

Evaluation of Acoustic Performance of Proximal Rachis of Coconut Leaf

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ABSTRACT: Nowadays noise is recognized as a serious health hazard. Sound insulation plays a vital role in many areas like military applications, aerospace applications and in room acoustics. Recently many organic materials are used as sound proofing materials such as coir, wooden panels and clothes. In the present study most commonly available material proximal rachis of coconut leaf is considered. The mechanical property of this material is determined and it shows a better agreement on strength requirements for sound insulation structures. Absorption coefficient is evaluated over a range frequency up to 1600 Hz in impedance tube. The proximal rachis of coconut leaf has a higher absorptivity in both higher and lower frequency. Transmission loss due to effect of absorptivity is determined. Assessment of TL is done by using generalized matrix method (GMM), and then modified it with TL due to absorptivity, which is called as modified GMM.

I.INTRODUCTION

A.GENERAL BACKGROUND

Sound is form of energy produced as a result of mechanical disturbances in a material which propagates as longitudinal waves in fluids and transverse or surface waves in solids. When these waves reach our ear, we will have the sensation of sound. Any undesirable or disagreeable sound can be treated as noise. Noise recognized as a serious health hazard in many areas and many applications especially in aerospace, military applications and room acoustics [1]. Sound insulation has a vital role in noise control, it has applications in automobile industries, factories, buildings and offices etc. [4]. Multi-layered structures like honeycomb sandwich structures, panels backed with various types of acoustic absorber, porous materials and composite materials are widely used as sound insulators.

The design of auditorium, ICU ward doors and automobile interiors are based on the principle of minimizing transmission loss (TL). Acoustic wave propagates outwards from the source; the intensity of the signal is reduced with increasing thickness as well as with the presence of absorptive material in the path of wave propagation. The suitability of sandwich structures in improving the noise insulation characteristics of homogeneous panels was investigated by Kurtze and Watters [11]. High transmission loss was achieved towards higher frequency ranges by a choice of a thick core, whose elastic modulus was much less than that of the skin layers. Acoustic attenuation is a measure of the energy loss of sound propagation in media. Many researches were conducted on sound insulator having sandwich structures. It was found that they show high absorptivity and transmission loss at higher frequency. The attainment of higher absorptivity and transmission loss at lower frequency is formidable one.

In the present work a disc made up of layered proximal rachis of coconut leaf was made. GMM (Generalized Matrix Method) corresponding to three media (air +material+ air) reported in [2] is availed and a code in MATLAB is developed to obtain TL for a range of frequencies varying from 100 to 1600 Hz. The main input for GMM is the acoustic impedance, which is the product of density of medium and velocity of sound through the medium. The velocity of sound is estimated by using the young's modulus obtained from the tension test and the density of the material. Comparison was made between TL of proximal rachis of coconut leaf and plywood. Since GMM doesn't account for absorptivity, tests were carried out using impedance tube to evaluate the absorptivity for a range frequency. Absorptivity of proximal rachis of coconut leaf was compared with the absorptivity of plywood, which was available in literature. This test data is used for the determination of transmission loss (Transmission loss due to absorptivity). The transmission loss due to absorptivity is arithmetically added with the transmission loss by GMM. A new approach; Modified GMM is put forward by accounting absorptivity of the material.

Acoustic attenuation in a medium with impedance plays an important role in many scientific researches and engineering field such as medical, vibration and noise control. If we can predict the transmission loss of any medium theoretically it will be cost effective, easy and large number of analysis also can be done with negligible expenditure. So, once good agreement between and test data is obtained, then analytical prediction for low frequency range can be determined with more confidence. Present study satisfies this requirement.

II. MATERIALS AND METHODS

Material

The figure 5.1 shows a compound leaf of a coconut tree. The small and narrow leaves are pinnate to a long stem (resembling spinal code) of its main big leaf is called rachis.



Figure 2.0.1 Proximal rachis of coconut compound leaf

Pinnate compound leaves have laminae called leaflets distributed at intervals along the rachis, whereas simple leaves have a single lamina [13]. Because of good strength, the rachis of coconut leaf is being used among the locals for tying application. It is locally called ‘Vazhutha’.

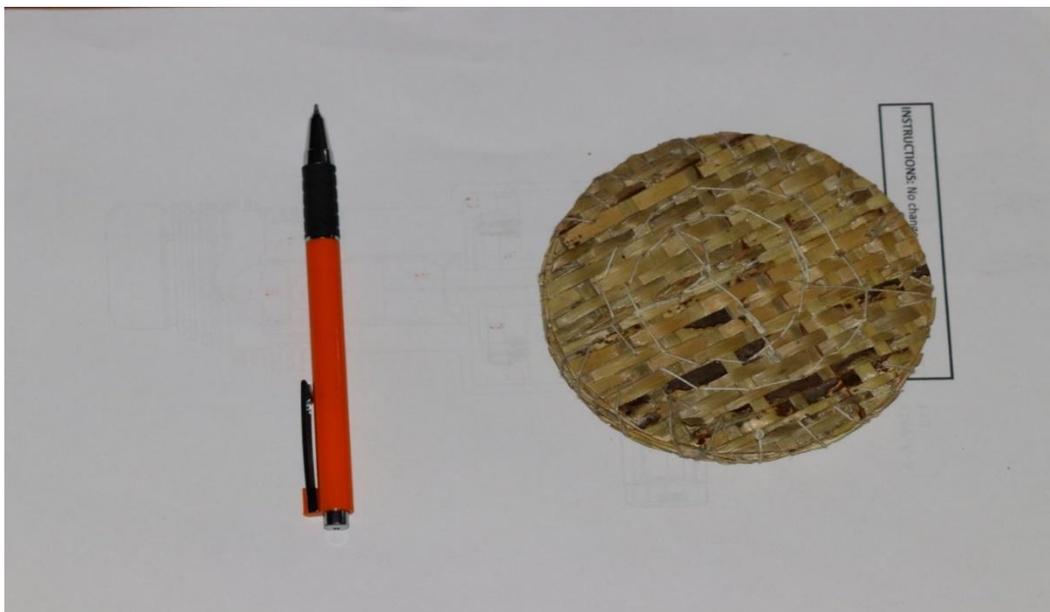


Figure 2.2 specimen

The proximal rachis of coconut leaf is extracted from the leaf, and dried. To prevent the microbial attacks, the stripes are dipped in copper sulphate solution. The stripes are then dried. Each stripes have dimension approximately of 3mm width and 1.5mm thickness. The specimen is a combination of panels. (With 2 mm thickness and 100mm diameter). The panels are made by weaving the stripes in crosswise. The panels are closely stacked and stitched with twine. Specimen has the final dimension with 100 mm diameter and 10 mm thickness. Figure 5-3 shows the prepared specimen.



Figure 2.3 Dried proximal rachis

The dried strip with dimensions width 16mm, length 150mm, thickness 1.5 mm is used for tensile test. The stress- strain curve of proximal rachis obtained by performing the tensile test, young’s modulus is obtained from the stress-strain curve is used for the theoretical evaluation of velocity of sound through the material medium.

A MATLAB program on the basis of GMM is developed to find the Transmission loss without considering the absorptivity. The inputs for the program are, number of media, impedance of each media, velocity of sound through each media, number of frequencies and their respective frequency values.

The experimental evaluation of absorption coefficient is carried out using impedance tube setup which works on the principle of two microphone transfer function method according to ASTM E1050. The impedance tube is having frequency measurement range of 50 to 1600 Hz. A 100 mm diameter specimen is tested in the impedance tube apparatus.

Since GMM doesn't account for absorptivity, test is carried out using impedance tube to evaluate the absorptivity for a range frequency. This test data is used for the determination of transmission loss (Transmission loss due to absorptivity). A MATLAB program is developed to find the Transmission loss due to absorptivity. The only input for the program is the absorptivity.

III. RESULT AND DISCUSSION

3.1 Tensile Test on Proximal Rachis of Coconut Leaf

The dried strip with dimensions width 16mm, length 150mm, thickness 1.5 mm is used for tensile test. The stress- strain curve of proximal rachis obtained by performing the tensile test, is shown in figure 6-1.

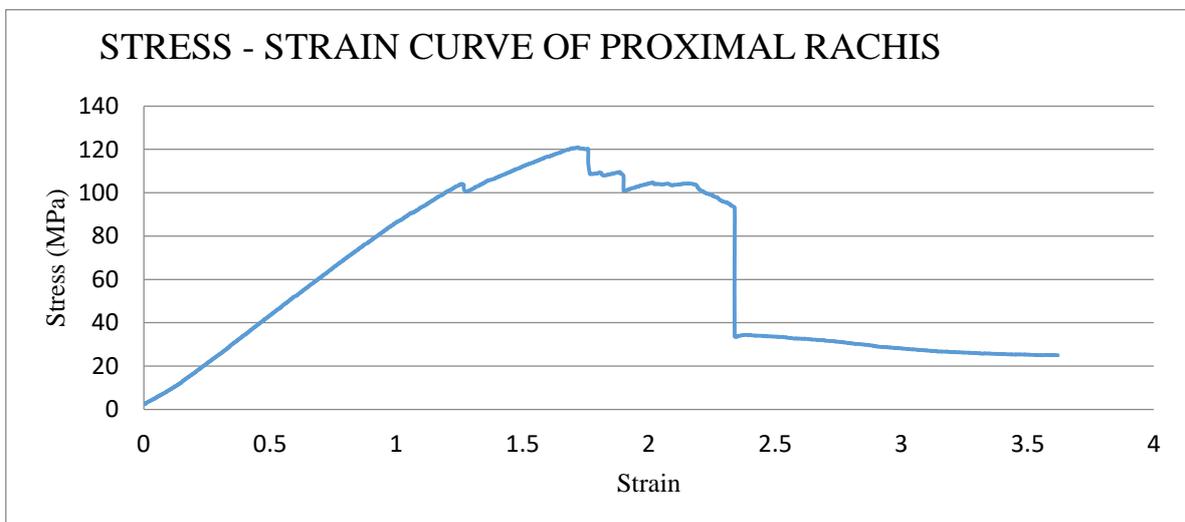


Figure 3.1 Stress-Strain curve of proximal rachis of coconut leaf



From the figure 3.1 it is observed that, up to 105 MPa the material obeys Hooke’s law. Young’s modulus of proximal rachis of coconut leaf obtained from the figure 3.1 is 8.6 GPa. The ultimate strength is 120 MPa. After this point, the material starts to fail. The young’s modulus is determined along the fiber direction.

3.2 Theoretical Evaluation of Velocity of Sound Using Young’s Modulus

The material properties, Young’s modulus (E) and density(ρ)of the selected material is experimentally evaluated. Hence the velocity of sound (c) through medium can be calculated as:

Young’s modulus of proximal rachis, E = 8.6 GPa

Mass of the specimen, m = 0.004 kg

Volume of the specimen, v = 3.6 x 10⁻⁶m³

Density of the material specimen, ρ = 1111.11 kg/m³

$$\begin{aligned} \text{The velocity of sound through the medium, } c &= \sqrt{\frac{E}{\rho}} \\ &= 2783.38 \text{ m/s} \end{aligned}$$

3.3 Prediction of Transmission Loss of Specimen Having No Sound Absorbing Element(GMM)

Estimation of TL without considering the absorptivity is done with a MATLAB program.

Proximal rachis of coconut leaf :

Density of the material specimen, ρ = 1111.11 kg/m³

The velocity of sound through the medium, c = 2783.38 m/s

Impedance of the material medium = 6425971.35 kg s/m²

The transmission loss of proximal rachis of coconut leaf estimated by GMM are tabulated in table 3.1.

Table 3.1 Transmission loss for proximal rachis of coconut leaf by GMM

Frequency (Hz)	Transmission loss for proximal rachis of coconut leaf (dB)
100	18.56
200	24.53
300	28.04
400	30.54
500	32.48
600	34.06
700	35.39
800	36.56
900	37.58
1000	38.49
1100	39.32
1200	40.08
1300	40.77
1400	41.42
1500	42.02
1600	42.58

From the table 3.1 it was observed that the values of TL increasing linearly with frequency. It has minimum TL at 100 Hz and has a maximum TL at 1600 Hz.

3.4 Comparison of TL of Proximal Rachis of Coconut Leaf With Plywood

The transmission loss of plywood by GMM is estimated. TL of proximal rachis of coconut leaf was then compared with the TL of plywood.

Plywood :

Velocity of sound through plywood = 3860 m/s

Density of the specimen = 780 kg/m³

Impedance of the plywood medium = 3010800 kg s/m²

The transmission losses of plywood for a range of frequency are estimated by GMM, and are tabulated along with the TL of proximal rachis of coconut leaf in table 3.2.



Table 3.2 Comparison of TL for proximal rachis with plywood evaluated by GMM

The TL values from table 3.2 are plotted against frequency as shown in figure 3.2 for the comparison.

Frequency(Hz)	Transmission loss for plywood(dB)	Transmission loss for proximal rachis of coconut leaf (dB)
100	15.54	18.56
200	21.47	24.53
300	24.97	28.04
400	27.47	30.54
500	29.40	32.47
600	30.98	34.06
700	32.32	35.39
800	33.48	36.56
900	34.50	37.58
1000	35.42	38.49
1100	36.25	39.32
1200	37.00	40.08
1300	37.70	40.78
1400	38.34	41.42
1500	38.94	42.02
1600	39.50	42.58

Figure 3.2 Comparison of TL for proximal rachis and plywood evaluated by GMM

From the figure 3.2 it is observed that TL of proximal rachis of coconut leaf was higher than that of plywood. Hence, theoretically the proposed material is capable for noise insulation than the plywood.

3.5 Determination of Sound Absorption Coefficient of Specimen Using The Impedance Tube

Specimen is made from proximal rachis of coconut leaf. It is tested for absorptive coefficient as per ASTM E1050 with the support of LPSC Thiruvananthapuram. The figure 3.3 and table 3.3 showing the absorptivity of material against frequency.

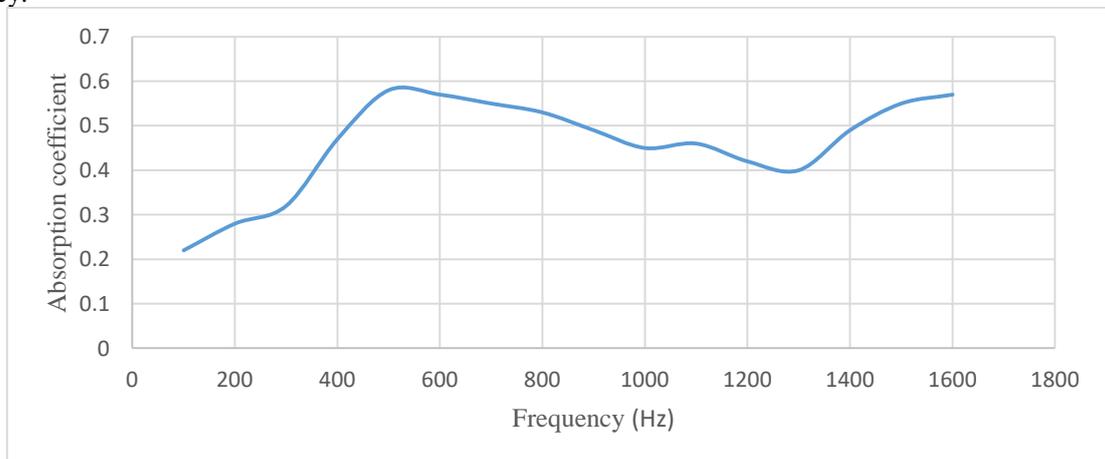


Figure 3.3 Absorption coefficient curve of proximal rachis of coconut leaf



From the experimental results, it is observed that there is an appreciable change in absorption coefficient of the specimen at various frequency range as shown in figure 3.3.

Table 3.3 Experimentally evaluated absorption coefficient of proximal rachis.

Frequency (Hz)	Absorption Coefficient
100	0.22
200	0.28
300	0.32
400	0.47
500	0.58
600	0.57
700	0.55
800	0.53
900	0.49
1000	0.45
1100	0.46
1200	0.42
1300	0.4
1400	0.49
1500	0.55
1600	0.57

From the table 3.3, it was found that between 100 Hz and 500 Hz the absorptivity increases, at 500Hz the material shows maximum absorptivity 0.58. Exceeding 500 Hz, the absorptivity varies inversely with frequency up to 1200 Hz. After 1300 Hz the absorptivity shows sharp increase in its value.

3.6 Comparison of Absorption Coefficient of Proximal Rachis With Plywood

In the figure 3.4 the absorptivity of proximal rachis is compared with the available impedance tube test result of plywood

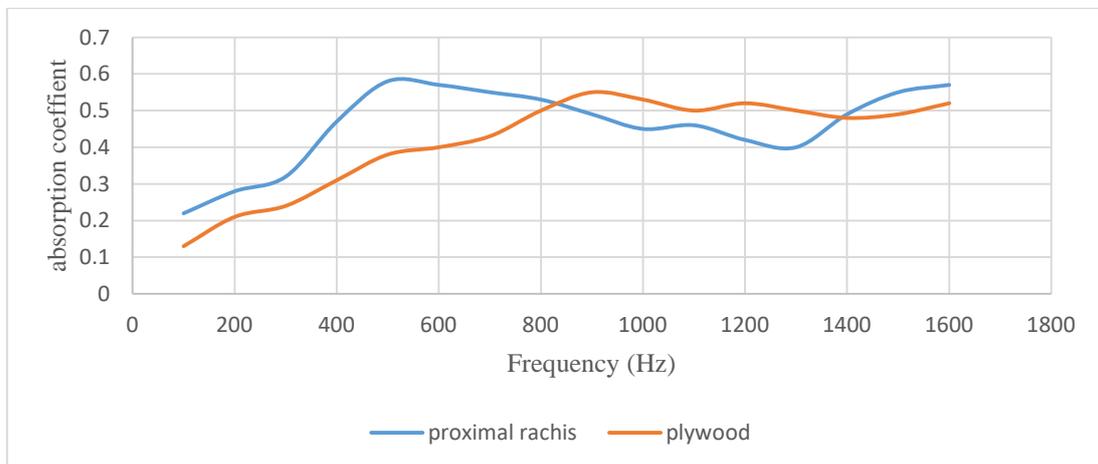


Figure 3.4 Comparison of absorptivity



From the figure 3.4 it is found that the absorptivity of proximal rachis is higher than that of plywood at lower frequencies. Between the frequency limits 1000Hz and 1400Hz the proximal rachis shows lower absorptivity than plywood. Absorptivity of both material increases at higher frequencies, after 1400Hz. This is common tendency of solid materials reported in literatures [3].

3.7 Evaluation of Transmission Loss Due To The Absorptivity

The TL due to absorptivity is evaluated using a MATLAB program. In table 3.4, the TL due to absorptivity and the respective absorptivity along with the frequencies are tabulated.

Table 3-4 Transmission loss due to absorptivity

Frequency(Hz)	Absorptivity	Transmission loss by absorptivity (dB)
100	0.22	2.48
200	0.28	3.28
300	0.32	3.85
400	0.47	6.34
500	0.58	8.67
600	0.57	8.43
700	0.55	7.98
800	0.53	7.55
900	0.49	6.73
1000	0.45	5.97
1100	0.46	6.16
1200	0.42	5.44
1300	0.4	5.1
1400	0.49	6.73
1500	0.55	7.98
1600	0.57	8.43

From the table 3.4, it is found that the transmission loss due to absorptivity has a maximum value of 8.67 dB at a frequency of 500 Hz. The transmission loss due to the absorptivity is much lower than the TL by GMM.

3.8 Modified GMM

Since GMM doesn't account for absorptivity, the transmission loss due to absorptivity is arithmetically added with the transmission loss by GMM. A new approach named Modified GMM is put forward by accounting absorptivity of the material. It is shown in table 3.5

Table 3.5 Transmission loss of proximal rachis of coconut leaf by modified GMM

Frequency(Hz)	Transmission loss by GMM (dB)	Transmission loss by absorptivity (dB)	Transmission loss by Modified GMM (dB)
100	18.55	2.48	21.03
200	24.53	3.28	27.81
300	28.04	3.85	31.89
400	30.54	6.34	36.88
500	32.47	8.67	41.14
600	34.06	8.43	42.49
700	35.39	7.98	43.37
800	36.56	7.55	44.10
900	37.58	6.73	44.31
1000	38.49	5.97	44.46
1100	39.32	6.16	45.48
1200	40.08	5.44	45.52
1300	40.77	5.1	45.87
1400	41.42	6.73	48.15
1500	42.02	7.98	50.00
1600	42.58	8.43	51.01

The figure 3.5 shows the variation of TL by modified GMM from the TL by GMM.

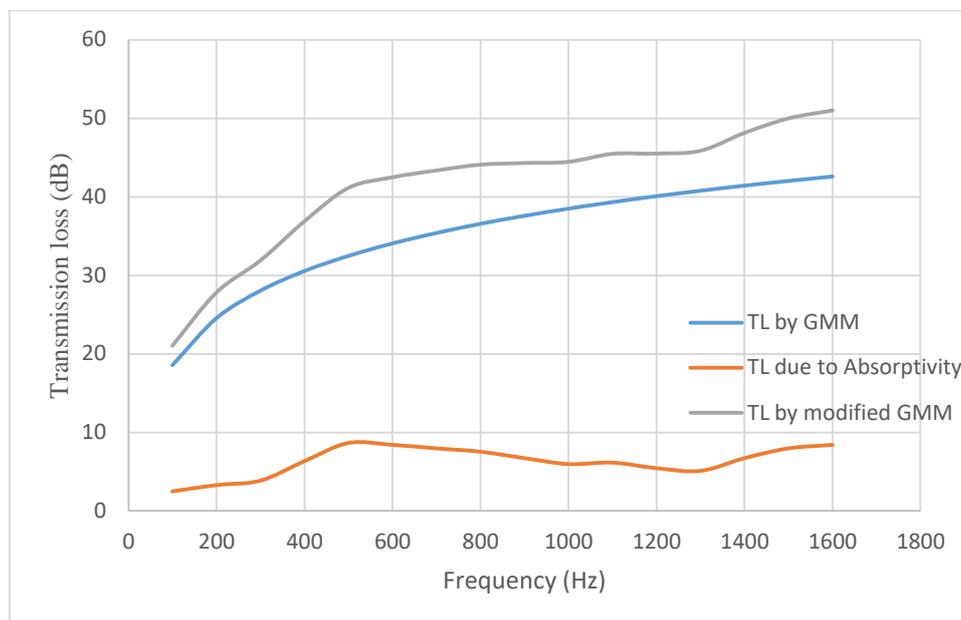


Figure 3.5 Comparison of TL by GMM with the TL by Modified GMM

From the figure 3.5, it is observed that the transmission loss evaluated by modified GMM shows a considerable variation from TL evaluated by GMM, in frequency range of 100 Hz to 600 Hz. Because in this range of frequency, the material shows higher absorptivity, correspondingly the TL due to absorptivity is observed to be higher. Within the frequency range 600 Hz to 1300 Hz TL by modified GMM observed to have only minor increase with increase in frequency, because of corresponding dip in value of TL due to absorptivity. Beyond 1400 Hz, the TL due to absorptivity increases abruptly bringing corresponding change in TL by modified GMM.

IV. CONCLUSION

The specimen is made successfully in required dimensions with a minimum error. Tensile test is conducted on this material show an ultimate strength of 120 MPa and young's modulus 8.6 GPa which gives a better agreement with plywood having young's modulus 8.5 GPa. Evaluation of velocity of sound through the medium is done with the young's modulus obtained from the tensile test. The theoretical prediction of transmission loss of three medium proximal rachis, without considering the effect of absorption coefficient in the GMM has been developed. Theoretical prediction of transmission loss of proximal rachis of coconut leaf is compared with the plywood. From the comparison it is found that the transmission loss of proximal rachis is higher than that of plywood.

The absorptive coefficient of proximal rachis of coconut leaf having 10 mm thickness is determined. The proximal rachis of coconut leaf has higher absorptivity compared to plywood at both higher and lower frequency. The proximal rachis shows a higher absorption coefficient in and around of 500 Hz. Exceeding the frequency 1200 Hz, the absorption coefficient increases. Transmission loss due to the effect of absorptivity is determined by available equations. The transmission loss of material medium is modified considering the absorptive coefficients, this is implemented in the modified GMM.

The present study brings out a design tool for the estimation of sound transmission loss of proximal rachis of coconut leaf considering the effect of absorption coefficient. The input parameters can be confined to impedance and absorption coefficients of the medium. The proposed material is a better replacement for plywood as partition walls in a hall. It is a cost effective, low frequency sound absorbing material that can be used for various applications like automobile interiors, room acoustics, and ceiling of audio recording studios.

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