental system.

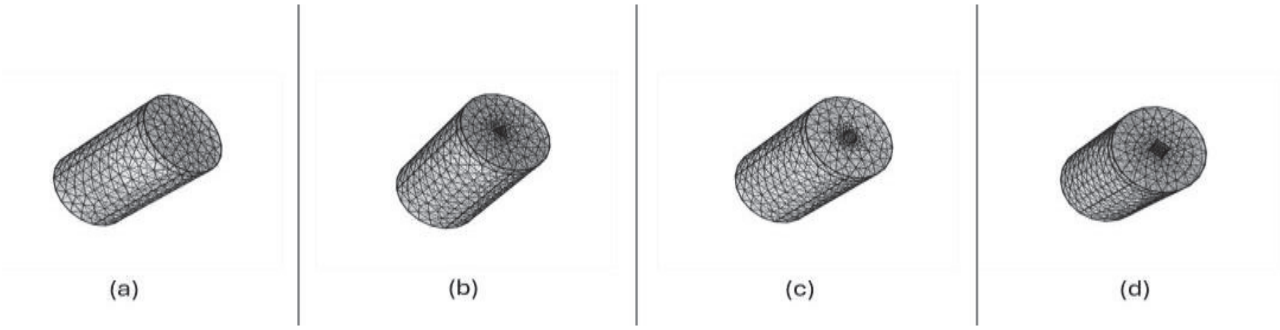


Fig. 3 The meshed COMSOL model respectively, undamaged, triangular, circular, square damage.

Modeling was performed using the Delany–Bazley–Miki model. Fig. 3 illustrates the meshed COMSOL models: (a) the undamaged Araldite plate; (b) the Araldite plate with triangular damage; (c) the Araldite plate with circular damage; and (d) the Araldite plate with square damage. It should be noted that the acoustic properties were assumed to be identical for all Araldite plates. Although acoustic properties depend on material characteristics, variations in the manufacturing process—such as mixing ratios, curing conditions, and the presence of additives—can lead to differences in porosity and flow resistivity. In our laboratory samples, the porosity was measured to be approximately 0.85, and the flow resistivity was determined to be 1,500 Pa·s/m, values that were used in the simulations to represent the material's acoustic behavior. Frequency domains were then defined in COMSOL, and sound absorption coefficient graphs were generated for 0–1,000 Hz and 0–20,000 Hz.

3. Results

3.1 Experimental Results

Table 1 presents the sound absorption coefficient results measured using the impedance tube for the 4 mm thick Araldite plate under damaged and undamaged conditions at 1,000 Hz. The results indicate that the coefficients for the undamaged and damaged plates are very close, achieving approximately 20–25% sound absorption. When the thickness remains the same and the frequency range is extended to 0–20,000 Hz, the sound absorption of the material varies between 15–18%. Table 2 shows the sound absorption coefficients of the 4 mm thick plate for the 20,000 Hz frequency range. It can be observed that, at a constant thickness, the sound absorption coefficient decreases as the frequency increases. Table 3 presents the sound absorption coefficient results measured using the impedance tube for the 6 mm thick Araldite plate under damaged and undamaged conditions at 1,000 Hz.

Table 1 Sound absorption coefficient of 4 mm Araldite plate at 1,000 Hz.

Damage geometry	Sound absorption coefficient
Undamaged	0.24
Circle	0.26
Square	0.21
Triangle	0.20

Table 2 Sound absorption coefficient of 4 mm Araldite plate at 20,000 Hz.

Damage geometry	Sound absorption coefficient
Undamaged	0.18
Circle	0.15
Square	0.15
Triangle	0.13

Table 3 Sound absorption coefficient of 6 mm Araldite plate at 1,000 Hz.

Damage geometry	Sound absorption coefficient
Undamaged	0.28
Circle	0.20
Square	0.20
Triangle	0.23

Table 4 Sound absorption coefficient of 6 mm Araldite plate at 20,000 Hz.

Damage geometry	Sound absorption coefficient
Undamaged	0.18
Circle	0.15
Square	0.15

The plate exhibits approximately 25% sound absorption and shows similar results for both damaged and undamaged conditions. Small differences in the results may be due to changes in the material's acoustic parameters, such as flow resistivity or surface roughness, during the introduction of damage. Table 4 shows the results of acoustic tests for the 6 mm thick Araldite plate up to 20,000 Hz. According to these results, the material exhibits sound absorption between 15–18%. The absorption values for the 4 mm and 6 mm plates are similar in experiments up to 20,000 Hz, indicating that the change in thickness does not affect results at high frequencies. Further increases in thickness may lead to differences. Additionally, at a constant thickness, the sound absorption coefficient decreases as the frequency increases from 1,000 Hz to 20,000 Hz. The shape of the damage—whether square, triangular, or circular—did not affect the results. For example, in the tests at 20,000 Hz, the 6 mm thick plate exhibited a 15% sound absorption coefficient for all three damage geometries.

3.2 Numerical Results

A COMSOL model was developed to validate the measurement results obtained from the impedance tube experiments. Within the model, SAC–frequency graphs were generated for two different specimen thicknesses, two distinct frequency ranges, and four types of induced damage. Figs. 4-13 were then utilized to determine the sound absorption coefficient of the Araldite plate within the specified frequency ranges.

In Fig. 4, the measurements conducted for the 4 mm thick plate at 1,000 Hz revealed a sound absorption coefficient of 11%. When triangular, square, and circular damages were introduced to the plate of the same thickness, the COMSOL model showed an increase in SAC to 16%. A similar trend was observed when the plate thickness was increased, indicating that thicker plates also exhibit enhanced sound absorption. Both cases are illustrated in Figs. 6 and 7, showing the consistent effect of damage and thickness on acoustic performance.

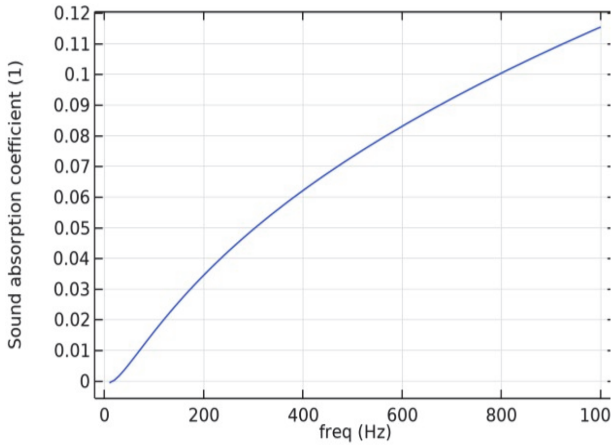


Fig. 4 Numerical (FEM) results for the 4 mm thick undamaged Araldite plate in the 0–1,000 Hz frequency range.

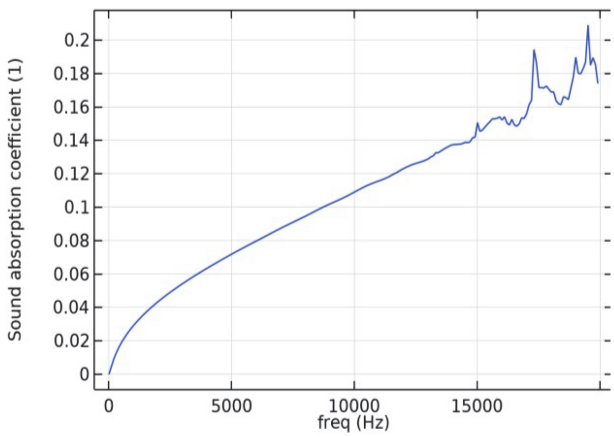


Fig. 5 Numerical (FEM) results for the 4 mm thick undamaged Araldite plate in the 0–20000 Hz frequency range.

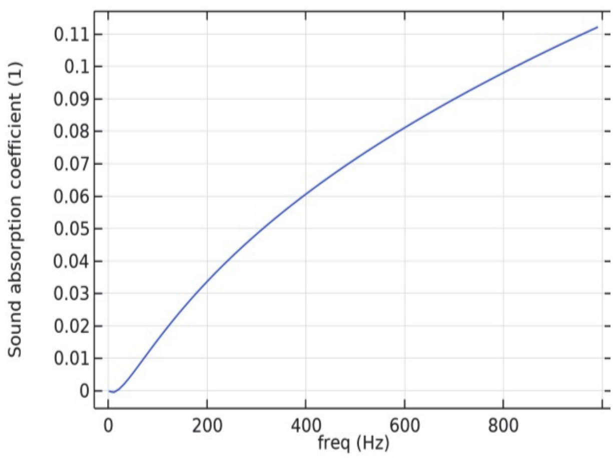


Fig. 6 Numerical (FEM) results for the 6 mm thick undamaged Araldite plate in the 0–1000 Hz frequency range.

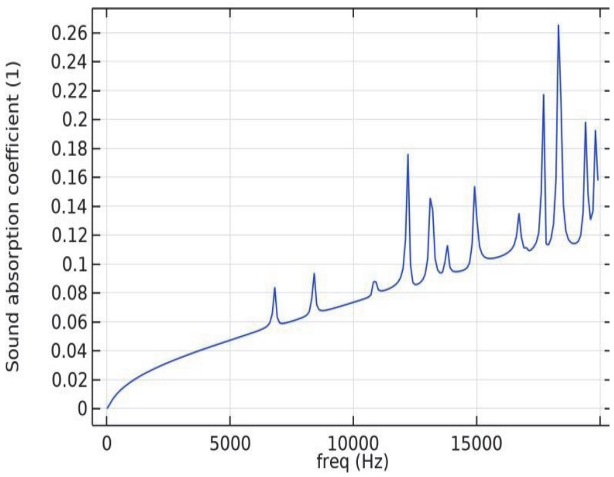


Fig. 7 Numerical (FEM) results for the 6 mm thick undamaged Araldite plate in the 0–20,000 Hz frequency range.

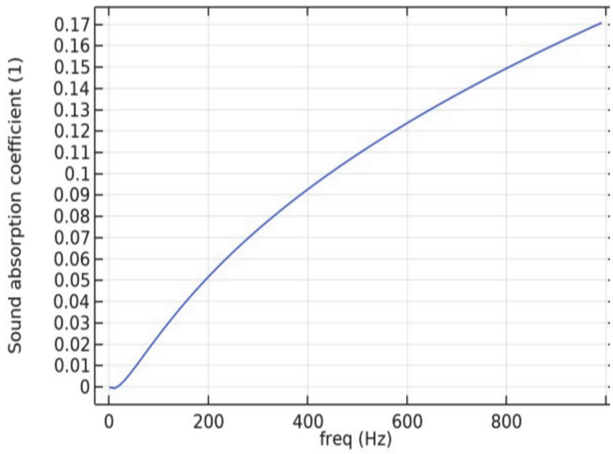


Fig. 10 Numerical (FEM) results for the 6 mm thick Araldite plate with all damage types in the 0–1,000 Hz frequency range.

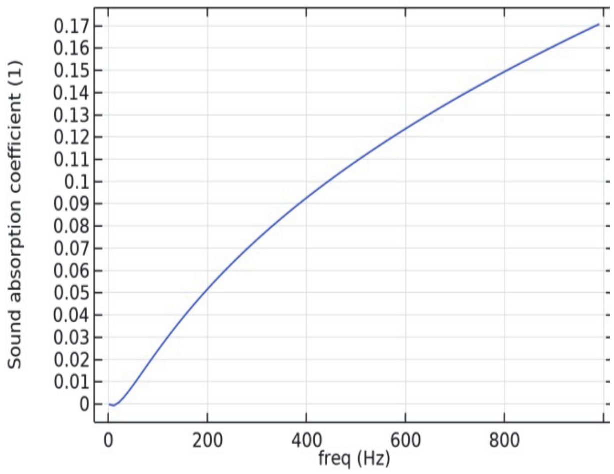


Fig. 8 Numerical (FEM) results for the 4 mm thick Araldite plate with all damage types in the 0–1,000 Hz frequency range.

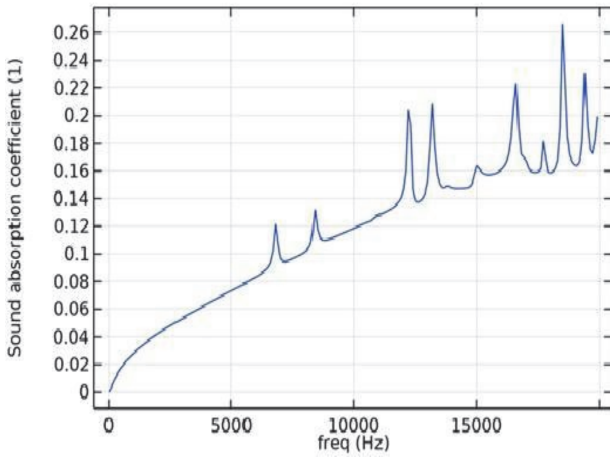


Fig. 11 Numerical (FEM) results for the 6 mm thick Araldite plate with circular damage in the 0–20,000 Hz frequency range.

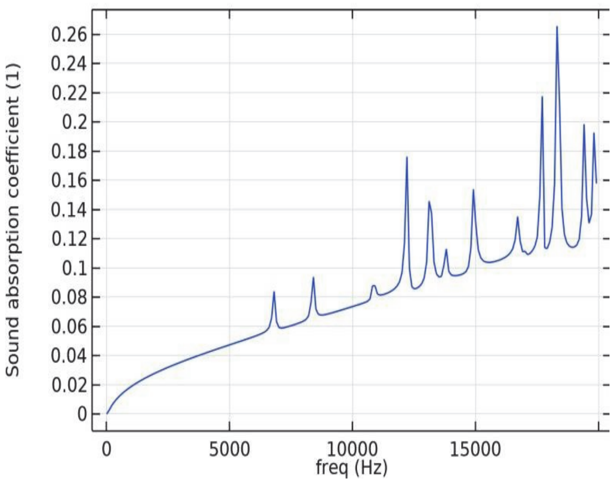


Fig. 9 Numerical (FEM) results for the 4 mm thick Araldite plate with all damage types in the 0–20,000 Hz frequency range.

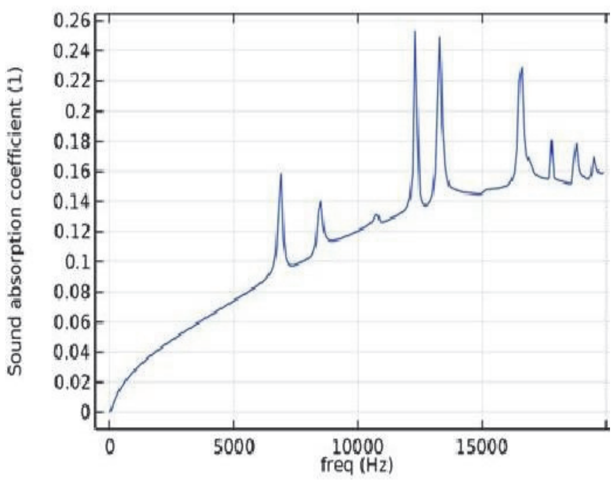


Fig. 12 Numerical (FEM) results for the 6 mm thick Araldite plate with square damage in the 0–20,000 Hz frequency range.

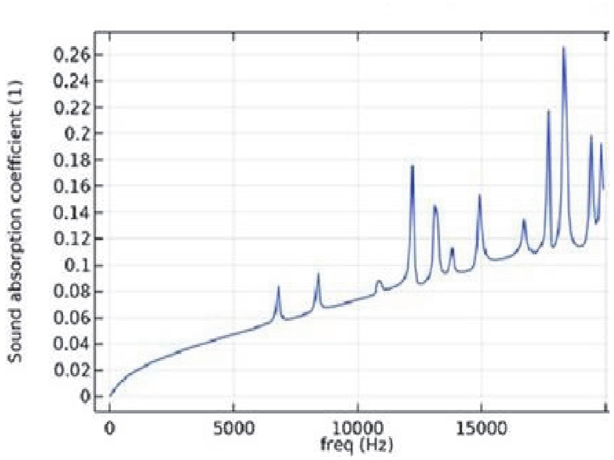


Fig. 13 Numerical (FEM) results for the 6 mm thick Araldite plate with triangular damage in the 0–20,000 Hz frequency range.

When the plate thickness was increased to 6 mm, measurements were performed within the 0–1,000 Hz and 0–20,000 Hz frequency ranges to examine the effect of damage. As shown in Fig. 6, the SAC value was 0.11 at 1000 Hz in the absence of damage, while Fig. 7 illustrates that it was 0.16 at 20,000 Hz. Figs. 11-13 present the SAC values of Araldite plates with circular, square, and triangular damages, respectively, at 20,000 Hz, all of which were found to be 0.17.

These findings suggest that while the presence of damage leads to a noticeable increase in SAC, the geometry of the damage does not significantly influence the overall results. However, variations between 5,000 Hz and 15,000 Hz indicate that localized fluctuations in absorption behavior may occur depending on the damage condition. This implies that the primary factor affecting SAC is the existence of damage itself rather than its geometrical configuration.

3.3 Comparison of Experimental and Numerical Results

When comparing the experimental and numerical results at high frequencies (0–20,000 Hz), it is observed that the results for 4 mm and 6 mm thick plates are very close to each other, indicating that an increase in thickness does not significantly affect the outcome at high frequencies. This can be attributed to the high stiffness of the Araldite plates and their low porosity and flow resistance, which make them relatively insensitive to thickness variations. Fig. 16 presents the results for the 4 mm thick plate, while Fig. 17 shows the results for the 6 mm thick plate. On average, the sound absorption coefficient at 20,000 Hz can be considered approximately 16%.

In the 6 mm thick plate, an increase in frequency was observed to have a diminishing effect on the sound absorption coefficient, as confirmed by both experimental and numerical results. The discrepancies observed between the experimental and numerical results at low frequencies may be attributed to variations in acoustic properties, such as porosity and flow resistance, arising during the material fabrication and damage-induction processes. Additionally, the introduction of damage could have altered the mechanical properties within the material's internal structure, which may, in turn, lead to differences in acoustic behavior at low frequencies.

At low frequencies, some discrepancies are observed between numerical and experimental results. Fig. 14 presents a comparison of the SAC values for different damage types in the 4 mm thick plate within the 0–1000

Hz range, while Fig. 15 shows the corresponding comparison for the 6 mm thick plate. It is also evident that at low frequencies, the sound absorption coefficient is affected by the increase in thickness, with SAC values rising from 0.11 to 0.25.

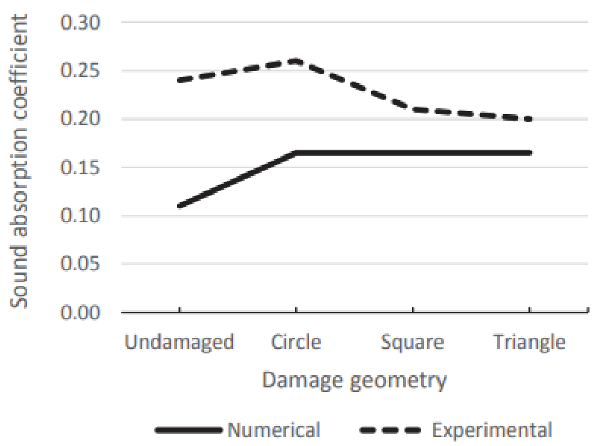


Fig. 14 Comparison of the experimental and numerical results for the sound absorption coefficient of the 4 mm thick Araldite plate with all damage types at 1,000 Hz.

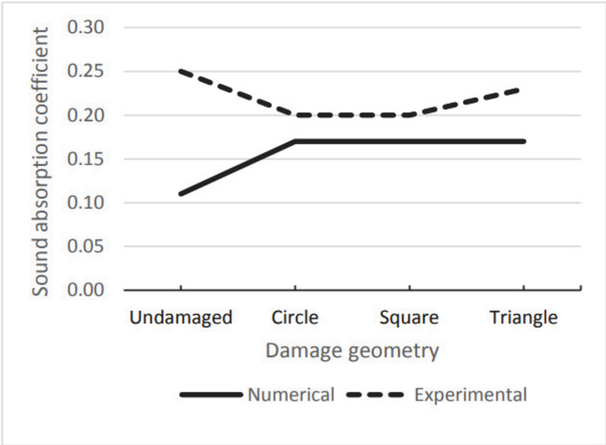


Fig. 15 Comparison of the experimental and numerical results for the sound absorption coefficient of the 6 mm thick Araldite plate with all damage types at 1,000 Hz.

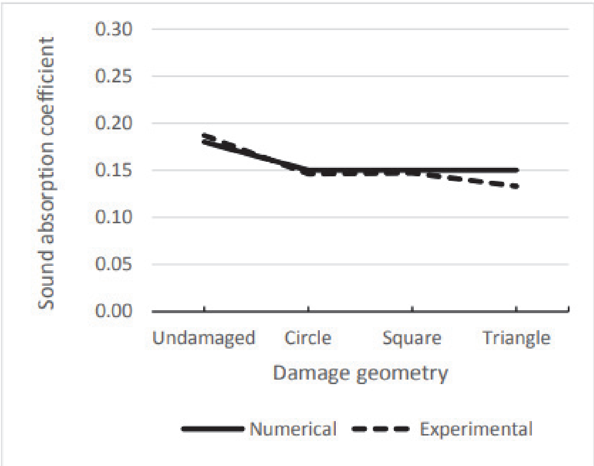


Fig. 16 Comparison of the experimental and numerical results for the sound absorption coefficient of the 4 mm thick Araldite plate with all damage types at 20,000 Hz.

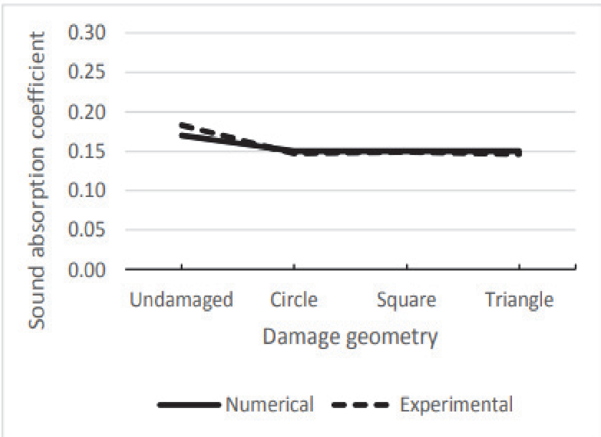


Fig. 17 Comparison of the experimental and numerical results for the sound absorption coefficient of the 6 mm thick Araldite plate with all damage types at 20,000 Hz.

4. Discussion

In previous studies, surfaces formed using Araldite adhesives have been examined from a mechanical perspective, showing that they are preferred due to their high impact resistance, elastic modulus, and hardness. In this study, the focus is extended to the acoustic performance of Araldite plates, with particular attention to how different types of damage, which may occur during maritime accidents, affect acoustic parameters, thereby evaluating their suitability for marine applications.

1. Among the tested Araldite plates, the highest sound absorption coefficient was observed in the 6 mm thick plate at 1,000 Hz. When both experimental and numerical results are considered together, this plate exhibited approximately 22.5% sound absorption. The introduced damages had a negligible effect on acoustic tests at low frequencies.

2. The closest agreement between COMSOL simulations and experimental results was observed for the 6 mm thick plate at 20,000 Hz. In both cases, the sound absorption coefficient of Araldite plates was around 15%. In the experimental study, the undamaged plate exhibited a sound absorption coefficient of 0.18. This discrepancy may be attributed to a very tight placement of the undamaged plate within the impedance tube, which could have affected the flow resistivity. At high frequencies, numerical results matched perfectly, indicating that minor damages do not significantly influence the sound absorption coefficient.

3. For a constant plate thickness, the sound absorption coefficient decreases as frequency increases. The main limitation of using Araldite resins is their relatively high cost. However, their resistance to harsh marine conditions and high mechanical strength makes them a viable choice when durability is required.

To further enhance the acoustic performance of Araldite plates, natural fibers that are environmentally friendly could be incorporated into the resin at specific ratios. This approach would allow the development of Araldite plates with optimal acoustic properties without compromising mechanical performance.

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