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Numerical Investigation on the Sound Absorption Coefficients of Malaysian Wood

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ABSTRACT

Sound absorption coefficients of materials are one of the most important information in order to determine the reverberation time of an enclosure. There are published data inside text books on sound absorption coefficients of typical materials. However, the sound absorption coefficients of Malaysian wood such as Chengal, Meranti, Nyatoh and Keruing, just to name a few, have not been established yet. Therefore, this paper presents preliminary results of the sound absorption coefficients of 100 types of Malaysian woods. Initial work has been carried out numerically using MATLAB based on the Delaney-Bazley approximation method. In general, it is found that at lower frequency (<500 Hz), as expected, the sound absorption coefficient of Malaysian wood is low and at higher frequency (>500 Hz), the sound absorption coefficient is high. Moreover, at higher frequency, with higher density value, the sound absorption coefficient of one species is lower compared to another species that has lower density. Further work will be continued by doing experimental justification in comparison with the numerical results.

INTRODUCTION

Sound absorption coefficients of materials are one of the most important information for architects, engineers and musicians, in determining the reverberation time of an enclosure, for examples theatres, classrooms, car interiors, studios and others. With this knowledge, it is by design that the enclosure should provide a suitable acoustic environment to the listeners, depending on its application, i.e. for music only, speech only or both.

There are standard values for sound absorption coefficients of typical materials, such as carpet, concrete, plywood, and others, available inside text books [1 – 4].

Previous work has also shown that a considerable amount of work has been carried out to determine the sound absorption coefficient of wood or wood-based related materials [5 – 10].

Wassilieff [5] studied the sound absorption coefficients of New Zealand pine (*Pinus radiate*) wood fibres and shavings by using a simple Rayleigh model which requires the airflow resistivity, porosity and tortuosity of the material as input. He also showed a reasonable agreement for wood fibres samples when a comparison to a single-parameter empirical model of Delany and Bazley [6] method is used.

Kang *et. al.* [7] found that the sound absorption coefficient of beech wood (*Fagus grandifolia*) has no difference in measurement when using the standing wave method compared to the two microphone method.

Yoshikawa [8] suggested new way to classify suitable woods that can be used for string instruments: transmission parameter and the antivibration parameter. This scheme can show distinctly the difference between the soundboards and frame boards that usually are the two substantial elements in string instruments.

Kidner and Hansen [9] showed that using the Delany and Bazley's approximation method is adequate when modelling sound absorption in porous materials in comparison to other complex method such as the Biot's model [10,11].

Bucur [12] has authored a comprehensive book on the wood acoustics. However, there is still lacking on the Malaysian wood properties in terms of the sound absorption coefficient.

Therefore, this paper reports some preliminary results on the sound absorption coefficients for 100 types of Malaysian woods. Numerical investigation was done using MATLAB, which utilises the Delany-Bazley approximation method.

BACKGROUND ON WOOD

Energy absorption

Wood is an extremely versatile material with a wide range of physical and mechanical properties among the many species of wood. It is also a renewable resource with an exceptional strength-to-weight ratio. Wood is a desirable construction material because the energy requirements of wood for producing a usable end-product are much lower than those of competitive materials, such as steel, concrete or plastic. As for energy absorption or shock resistance which is functional of the ability of a material to quickly absorb and form to another energy via deformation. Wood is remarkably resilient in this respect and is often a preferred material for shock loading.

Several parameters are used to describe energy absorption depending on the eventual criteria of failure considered. Work to proportional limit, work to maximum load, and work to total failure (i. e. toughness) describe the energy absorption of wood materials at progressively more severe failure criteria. These criteria also can be applied to the ability of wood to absorb sound and from that we can assume the sound absorption coefficient and determine the range of the sound absorption coefficient. In terms of determining the sound absorption coefficient of the wood, the vibration properties of primary interest in structural materials, which are speed of sound and internal friction, have to be determined and well-studied.

The speed of sound in a structural material of wood is a function of the modulus of elasticity and density. In wood, the speed of sound also varies with grain direction because the transverse modulus of elasticity is much less than the longitudinal value (as little as 1/20); the speed of sound across the grain is about one-fifth to one-third of the longitudinal value. For example, a piece of wood with a longitudinal modulus of elasticity of 12.4 GPa and density of 480 kg/m3 would have a speed of sound in the longitudinal direction of about 3,800 m/s. In the transverse direction, modulus of elasticity would be about 6,100 MPa and the speed of sound approximately 8,100 m/s. [13]

Malaysian Woods

Malaysian woods are divided into four categories [14]. They are heavy hardwoods (HHW), medium hardwoods (MHW), light hardwoods (LHW) and softwoods (SW). Hardwood trees have broad leaves and are deciduous – they lose their leaves at the end of the growing season. Hardwoods are angiosperms, which mean that they are using flowers to pollinate for seed reproduction. While the softwood trees are conifers (evergreens), have needles or scale-like foliage and are not deciduous. Softwoods are gymnosperms, meaning they do not have flowers and use cones for seed reproduction.

In Malaysia, there are more hardwoods compare to softwoods. Table 1 – Table 4 show the common names and botanical names for all 100 Malaysian woods, grouped into four categories, respectively; 14 HHW, 36 MHW, 47 LHW and 3 SW [14]. Common names of woods are used hereafter.

Table 1. Common names and botanical names of Malaysian *heavy* hardwoods [14]

No.	Common Names	Botanical Names
1	Balau / Selangan Batu	*Shorea spp*
2	Balau, Red/ Selangan Batu Merah	*Shorea spp*
3	Belian	*Eusideroxylon zwageri*
4	Bitis	*Madhuca spp. and Palaquium spp.*
5	Chengal	*Neobalanocarpus heimii*
6	Giam	*Hopea spp.*
7	Kekatong	*Cynometra spp.*
8	Keranji	*Dialium spp.*
9	Malangangai	*Eusideroxylon malangangai*
10	Merbau	*Intsia spp.*
11	Penaga	*Mesua ferrea*
12	Penyau	*Upuna borneensis*
13	Resak	*Vatica spp. and Cotylelobium*
14	Tembusu	*Fagraea spp.*

Table 2. Common names and botanical names of Malaysian *medium* hardwoods [14]

No.	Common Names	Botanical Names
1	Alan Batu	*Shorea albida*
2	Bekak	*Amoora spp.*
3	Derum	*Cratoxylum spp.*
4	Entapuloh	*Teijsmanniodendron spp.*
5	Geriting / Teruntum	*Lumnitzera spp.*
6	Kandis	*Garcinia spp.*
7	Kapur	*Dryobalanops spp.*
8	Kasai	*Pometia spp.*
9	Kayu Malam	*Diospyros spp.*
10	Kedang Belum / Tulang Daing	*Milletia spp.*
11	Kelat	*Eugenia spp.*
12	Keledang	*Artocarpus spp.*
13	Kempas	*Koompassia malaccensis*
14	Keruing	*Dipterocarpus spp.*
15	Keruntum	*Combretocarpus rotundatus*
16	Kulim	*Scorodocarpus borneensis*
17	Mata Ulat	*Kokoona spp.*
18	Mempening	*Lithocarpus spp. and Quercus spp.*
19	Mengkulang /Kembang	*Heritiera spp.*
20	Meransi	*Caralia spp.*
21	Merawan / Gagil	*Hopea spp.*
22	Merbatu	*Parinari spp. and Maranthes corymbosa*
23	Merpauh	*Swintonia spp.*
24	Mertas	*Ctenolophon parvilfolius*
25	Nyalin	*Xanthophyllum spp.*
26	Pauh Kijang	*Irvingia malayana*
27	Perah	*Elateriospermum tapos*
28	Petaling	*Ochanostachys amentacea*

29	Punah	*Tetramerista glabra*
30	Ranggu	*Koordersiodendron pinnatum*
31	Rengas	*Gluta spp. and Melanochyla spp.*
32	Semayur	*Shorea inaequilateralis*
33	Senumpul	*Hydnocarpus spp.*
34	Simpoh	*Dillenia spp.*
35	Tampoi	*Baccaurea spp.*
36	Tualang	*Koompassia excelsa*

Table 3. Common names and botanical names of Malaysian *light* hardwoods [14]

No.	Common Names	Botanical Names
1	Alan Bunga	*Shorea albida*
2	Ara	*Ficus spp.*
3	Babai	*Saraca spp.*
4	Bayur	*Pterospermum spp.*
5	Berangan	*Castanopsis spp.*
6	Bintangor	*Calophyllum spp.*
7	Binuang	*Octomeles sumatrana*
8	Dedali	*Strombosia javanica*
9	Durian	*Coelostegia , Durio spp. and Neesia spp.*
10	Geronggang / Serungan	*Cratoxylum spp.*
11	Gerutu	*Parashorea*
12	Jelutong	*Dyera spp.*
13	Jongkong	*Dactylocladus stenostachys*
14	Kedondong	*Species of Burseraceae*
15	Kelumpang	*Sterculia spp.*
16	Kembang Semangkok	*Scaphium spp.*
17	Ketapang	*Terminalia spp.*
18	Kungkur	*Pithecellobium spp.*
19	Laran	*Anthocephalus chinensis*
20	Machang	*Mangifera spp.*
21	Mahang	*Macaranga spp.*
22	Medang	*Species of Lauraceae*
23	Melantai / Kawang	*Shorea spp.*
24	Melunak	*Pentace spp.*
25	Mempisang	*Species of Annonaceae*
26	Meranti Bakau	*Shorea uliginosa*
27	Meranti, Dark Red /Obar Suluk	*Shorea spp.*
28	Meranti, Light Red / Red Seraya	*Shorea spp.*
29	Meranti, White / Melapi	*Shorea spp.*
30	Meranti, Yellow / Yellow Seraya	*Shorea spp.*
31	Merbulan	*Blumeodendron spp.*
32	Mersawa	*Anisoptera spp.*
33	Nyatoh	*Species of Sapotaceae*
34	Pelajau	*Pentaspadon spp.*
35	Penarahan	*Species of Myristicaceae*
36	Perupok	*Lopopethalum spp.*
37	Petai	*Parkia*
38	Pulai	*Alstonia spp.*
39	Ramin	*Gonystylus spp.*
40	Rubberwood	*Hevea brasiliensis*
41	Sengkuang	*Dracontomelum dao*
42	Sentang	*Azadirachta excelsa*
43	Sepetir	*Sindora spp. and Copaifera palustris*
44	Sesendok	*Endrospermum spp.*
45	Terap	*Artocarpus spp., Paratocarpus spp. and Antiaris toxicaria*
46	Terentang	*Campnosperma spp.*
47	White Seraya	*Parashorea spp.*

Table 4. Common names and botanical names of Malaysian *softwoods*[14]

No.	Common Names	Botanical Names
1	Damar Minyak	*Agathis borneensis*
2	Podo	*Podocarpus spp.*
3	Sempilor	*Dacrydium spp. and Phyllocladus spp.*

Note that, these woods are selected based solely on their commercially used and available in Malaysia. The main difference between the three categories of hardwoods is the priority given during the classification stages that considered natural durability over its average density [14]. This means that, for example, Merbau which is classified under HHW is naturally durable and has an average density of 800 kg/m^3. Meanwhile, Kempas is classified as MHW since its heartwood is found to be not durable even though its average density is higher at 890 kg/m^3. Average density is the only factor that determines the difference between MHW and LHW. In summary, Table 5 shows the density range at 15% moisture content for each category of Malaysian woods.

Table 5. Density range at 15% moisture content of Malaysian woods [14]

Classification	Density range (15% m.c.)
Heavy hardwood	800 – 1120 kg/m^3
Medium hardwood	720 – 880 kg/m^3
Light hardwood	400 – 720 kg/m^3
Softwood	Botanical distinction

In terms of natural durability, MTIB [14] has classified four groups to distinguish the difference of natural furability between Malaysian hardwoods, as shown in Table 6.

Table 6. Natural durability of Malaysian woods [14]

Group	Number of years
Very durable	Exceeding 10 years
Durable	5 – 10 years
Moderately durable	2 – 5 years
Non-durable	0 – 2 years

SIMULATION THEORY

A simple empirical model of the acoustic impedance of a porous material using the Delany-Bazley approximation method is used for this initial work, whereby the absorption coefficient can easily be calculated when acoustic impedance of a material is obtained [15]. The characteristic impedance, Z_0, of which is assumed to be positive time dependence e^{jwt}, is given by [9]

$$Z_0 = \rho_0 c_0 \,(1 + 0.0571\chi^{-0.754} - j0.087\,\chi^{0.732}), \qquad (1)$$

where ρ_0 and c_0 are the density and speed of sound in the fluid without the presence of the porous material, respectively. The non-dimensional parameter χ is defined as [9]

$$\chi = \rho_0 f/R_1, \qquad (2)$$

where f denotes the frequency in Hz and R_1 is the flow resistivity of the porous material. Flow resistivity is defined as the pressure required on generating a unit flow through the material per unit thickness. The validity of Eq. (1) extends over the range $0.01 < \chi < 0.1$. Bies and Hanson provided a formulation to extend the low and high frequency ranges for any value of χ [16].

The normal incidence sound absorption coefficient of porous materials, α, is given by [6]

$$\alpha = 1 - \left| \frac{Z - \rho_0 c_0}{Z + \rho_0 c_0} \right|^2 , \qquad (3)$$

where Z is the acoustic impedance of a rigidly-backed layer of thickness L, given by [6]

$$Z = Z_0 \coth(\gamma L). \qquad (4)$$

Here γ is the propagation coefficient, which is given by

$$\gamma = 2\pi f/c_0\,(0.189\,\chi^{-0.595}) + j\,(1 + 0.0978\,\chi^{-0.595}). \qquad (5)$$

Note that, it is assumed that the temperature and humidity are constant.

RESULTS AND DISCUSSION

Table 7 – Table 10 present the results for the sound absorption coefficient of Malaysian woods for HHW, MHW, LHW and SW, respectively for an octave frequency between 125 Hz – 4000 Hz. Note that, diameter of sample is set to be 10 cm in order to be perfectly fit into the impedance tube, which will be the future work of this research. Thickness of frame is 3.5 cm. At the time of writing, a few samples have not yet been able to be gathered; hence an estimation of the density and mass of these samples was considered, based on the density range listed in [14].

Table 7. Sound absorption coefficient for *heavy* hardwood

Type	Density (kg/m^3)	Sound absorption coefficients at octave frequency (Hz)					
		125	250	500	1k	2k	4k
Balau	860	0.07	0.18	0.34	0.59	0.74	0.86
Balau,Red	810	0.07	0.18	0.38	0.62	0.76	0.87
Belian	845	0.07	0.18	0.38	0.60	0.75	0.87
Bitis	830	0.07	0.18	0.38	0.61	0.76	0.87
Chengal	925	0.07	0.18	0.36	0.56	0.71	0.84
Giam	875	0.07	0.18	0.37	0.59	0.73	0.86
Kekatong	1155	0.08	0.17	0.31	0.47	0.63	0.78
Keranji	765	0.07	0.18	0.40	0.64	0.79	0.88
Malangangai	535	0.06	0.16	0.40	0.75	0.91	0.93
Merbau	800	0.07	0.18	0.39	0.62	0.77	0.88
Penaga	955	0.07	0.18	0.35	0.55	0.70	0.84
Penyau	1005	0.07	0.18	0.34	0.53	0.68	0.82
Resak	665	0.07	0.17	0.40	0.69	0.84	0.91
Tembusu	650	0.07	0.17	0.41	0.70	0.84	0.91

From Table 7, we can see that at lower frequency (< 500 Hz) the heavy hardwoods show a very small difference in terms of sound absorption coefficient despite changes in density. A bigger difference can be observed above 500 Hz. For example, when the density of the Malangangai is at 535 kg/m^3, the heavy hardwood becomes more absorptive, as high as 0.93 at 4 kHz. However, we can see that with higher density, e.g. Kekatong (density = 1,155 kg/m^3), the sound absorption coefficient is only 0.78 at 4 kHz. At low frequencies, the sound absorption coefficient remains generally at below 0.3.

Similarly, in Table 8, the same pattern can be observed. Moreover, we can also see that, in general, the hardwoods are less absorptive at low frequency and more absorptive at higher frequency. Similar observation can be seen in Table 9 and Table 10 for light hardwoods and softwoods, respectively.

Table 8. Sound absorption coefficient for *medium* hardwood

Type	Density (kg/m^3)	Sound absorption coefficients at octave frequency (Hz)					
		125	250	500	1k	2k	4k
Alan Batu	850	0.07	0.18	0.38	0.60	0.75	0.86
Bekak	770	0.07	0.18	0.39	0.64	0.78	0.88
Derum	715	0.07	0.17	0.40	0.67	0.81	0.90
Entapuloh	756	0.07	0.18	0.39	0.65	0.79	0.89
Geriting	755	0.07	0.18	0.39	0.65	0.79	0.89
Kandis	700	0.07	0.17	0.40	0.68	0.82	0.90
Kapur	585	0.06	0.17	0.41	0.73	0.88	0.92
Kasai	745	0.07	0.18	0.40	0.65	0.80	0.89
Kayu Malam	605	0.06	0.17	0.41	0.72	0.87	0.92
Kedang Belum	815	0.07	0.18	0.38	0.62	0.76	0.87
Kelat	505	0.06	0.16	0.40	0.75	0.92	0.94
Keledang	785	0.07	0.18	0.39	0.63	0.78	0.88
Kempas	890	0.07	0.18	0.37	0.58	0.73	0.86
Keruing	690	0.07	0.17	0.40	0.68	0.82	0.90
Keruntum	645	0.06	0.17	0.41	0.70	0.85	0.91
Kulim	655	0.07	0.17	0.41	0.70	0.84	0.91
Mata Ulat	905	0.07	0.18	0.37	0.57	0.72	0.85
Mempening	1010	0.07	0.18	0.34	0.52	0.68	0.82
Mengkulang	635	0.06	0.17	0.41	0.71	0.85	0.91
Meransi	680	0.07	0.17	0.40	0.68	0.83	0.90
Merawan	497	0.06	0.16	0.40	0.76	0.93	0.94
Merbatu	695	0.07	0.17	0.40	0.68	0.82	0.90
Merpauh	675	0.07	0.17	0.40	0.69	0.83	0.91
Mertas	805	0.07	0.18	0.39	0.62	0.77	0.87
Nyalin	610	0.06	0.17	0.41	0.72	0.87	0.92
Pauh Kijang	940	0.07	0.18	0.36	0.56	0.71	0.84
Perah	1235	0.08	0.16	0.29	0.44	0.60	0.76
Petaling	897	0.07	0.18	0.37	0.58	0.73	0.85
Punah	625	0.06	0.17	0.41	0.71	0.86	0.92
Ranggu	705	0.07	0.17	0.40	0.67	0.82	0.90
Rengas	720	0.07	0.17	0.40	0.66	0.81	0.90
Semayur	794	0.07	0.18	0.39	0.63	0.77	0.88
Senumpul	778	0.07	0.18	0.39	0.63	0.78	0.88
Simpoh	685	0.07	0.17	0.40	0.68	0.83	0.90
Tampoi	640	0.06	0.17	0.41	0.70	0.85	0.91
Tualang	820	0.07	0.18	0.38	0.61	0.76	0.87

Table 9. Sound absorption coefficient for *light* hardwood

Type	Density (kg/m^3)	Sound absorption coefficients at octave frequency (Hz)					
		125	250	500	1k	2k	4k
Alan Bunga	575	0.06	0.16	0.41	0.73	0.89	0.92
Ara	360	0.05	0.14	0.36	0.36	0.98	0.95
Babai	515	0.06	0.16	0.40	0.75	0.92	0.93
Bayur	395	0.05	0.14	0.38	0.76	0.97	0.95
Berangan	620	0.06	0.17	0.41	0.71	0.86	0.92
Bintangor	475	0.06	0.15	0.39	0.76	0.94	0.94
Binuang	280	0.05	0.13	0.33	0.69	0.98	0.95
Dedali	590	0.06	0.17	0.41	0.73	0.88	0.92
Durian	430	0.06	0.15	0.38	0.76	0.96	0.95
Geronggang	350	0.05	0.14	0.36	0.75	0.99	0.95
Gerutu	725	0.07	0.18	0.40	0.66	0.81	0.89
Jelutung	425	0.06	0.15	0.38	0.76	0.96	0.94
Jongkong	600	0.06	0.17	0.41	0.72	0.87	0.92
Kedondong	518	0.06	0.16	0.40	0.75	0.92	0.93
Kelumpang	570	0.06	0.16	0.41	0.73	0.89	0.92
Kembang Semangkuk	560	0.06	0.16	0.40	0.74	0.89	0.93
Ketapang	385	0.05	0.14	0.37	0.76	0.98	0.95
Kungkur	465	0.06	0.15	0.39	0.76	0.94	0.94
Laran	300	0.05	0.13	0.34	0.72	0.99	0.95
Machang	555	0.06	0.16	0.40	0.74	0.89	0.93
Mahang	495	0.06	0.16	0.40	0.76	0.93	0.94
Medang	355	0.05	0.14	0.36	0.75	0.99	0.95
Melantai	415	0.06	0.15	0.38	0.76	0.97	0.95
Melunak	540	0.06	0.16	0.40	0.74	0.91	0.93
Mempisang	380	0.05	0.14	0.37	0.76	0.98	0.95
Meranti Bakau	750	0.07	0.18	0.39	0.65	0.79	0.89

Meranti, Dark Red	565	0.06	0.16	0.41	0.74	0.89	0.93
Meranti, Light Red	626	0.06	0.17	0.41	0.71	0.86	0.91
Meranti putih	500	0.06	0.16	0.40	0.76	0.93	0.94
Meranti, Yellow	595	0.06	0.17	0.41	0.72	0.87	0.92
Merbulan	670	0.07	0.17	0.40	0.69	0.83	0.91
Mersawa	520	0.06	0.16	0.40	0.75	0.92	0.93
Nyatoh	410	0.06	0.15	0.38	0.76	0.97	0.95
Pelajau	490	0.06	0.16	0.40	0.76	0.93	0.94
Penarahan	382	0.05	0.14	0.37	0.76	0.98	0.95
Perupok	480	0.06	0.15	0.40	0.76	0.94	0.94
Petai	686	0.07	0.17	0.40	0.68	0.83	0.91
Pulai	370	0.05	0.14	0.37	0.75	0.98	0.95
Ramin	530	0.06	0.16	0.40	0.75	0.91	0.93
Rubberwood	615	0.06	0.17	0.41	0.71	0.86	0.92
Sengkuang	510	0.06	0.16	0.40	0.75	0.92	0.93
Sentang	676	0.07	0.17	0.40	0.69	0.83	0.91
Sepetir	532	0.06	0.16	0.40	0.75	0.91	0.93
Sesendok	315	0.05	0.13	0.35	0.73	0.99	0.95
Terap	400	0.05	0.14	0.38	0.76	0.97	0.95
Terentang	330	0.05	0.14	0.35	0.74	0.99	0.95
White Seraya	420	0.06	0.15	0.38	0.76	0.96	0.95

Table 10. Sound absorption coefficient for softwood

Type	Density (kg/m^3)	Sound absorption coefficients at octave frequency (Hz)					
		125	250	500	1k	2k	4k
Damar minyak	580	0.06	0.16	0.41	0.73	0.88	0.92
Podo	735	0.07	0.18	0.40	0.66	0.80	0.89
Sempilor	445	0.06	0.15	0.39	0.76	0.95	0.94

Figure 1 illustrates the sound absorption coefficient for selected heavy hardwoods that include Balau, Chengal, Kekatong, Merbau and Keranji. Note that, these woods are selected solely due to illustration purposes only.

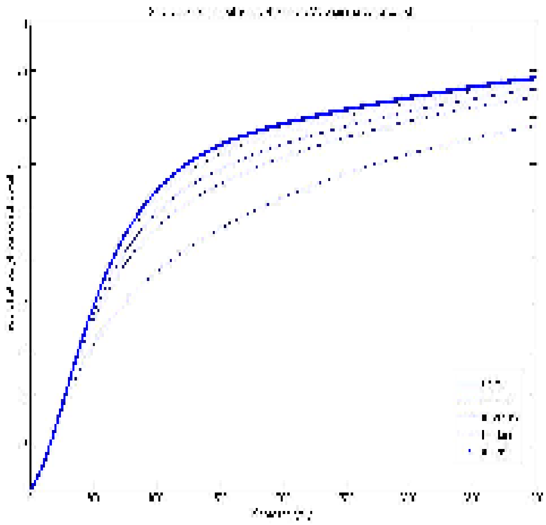


Figure 1. Sound absorption coefficient of selected heavy hardwoods

Similarly, Figure 2 illustrates the sound absorption coefficient for selected medium hardwoods that include Kapur, Keledang, Kempas, Keruing and Rengas.

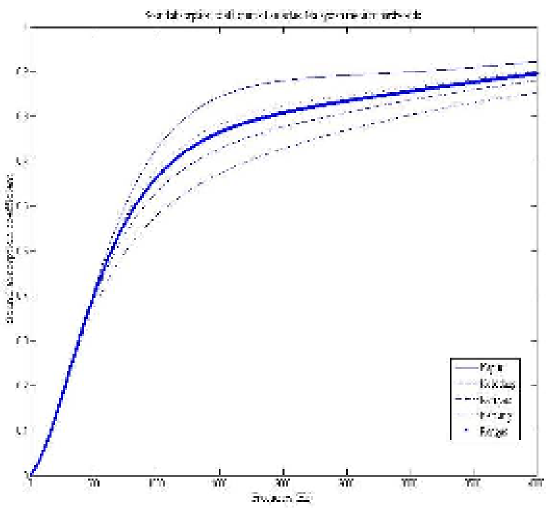


Figure 2. Sound absorption coefficient of selected medium hardwoods

Figure 3 illustrates the sound absorption coefficient for selected light hardwoods that include Berangan, Durian, Meranti putih, Nyatoh and Ramin. Meanwhile, Figure 4 illustrates the sound absorption coefficient for all softwoods.

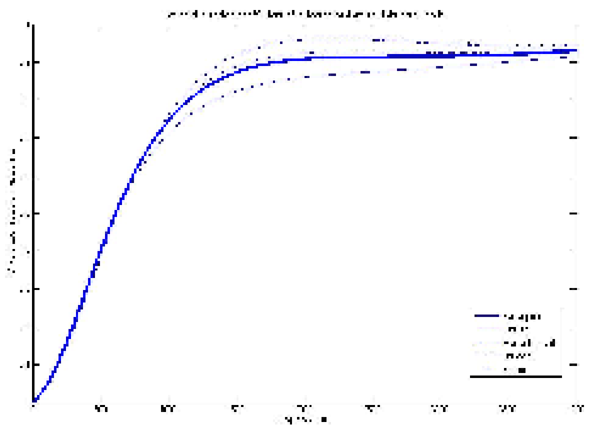
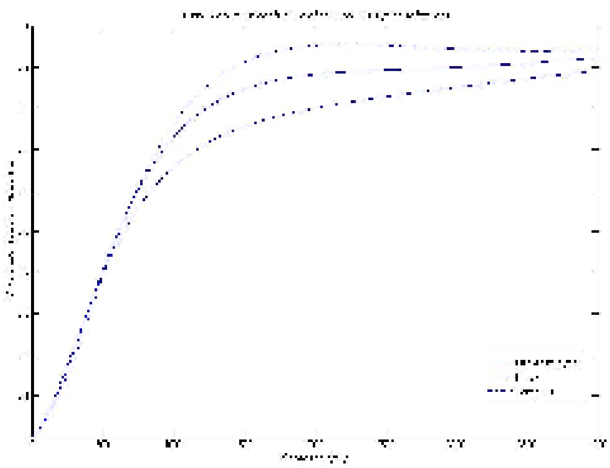


Figure 3. Sound absorption coefficient of selected light hardwoods

Figure 4. Sound absorption coefficient of softwoods



In comparison to the four categories of Malaysian wood, in general, softwoods are found to be having the least sound absorption coefficient for almost all frequencies. This may be due to the fact that it does not contain any fibres or vessels.

CONCLUSIONS

This paper reports preliminary results on the sound absorption coefficient of 100 types of Malaysian woods. Initial work has been carried out numerically using MATLAB based on the Delaney-Bazley approximation method. In general, it is found that at lower frequency (<500 Hz), as expected, the sound absorption coefficient of Malaysian wood is low and at higher frequency (>500 Hz), the sound absorption coefficient is high. Moreover, at higher frequency, with higher density value, the sound absorption coefficient of one species is lower compared to another species that has lower density. Experimental work will follow in order to justify the results from this numerical investigation.

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