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PHYSICAL AND MECHANICAL CHARACTERIZATION OF STRUCTURAL WOOD USED IN PAKISTAN

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ABSTRACT

Six species of wood (*Vachellia nilotica, Eucalyptus camaldulensis, Ziziphus mauritiana, Albizia lebbeck, Melia azedarach, Dalbergia sissoo)* were tested in compression and tension parallel to the grain. The specimens were collected from different areas of Pakistan. The compressive strengths, tension parallel to grain and hardness of the wood were determined by testing rectangular shape wooden specimens (ASTM D143 2014, Janka 1906). It was observed that compressive and tensile strength of *Vachllia nilotica* parallel to the grain is higher than other species whereas, *Eucalyptus camaldulensis* hardness behaviour along radial and tangential surface is higher among the wooden samples tested.

KEYWORDS: Wood, compressive strength, tensile strength, hardness, *Vachellia nilotica, Eucalyptus camaldulensis, Ziziphus mauritiana, Albizia lebbeck, Melia azedarach, Dalbergia sissoo.*

INTRODUCTION

The use of natural wood for structural purpose is increasing worldwide with the passage of time. However, the mechanical properties of structural wood have not been investigated in detail in Pakistan and worldwide. Hence in order to fully utilize the potential of wood, particularly in multi-dimensional structures, every country must have knowledge of the mechanical and physical behavior of the wooden species. The wood products used worldwide comes from both developing (about 60%) and developed countries (about 40%). The uses of wood products are extensive. Wood products ranges from wooden plank floor system, load bearing beams etc (Guo et al. 2017). Laminated woods are also being frequently used worldwide (Yue et al. 2019). The cross laminated products of different species have been investigated by the researchers (He et al. 2020, Ukyo et al. 2021). Layered wood products are more strong in compression and bending as compared with single layered (Akbulut and Ayrilmis 2019, Florisson et al. 2021). Researchers have studied the behaviour of wood panels against cyclic loading. The tests results are promising (Kulman et al. 2019). The use of wood dust is also found beneficial for improving the compressive properties of brick (Arulmani et al. 2017). Woodwork waste has been used for the purpose of thermal treatment (Kajda-Szcześniak and Jaworski 2018). Proper thermal treatment can improve certain properties of the wood (Pulngern et al. 2020). The waste generated from cutting of the wood can be used as a raw material for production of fibreboards (Ihnát et al. 2017). Design manuals are available in developed countries for solid seasoned timber (Han et al. 2019). There must be a balance between plantation of new trees and wood utilization (Puettmann and Wilsontn 2005, Winjum et al. 1998).

The properties of same species vary with the environmental conditions like temperature, humidity, water and soil. Researchers have observed variation up to 20% in elastic modulus (Moshtaghin et al. 2016). Researchers (Osuji and Nwankwo 2017) have examined physical and mechanical properties of wood like Albizia, Dahoma or Ekhimi, Ekki and Opepe; and have found variation in same species. Strength class system was also developed by researcher for non destructive testing using mechanical properties test results of wood (Zziwa 2012). Tensile and bending characteristics of the wood have been investigated by the researchers using four point bending test on wooden beam (Yusof 2019). Heat treatment also affects the properties of wood. It was observed that *Eucalyptus camaldulensis* compressive strength and surface roughness changes with the heat treatment (Unsal and Ayrilmis 2005). The fibers of the wood are also used for enhancing the tensile properties of material by their use with epoxy composites (Vinod et al. 2020). The use of fibers of wood are also found beneficial in automobile industry. Fibers of *Albizia lebbeck* bark can be used as green composites in automobile industries (Manimaran et al. 2019). The variation in some wooden species was observed when they are tested for ultrasonic wave velocity. It was observed that variation of ultrasonic pulse velocity along height of *Melia azedarach* was very small (Duong et al. 2019). Researchers have developed correlation between different species of wood using properties like bending, tensile and modulus of elasticity and rupture (Sun et al. 2019, Sunny et al. 2020).

Pakistan being an under-developed country does not possess the knowledge about mechanical and physical properties of woods. Due to lack of knowledge, the wood being used in construction based on rough estimation of mechanical properties. In Pakistan, whenever timber structural member is required, either imported glulam or locally available solid seasoned timber found in timber market is used. The guidelines are also not available for appropriate selection of wood structural members, as wood mechanical properties vary from species to species and territory to territory. Locally available timber structural members are abundantly used for retrofitting of old timber buildings, but economy is compromised because of unavailability of any guidelines for timber obtained from local markets. This study herein presents a comprehensive approach for mechanical characterization of natural structural wood commonly available in Pakistan.

MATERIAL AND METHODS

Sample collection

Random sampling method is used for selection of test specimens. Random sampling provides better estimates of mechanical properties. According to random sampling method, any species of wood can be taken from any region or place. In total, six species of wood were collected from different cities in order to check possibility of difference in the mechanical and physical properties of same species. Seasonal temperature and drought condition can also affects the properties of wood (Hacura et al. 2015). The details of the wood samples collected are mentioned in Tab. 1 and shown in Fig. 1.

Tab. 1: Details of wood species collected.

Scientific name of the specie	Local name (Pakistan)	Cities (Pakistan)	Density ($g·cm^{-3}$)
Vachellia nilotica	Kikar	Dera Ismail Khan	0.65
		Khushab	0.60
Eucalyptus camaldulensis	Safeda	Sheikupura	0.71
		Khushab	0.70
Ziziphus mauritiana	Bair	Khushab	0.64
		Jhelum	0.59
Albizia lebbeck	Shreen	Sarai Alamgeer	0.50
		Gujranwala	0.73
Melia azedarach	Dharaik	Sarai Alamgeer	0.58
		Gujranwala	0.78
Dalbergia sissoo	Tali	Gujranwala	0.69
		Zafarwal	0.75

(a) (b) (c)

(d) (e) (f)

Fig. 1: Logs of (a) Eucalyptus camaldulensis (Safeda), (b) Albizia lebbeck (Shreen), (c) Ziziphus mauritiana (Bair), (d) Vachellia nilotica (Kikar), (e) Melia azedarach (Dharaik), (f) Dalbergia sissoo (Tali).

Samples preparation

The logs of wood were cut according to different testing requirements (ASTM D143 2014, Janka 1906). The size of the specimens tested is illustrated in Tab. 2. The logs were cut into straight planks and then these planks were cut down further in the samples of required dimensions. The cutting of logs was done in such a way that the possibility of the sample having a knot is minimum.

Tab. 2: Details of samples.

Mechanical properties	Dimensions (mm)	Number of samples
Compression parallel to grain	50 x 50 x 250	36
Tension parallel to grain	25 x 25 x 450	36
Hardness	50 x 50 x 150	36

Seasoning

Wood drying or wood seasoning diminishes the moisture content of wood before its use. When wood is utilized as a construction material, it is essential to dry it properly as moisture variation can cause shrinkage in wood. The wood samples collected were wet because of the rainfall of winter season. The cut samples were placed under natural sunlight for drying for about 4 weeks. The thermal treatment can affect the behaviour of structural wood (He et al. 2020, Xie et al. 2020). The moisture content variation can also affects the density of wood (Yanming et al. 2018). The moisture content of the tested sample varies from 13 to 18%.

RESULTS AND DISCUSSIONS

Compression and tension test

The displacement controlled uniaxial compression test was performed using Universal testing machine under controlled loading rate of 2 mm·min^{-1}. Tension test was also performed on universal testing machine.

Eucalyptus camaldulensis (Safeda)

Samples from cities of Sheikupura and Khusab were tested for compression and tension. The samples failed in crushing and shear during compression test (Fig. 2). The compressive strength of wooden sample from city of Sheikupura and Khushab was 45 MPa and 33 MPa resp. The compression test performed by the researches on *Eucalyptus camaldulensis* in Thailand had compressive strength from 39 to 48 MPa (Nezu et al. 2020). The tensile strength of wooden sample from city of Sheikupura and Khushab was 17.38 MPa and 14.03 MPa, resp.

(a) (b)

Fig. 2: Failure pattern under compression and tension for Eucalyptus camaldulensis (Safeda) from city of (a) Sheikupura, (b) Khushab.

Ziziphus mauritiana (Bair)

Samples from cities of Khushab and Jhelum were tested for compression and tension. The samples failed in crushing during compression test (Fig. 3). The compressive strength of wooden sample from city of Khushab and Jhelum was 29 MPa and 40 MPa, resp. The compression test performed by other researches on *Ziziphus mauritiana* had maximum compressive strength of 26 MPa (Damme 2006). The tensile strength of wooden sample from city of Khushab and Jhelum was 18.21 MPa and 12.38 MPa, resp.

(a) (b)

Fig. 3: Failure pattern under compression and tension for Ziziphus mauritiana (Bair) from city of (a) Khushab, (b) Jhelum.

Albizia lebbeck (shreen)

Samples from city of Sari Aalamgeer and Gujranwala were tested for compression and tension. The samples failed in crushing during compression test (Fig. 4). The compressive strength of wooden sample from city of Sari Aalamgir and Gujranwala was 28.6 MPa and 29.5 MPa resp. The compression test performed by other researches on *Albizia lebbeck* had maximum compressive strength of 33.5 MPa (Tang et al. 2016). The tensile strength of wooden sample from city of Sari Aalamgeer and Gujranwala was 19.56 MPa and 9.6 MPa, resp.

(a) (b)

Fig. 4: Failure pattern under compression and tension for Albizia lebbeck (Shreen) from city of (a) Sari Alamgir, (b) Gujranwala.

Melia azedarach (Dhariak)

Samples from city of Sari Aalamgeer and Gujranwala were tested for compression. The samples failed in shear and crushing during compression test (Fig. 5). The compressive strength of wooden sample from city of Sari Aalamgeer and Gujranwala was 32 MPa and 24 MPa resp. The compression test performed by other researches on *Melia azedarach* had maximum compressive strength of 27.2 MPa (Tang et al. 2016). The tensile strength of wooden sample from city of Sari Aalamgir and Gujranwala was 20.62 MPa and 7.18 MPa resp.

(a) (b)

Fig. 5: Failure pattern under compression for Melia Azedarach (Dhariak) from city of (a) Sari Aalamgeer, (b) Gujranwala.

Vachllia nilotica (Kikar)

Samples from city of Dera Ismail Khan and Khushab were tested for compression and tension. The samples failed in shear during compression test (Fig. 6). The compressive strength was 42 MPa and 44 MPa for city of Dera Ismail Khan and Khushab resp. The compression test performed by other researches on *Nilotica* had compressive strength about 32 MPa (Mahmood et al. 2016). The tensile strength was 34.33 MPa and 32.54 MPa for city of Dera Ismail Khan and Khushab resp.

(a) (b)

Fig. 6: Failure pattern under compression for Vachllia nilotica (Kikar) from city of (a) Dera Ismail Khan, (b) Khushab.

Dalbergia sissoo (Tali)

Samples from city of Gujranwala and Zafarwal were tested for compression and tension. The samples failed in shear during compression (Fig. 7). The compressive strength was 34 MPa and 36 MPa for city of Gujranwala and Zafarwal resp. The compression test performed by other researches on *Dalbergia sissoo* had compressive strength about 56 MPa (Mahmood et al. 2016). The tensile strength was 12.48 MPa and 21.65 MPa for city of Gujranwala and Zafarwal, resp.

(a) (b)

Fig. 7: Failure pattern under compression for Dalbergia sissoo (Tali) from city of (a) Gujranwala, (b) Zafarwal.

The load displacement comparison of all species in compression and tension test is shown in Figs. 8 and 9.

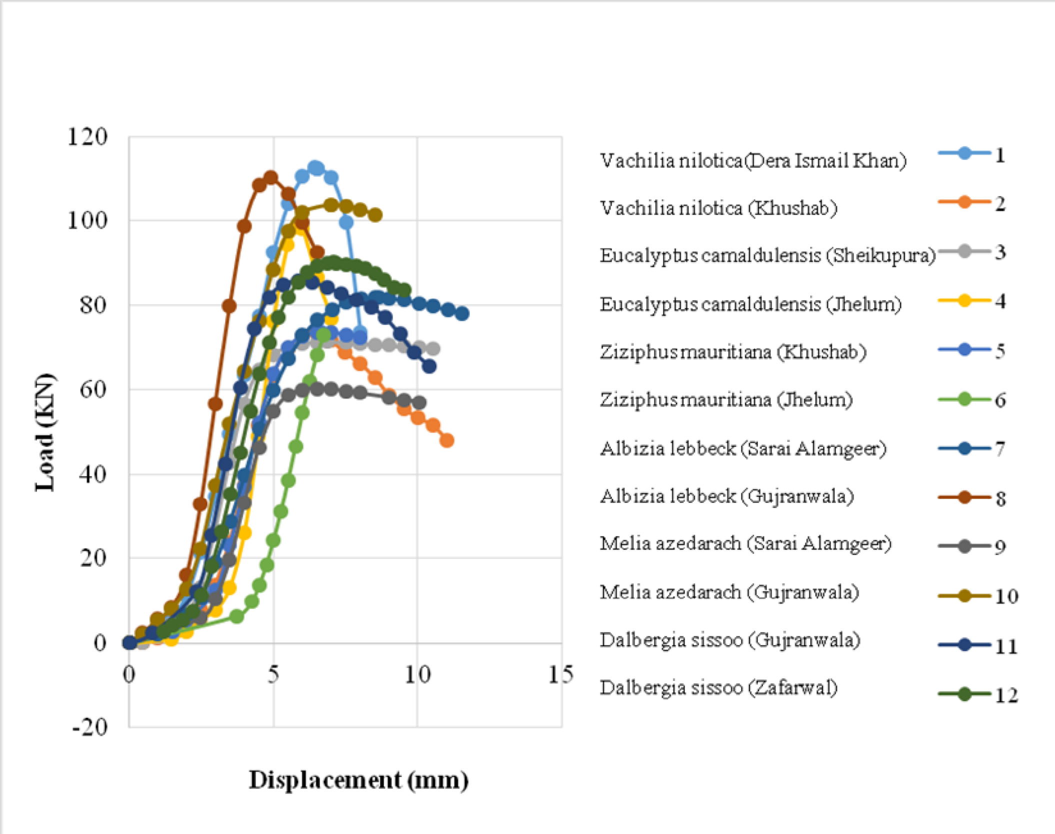

Fig. 8: Comparison of compressive strength of tested wooden samples.

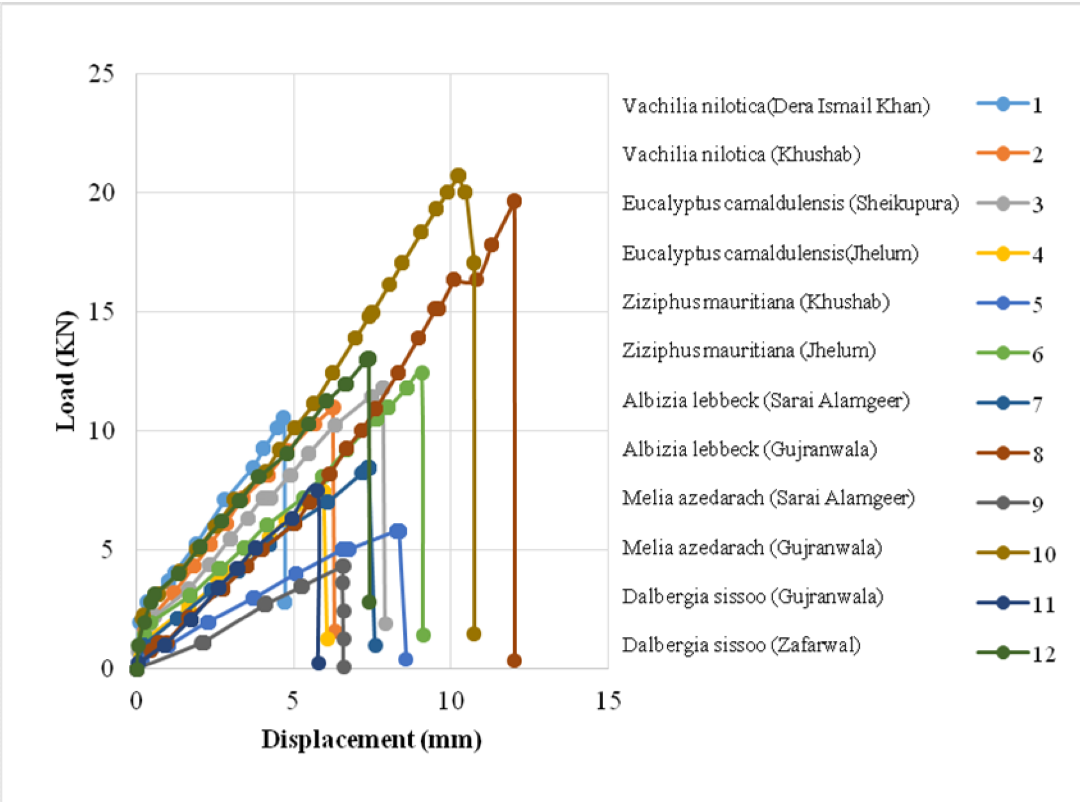

Fig. 9: Comparison of tensile strength of tested wooden samples.

Hardness test

The hardness of wood samples were measured using Gabriel Janka test (Janka 1906). It is a measure of a force which is required for penetration of 11.28 mm steel ball halfway into the tested specimen. Hardness test was also performed on Universal testing machine. The wooden samples were tested along end, tangential and radial surface. The test assembly for UTM and tested specimen is shown in Fig. 10. The results of tested wooden samples are summarized in Tab. 2 and shown in Fig. 11.

Fig. 10: Tested specimens for hardness.

Tab. 2: Details of wood species tested for hardness.

Scientific name of the specie	Cities (Pakistan)	Hardness		
		End surface (kN)	Radial surface (kN)	Tangential surface (kN)
Vachellia nilotica	Dera Ismail Khan	8.90	9.72	7.80
	Khushab	9.24	7.00	10.38
Eucalyptus camaldulensis	Sheikupura	10.44	10.34	11.14
	Khushab	6.44	7.30	5.70
Ziziphus mauritiana	Khushab	7.64	5.58	5.78
	Jhelum	5.56	5.14	4.68
Albizia lebbeck	Sarai Alamgeer	8.10	4.24	4.14
	Gujranwala	5.74	5.72	5.72
Melia azedarach	Sarai Alamgeer	6.90	5.00	5.08
	Gujranwala	5.32	5.26	5.46
Dalbergia sissoo	Gujranwala	7.88	6.98	6.70
	Zafarwal	6.28	6.34	5.58

Tiny cracks and bulging pattern was observed when specimens were tested for hardness. When load is applied through a circular ball the grains tend to move inside the timber creating a hole in the surface. When there is moisture in the wood the grains tend to move upward because load is being applied downwards towards the body of wood causing the grains to bulge around the application of load. But, when the moisture content in the wood is less the grains do not move upwards rather they move apart causing tiny cracks around the application of load. Tiny cracks are more often formed rather than bulging failure. The hardness test results obtained are in good agreement with the past published result (Mahmood et al. 2016).

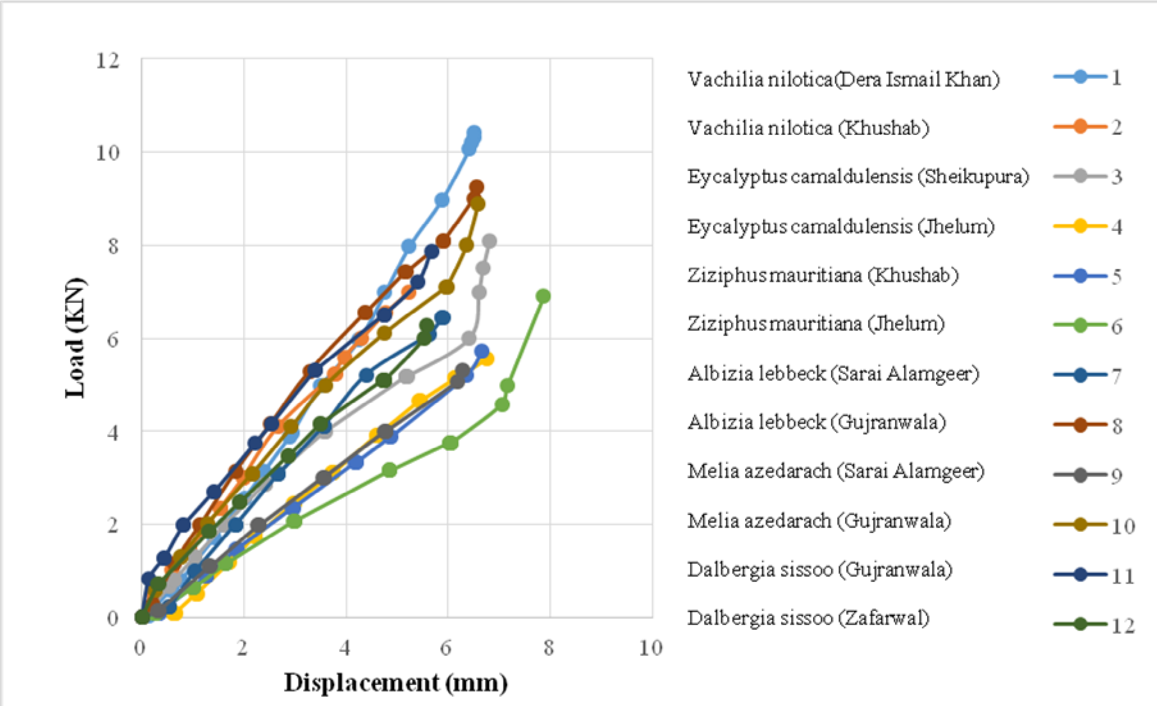

Fig. 11: Comparison of hardness of tested wooden samples.

CONCLUSION

Based on the compression, tension and hardness test on 6 different species of the wood, following conclusion can be drawn for compression parallel to grain: *(1)* The results show that *Vachellia nilotica* (of city Khushab) having compressive strength of 41.16 MPa is highest among the wooden species tested. *(2) Melia azedarach* (of city Gujranwala) having compressive strength of 21.91 MPa is lowest among the wooden species tested. *(3)* The most common failure patterns in tested specimens were crushing and shearing. None of them have failure patterns of splitting and end rolling.

For tension parallel to grain: *(1)* The maximum tensile capacity was 33.59 MPa for *Vachllia nilotica* (of city Dera Ismail Khan). *(2)* The minimum tensile capacity was 9.95 MPa for *Ziziphus mauritiana* (of city Jhelum). *(3)* The most common failure pattern in this tested specimens were shearing and splitting.

And for hardness test as well: *(1)* The maximum hardness was 10.03 kN for *Vachllia nilotica* (of city of Dera Ismail Khan) and the minimum value was 5.25 kN for *Melia azedarach* (of city of Gujranwala). *(2)* The maximum hardness value at radial and tangential surface was 10.03 kN for *Eucalyptus camaldulensis* (of city of Sheikhupura) and the minimum value at tangential and radial surface was 4.5 kN for *Melia azedarach* (of city of Sarai Alamgeer).

During the load application, the failure patterns were either tiny cracks around the circle or bulging occurs around the point of load application was observed.

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