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The Sustainable Development Goal (SDG) 9: A Case Study of Effectiveness of Ultrasonic Pulse Velocity on Different Lengths of Bintangor and Yellow Meranti Species

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Abstract

This study promotes Sustainable Development Goal (SDG) 9, which focuses on building resilient infrastructure, promoting inclusive and sustainable industrialisation, and fostering innovation. By using Non-Destructive Testing (NDT) techniques, particularly Portable Ultrasonic Non-Destructive Indicator Testing (PUNDIT), the study promotes the assessment and maintenance of materials without causing damage. For this study, PUNDIT is used to evaluate the effect of pulse velocity on two selected Malaysian tropical timber species, i.e. Bintangor and Yellow Meranti. This research is concentrated on assessing the relationship between timber lengths and pulse velocity parallel to the grain directions. Forty (40) readings of pulse velocity were measured for each species using a series of lengths in increments of 215 mm. The readings were measured using the direct transmission method. The result of the experimental laboratory test indicates that there was a weak correlation between timber length and pulse velocity. The relation was insignificant since the r-squared of the pulse velocity to the timber length was 24% and 16% for the Bintangor and Yellow Meranti, respectively. The inconsistent pulse velocity is likely related to the strength group, density, moisture content and unforeseen defects inside the specimens. In conclusion, it is found that utilising the PUNDIT pulse velocity to measure the length of Bintangor and Yellow Meranti timber is inappropriate. It is proposed that a distinct density range between the chosen species be considered for the upcoming test. The results shared in this research evaluated how the quality of timber species contributes to the construction of safe and durable buildings and structures, aligning with the goal of developing resilient infrastructure, as specified in SDG 9.

Keywords: Pulse Velocity, Tropical Timber, Transit Time, Timber Grading

Introduction

The slogan "Innovate for Progress, Build for Tomorrow!" embodies the essence of Sustainable Development Goal 9 (SDG 9), which focuses on industry, innovation, and infrastructure. It reflects the idea that innovation and technological advancement are the driving forces behind progress and sustainable development. This idea highlights the importance of using the Non-Destructive Test (NDT) method in determining the structural strength of structural members, including structural timber components. Timber is the primary natural resource in our country. It is the earliest construction material used widely in the construction sector. A typical structural member intended for timber was frames, columns, beams, and trusses, also used as concrete frames. Many problems in timber construction are often due to performance issues, likely caused by the quality of the timber. There is no modern method for measuring length besides essential equipment, such as tape measures, which are limited, especially by the working area.

NDT is carried out to inspect the quality of timber before it is prepared to perform as structural members in the construction sector. It is a well-known method for investigating the uniformity, quality, and serviceability of timber structures for such buildings. It is an accurate and uncomplicated technique to adopt in site testing and is also costless compared to destructive techniques. The ultrasonic pulse velocity (UPV) was used to assess the structural integrity of timber elements in monumental buildings by (Shaji et al., 2000). The effect of moisture content, specific gravity, internal voids and external voids on the pulse velocity was measured for tests of different samples. The test results on six timber species established a correlation between compressive strength parallel to the grain and ultrasonic pulse velocity perpendicular to the grain. They reported that the test on the laboratory samples, large timber joints, and beams of actual buildings was the recommended procedure. It can be used effectively for non-destructive service assessment of wood (Shaji et al., 2000).

Non-destructive evaluation is not a new technique; it has been used for many years in timber construction. However, the accuracy of UPV in determining the effects of length, timber species and strength group for tropical timber has yet to be reported. Thus, this method must be tested and verified to suit Malaysia's specific timber species and conditions. Duju et al (2000) established a non-destructive method for estimating timber strength incorporating four tropical timber species of varying density classes: Cotylelobium melanoxylon, Shorea albida, Palaquium folanigerum, and Dacrydium pectinatum. Specimens were prepared with nominal cross-sections of 100mm by 100mm and lengths of 2000mm, totalling 157 specimens tested in their green condition. Four methods for measuring the modulus of elasticity (E_{fr} et al.) were compared and utilised to predict the bending strength of full-size structural components. They found that the correlation coefficients for these methods were 0.83, 0.78, 0.82, and 0.80, respectively, which were significant at the 1% level. This relation indicates strong correlations between modulus of elasticity and bending strength across the timber species studied.

In a similar study conducted by Sandoz et al (2000), non-destructive testing successfully predicted the modulus of elasticity and proved a viable parameter for estimating bending strength. Over the past decade, significant advancements have been made in ultrasonic-based methods applied to wood. Stress wave propagation and natural frequency vibration methods have been the primary techniques used for timber grading. To enhance the sensitivity of the stress wave method, acousto-ultrasonics (AUS) have been introduced to complement initial time information. The integration of time and spectral AUS data has facilitated exploratory research in the NDT of wood (Sandoz et al., 2000).

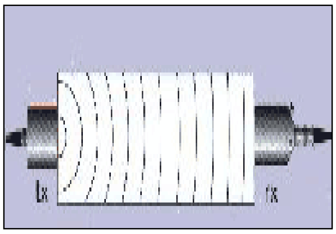
In a study conducted by Palizi et al (2023), the objective was to establish robust models for predicting the modulus of elasticity (MOE) of wood species in three principal directions across different moisture levels, utilising the ultrasonic pulse velocity (UPV) technique. The research encompassed the development of 72 models employing various input variables and methodologies. These models were then trained and tested using experimental data. The findings indicate that the developed models and the UPV technique have the potential to improve the accuracy of MOE predictions for wood species substantially. A separate study by Dündar et al (2016) concluded that ultrasonic velocity, in conjunction with specific gravity, can serve as predictive parameters for assessing the dimensional stability of oak and chestnut wood during the manufacturing process. Few tropical timber species in relations to the MOE measured using ultrasonic wave non-destructive test method and static destructive test were reported by Puaad et al. (2014). Timber beams from eight selected Malaysian timber of different strength grouping; Resak (SG4), Kapur (SG4), Merpauh (SG4), Bintangor (SG5), White Meranti (SG5), Jelutong (SG6), Sesendok (SG7) and Kelampayan (SG7) were used. Their results from static and non-destructive tests were statistically correlated and compared taking into account the density of the timber. The mean value for the MOE established from the NDT tests were found to be higher than the corresponding value established from static tests.

One commonly available equipment for measuring UPV is PUNDIT, produced by CNS Farnell. It consists of electronic circuitry for generating ultrasonic pulses and measuring the travel time of pulses through the medium to be tested. Achieving the quality of the materials from ultrasonic pulse velocity concepts will require a high order of accuracy in this measurement. The instrument generates suitable pulses and accurately measures the time transmission (transit time) through the material tested. The material's length (path length) needs to be calculated as part of the velocity determination. The formula of pulse velocity is as in equation 1.

$$\text{Pulse velocity, } v = \frac{\text{Path length (mm)}}{\text{Transit time }(\mu\text{m})} \quad \text{.............[Equation 1]}$$

Using PUNDIT, there are three methods of determining ultrasonic pulse velocity. The transmission can be located through direct, semi-direct, or indirect methods. The direct transmission arrangement is the most qualified since the longitudinal pulse leaving the transmitter propagated mainly in the expected direction to the transducer face, as shown in Figure 1. For semi-direct transmission, the arrangement has a sensitivity intermediate between the other two. It is generally found to be sufficiently accurate to take this as the distance measured from centre to centre of the transducer faces.

This arrangement is otherwise similar to direct transmission. Figure 2 shows the arrangement of the semi-direct transmission testing. Indirect transmission should be used when only one face of the material is accessible, when the depth of a surface crack is to be determined or when the quality of the surface material relative to the overall quality is of interest. Figure 3 shows the arrangement of the indirect test. Figures 1 to 3 are depicted by CNS Farnell, (2004), respectively.



.Figure 1: Direct Transmission

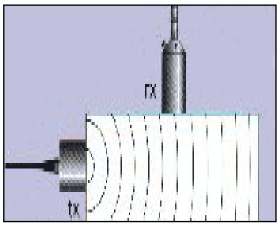


Figure 2: Semi-direct Transmission

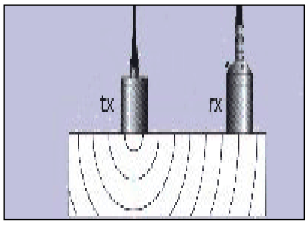


Figure 3: Indirect Transmission

PUNDIT Plus is a pundit family of ultrasonic pulse velocity (UPV) instruments. It is accepted by users worldwide as the industry standard for non-destructive concrete testing. The PUNDIT is essential for this method based on its quality and popularity. Pundit Plus is the new generation unit, using the latest microprocessor technology to meet today's increasing demands for accuracy, reliability, and ease of use (GENEQ, 2000).

Building upon previous research observations and leveraging the functionality of the PUNDIT, this study aims to assess the correlation between timber lengths and velocity by employing PUNDIT for two chosen timber species. Additionally, it seeks to compare the efficacy of velocity measurements on two distinct strength groups of timber, namely Bintangor (SG5) and Yellow Meranti (SG6) species.

Research Methodology and Material Selection

The primary equipment utilised in this experiment was the PUNDIT Plus. It automatically provided transit time values in microseconds (µs) through its display, employing principles to ascertain the velocity of ultrasonic pulses within a material medium. This equipment comprises an emitter, a transmitter, and a receiver transducer, which function to measure the time taken for the pulse to travel from transmitter to receiver (see Figure 6). A grease was applied to the wood surface to ensure precise readings during the experiment. This process involved applying grease at both ends of the samples. Figures 6(a) to 6(e) and Figure 7 depict the equipment and materials utilised in the experiment.

(a) (b) (c)

(d) (e)

Figure 6: Instrumentations and sample length: (a) receiver transducer; (b) transmitter transducer; (c) front panel PUNDIT; (d) direct transmission test; (e) placement of transmitter transducer

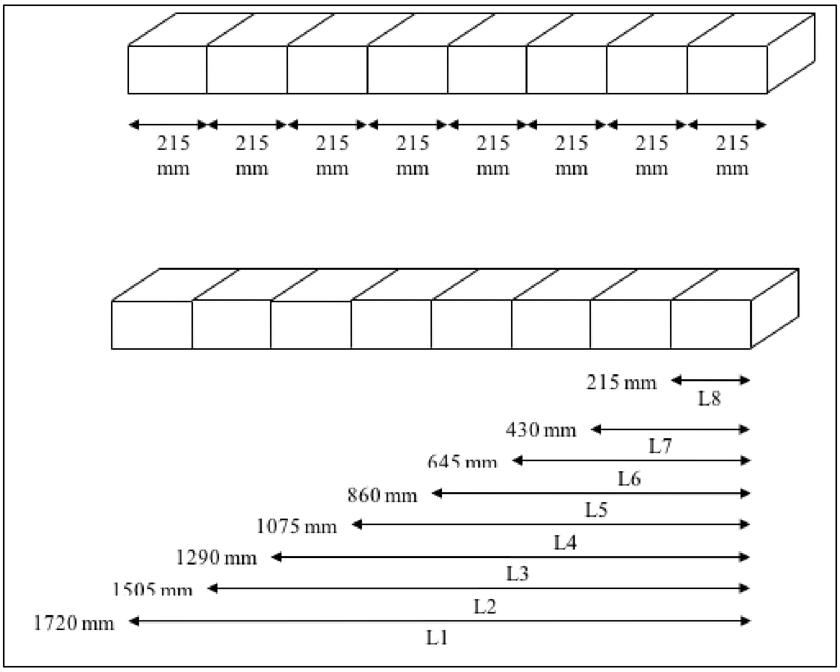


Figure 7: Length of timber samples cut from longest (L1) to shortest (L8)

The non-destructive testing procedure involved elongating the pulse velocity parallel to the grain across a span length. Each time, the receiver and transmitter transducers were positioned in contact with the specimen at lengths ranging from L1 to L8. Pulse velocity measurement was conducted by placing the transducer at each end of the specimen for direct transmission. With the transducers firmly pressed at both ends of the sample, the PUNDIT display indicated transit time in microseconds (µs). Following the most extended sample test (L1), the timber sample was shortened by 215 mm, and the UPV test was repeated for the subsequent length. To ensure precision and accuracy, data for each specific length were obtained from an average of three repetitions of tests. All experiments followed identical steps from L1 to L8, with consistent sample distances for both Bintangor and Yellow Meranti specimens.

Two (2) tropical timber species in the range of 10% to 12% moisture content were selected for the test, which represents strength group (SG) 5 and SG 6 as classified in

Malaysian Standard (MS) 544 Part-2: 2017. Bintangor is the standard Malaysian name for timber of Calophyllum species belonging to the Guttiferae family and SG5. It is categorised as light hardwood with a 465-865 kg/m^3 density. It is widely grown from lowland forests to upper mountain forests and abundant in some peat swamp forests. Its sapwood is well-defined from the heartwood, deep red, red-brown, pink or orange-brown, and its coarse to coarse and uneven texture. Bintangor is commonly used for light construction, flooring (light traffic), parquet flooring, panelling, joinery, railway sleepers, posts, beams, joists, rafters, plywood (light structural), wooden pallets, door and window frames and staircase (angle blocks, rough brackets, apron linings) (Anon, 2024).

The second species is Yellow Meranti, categorised under SG6, with a density range between 575 and 735 kg/m^3 when air dry. Its texture is moderately coarse but even, usually interlocked and sometimes wavy grain, and moderately challenging to treat with preservatives. This timber is classified as not durable under Malaysian conditions. This light hardwood timber, also known as Shorea species, belongs to the Dipterocarpaceae family. The sapwood is lighter and clearly defined from the heartwood, which is lighter yellow-brown with a green tinge, darkening to deeper shades of yellow-brown or brown. The timber dries moderately slowly, with little degradation, except for some cupping, bowing and powder-post beetle attacks in the sapwood. Its shrinkage is relatively high to high, especially in the tangential direction. Radial shrinkage ranges between 0.9% and 1.2%, while tangential shrinkage ranges between 3.1% and 3.8% (Anon, 2024).

Yellow Meranti is suitable for general utility purposes, light construction, planking for vehicle bodies as well as ship and boat building, panelling, mouldings, partitioning, shop and office fittings, furniture, joinery, flooring, decking, staircase (angle blocks, rough bracket, apron lining, baluster, balustrade and spandrel framing), tool handles (non-impact), pallets, railway sleepers, posts, beams, joists, rafters and pencil. This timber is highly prized as a plywood species (Anon, 2024).

Result and Discussion

After obtaining the transit time values, each timber's pulse velocity was manually calculated using Equation 1. The mean pulse velocity values shown in Table 1 are the Average of five readings at one location of the five timber blocks. The pulse velocity fluctuation for the Bintangor species is dispersed, as shown in Figure 8.

Table 1
Pulse Velocity of Bintangor

UPV Measuring Length (mm)	No. of Samples (S) and Pulse Velocity (km/s)					
	S1	S2	S3	S4	S5	Avg. Value (km/s)
1720	4.388	4.161	4.358	5.160	4.743	4.562
1505	4.358	3.761	4.082	5.223	4.962	4.477
1290	4.117	4.418	4.532	4.448	4.108	4.325
1075	4.566	4.796	4.708	4.607	4.503	4.636
860	4.581	4.587	4.370	4.757	4.523	4.564
645	4.564	4.796	4.353	4.314	4.490	4.503
430	4.488	4.538	4.181	5.137	4.951	4.659
215	2.282	2.098	2.012	4.971	4.670	3.207
					Total Average	4.367

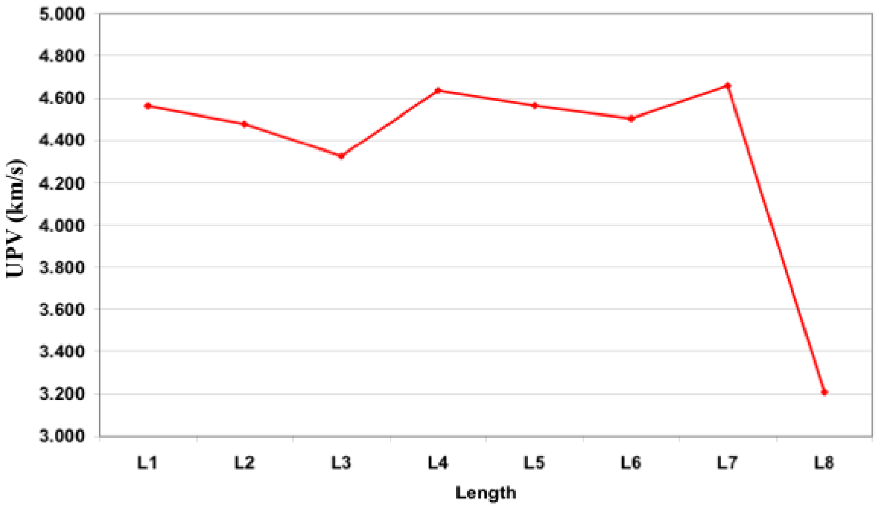


Figure 8: Average fluctuation of Pulse Velocity for Bintangor

Figure 8 shows that the pulse velocity is not linear to the length of the timber. The shortest end, L8, decreased sharply. The pulse velocity ranged between 3.209 km/s and 4.659 km/s. The variations in the graph could not be detected physically from the samples, as no defects or noticeable effects were recorded. Thus, it is suggested that the obstacles are within the unforeseen characteristics of the timber specimens, such as different fibre grain direction, density, or localised moisture content.

In the Yellow Meranti species performance context, the average pulse velocity values depicted in Table 2 were utilised to generate the line chart in Figure 9.

Table 2
Pulse Velocity of Yellow Meranti

UPV Measuring Length (mm)		No. of Samples (S) and Pulse Velocity (km/s)					
		S1	S2	S3	S4	S5	Avg. Value (km/s)
L1	1720	5.244	5.202	4.574	5.119	5.160	5.060
L2	1505	5.331	5.265	4.886	5.548	5.443	5.295
L3	1290	5.375	4.618	4.754	4.618	5.435	4.960
L4	1075	5.364	4.760	4.665	4.682	4.886	4.871
L5	860	5.580	4.992	4.736	4.886	4.394	4.918
L6	645	5.338	5.666	5.052	5.019	4.981	5.211
L7	430	4.881	5.644	4.881	5.513	5.459	5.276
L8	215	5.466	5.392	4.782	5.449	5.484	5.315
Total Average (m/s)							5.113

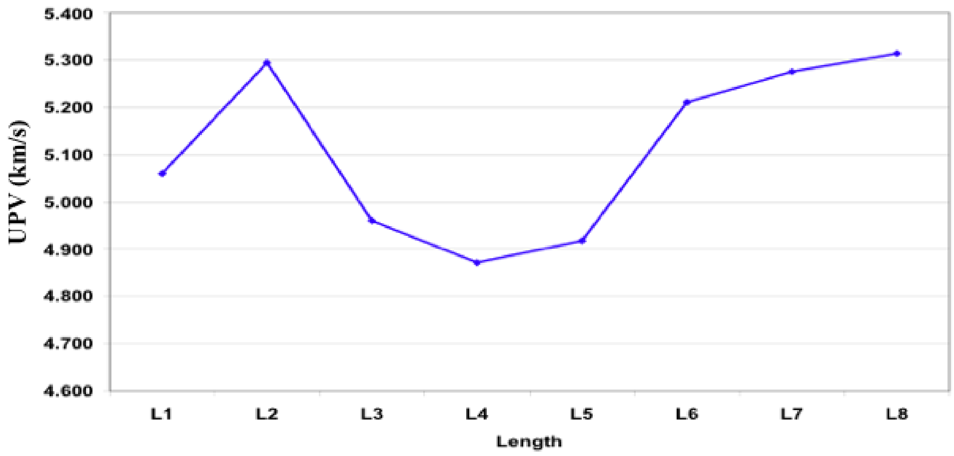


Figure 9: Average fluctuation of Pulse Velocity for Yellow Meranti

Figure 9 shows that the pulse velocity initially increased slightly but declined from L2 to L4. After a significant drop, the velocity gradually increased continuously up to L8. This reading shows that Yellow Meranti's velocity was higher than Bintangor's. In this condition, it is likely that other properties of the timber significantly affect the pulse velocity evaluation. Physical properties such as density, moisture content, and the anatomy of the wood species might contribute to the insignificant relations between the length and its pulse velocity.

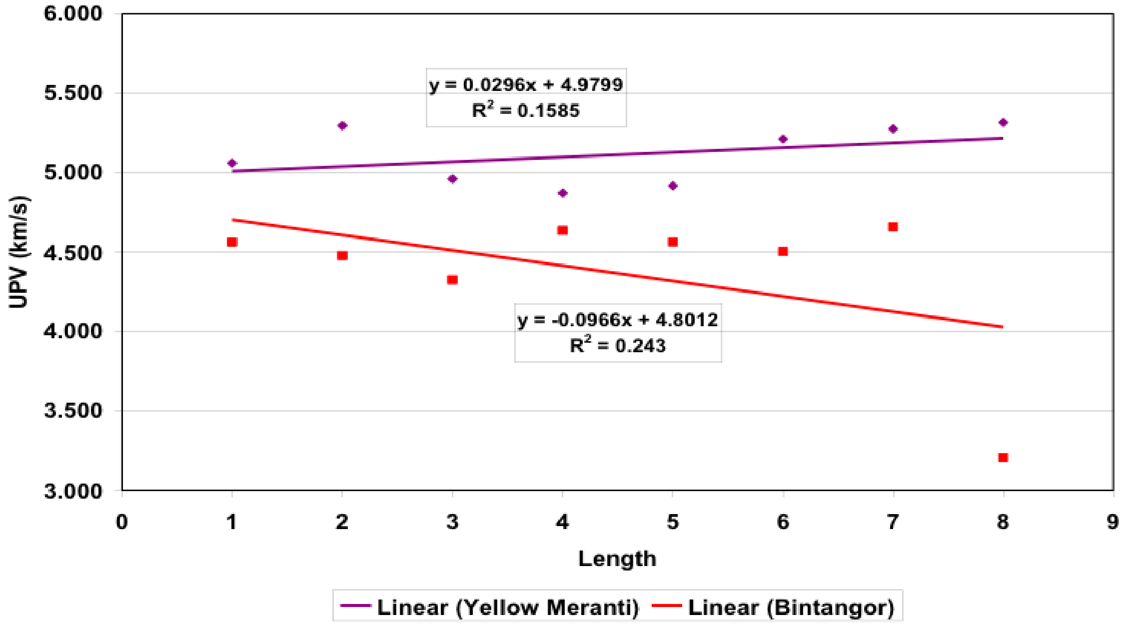


Figure 10: Line Regression of Pulse Velocity and Timber Length

Figure 10 shows the correlation between timber length and pulse velocity for the Bintangor and Yellow Meranti species. Based on the graph, the finest relationship of Bintangor was established using the line regression method as y = - 0.0966x + 4.8012. The coefficient of determination is R^2 = 0.243. Based on the R^2 value, it is evident that the correlation between timber lengths and pulse velocity is insignificant or very weak. Due to the limitation of the coefficient interpretation, it has a weak or low correlation when R^2 is located in the range of < 0.5 or > -0.5. Only 24.3% of the variation in pulse velocity is influenced by timber length, while the other 75.5% are other factors that are approximately effective to the pulse velocity.

For Yellow Meranti, a regression line was identified as y = 0.0296x + 4.9799 with a coefficient of determination, R^2 = 0.159. This coefficient is within the range of -0.5 to 0.5, indicating a weak relationship where only 15.85% of the timber length is related to the pulse velocity. The remaining 84.15% is contributed by other factors such as moisture content, modulus of elasticity and unforeseen properties. Even though the relationship between pulse velocity and lengths of both species is insignificant, the data reflects the different species themselves. As the result of the average value for Yellow meranti (SG6) (5.113 km/s) is higher than Bintangor (SG5) (4.367 km/s), it shows that the pulse velocity value is significant to different types of timber species and strength grade of the timber species, rather than their specimens length (Figure 11).

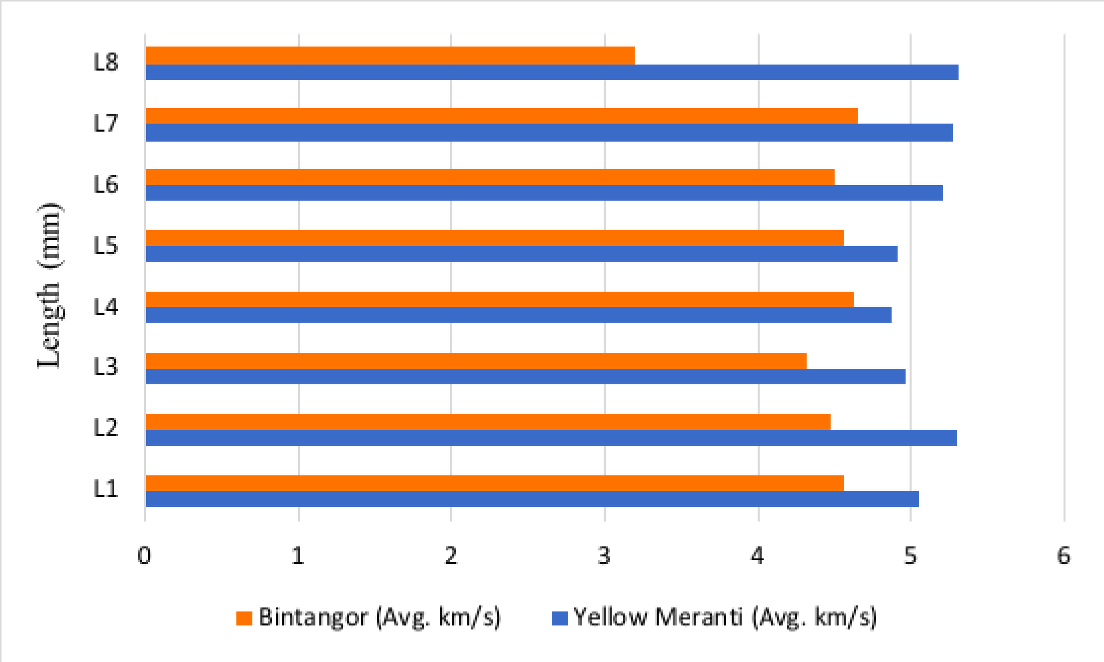


Figure 11: Pulse Velocity Differences between Timber Species

In summary, the findings of this study provide valuable insights that can guide future research and development efforts. Proposing further tests with different density ranges of timber species indicates an ongoing commitment to innovation and improvement in testing methods. The study employs an advanced technique (PUNDIT) to measure pulse velocity in timber, representing an innovative material testing approach. Innovation in NDT methods contributes to the broader material science and engineering field. This study supports SDG 9 by enhancing material testing techniques, promoting the efficient use of resources, and fostering ongoing innovation and research in sustainable infrastructure and industrialisation.

Conclusions

From the analysis, the average value for Yellow Meranti (SG6) (5.113 km/s) is higher than Bintangor (SG5) (4.367 km/s). It shows that the pulse velocity value is significant for different types of timber species and the strength grade of the timber species. **The research revealed a weak correlation between timber length and pulse velocity,** indicating that pulse velocity does not reliably gauge the length of specific timber species. This observation could prompt the development of more precise and customised testing methodologies. The research identified a notable distinction between the Yellow Meranti and Bintangor species, exhibiting varied pulse velocity ranges across all measured lengths. These distinctions serve as valuable evidence to demonstrate the potential of UPV in distinguishing between strength groups or densities within tropical timber species.

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