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MACHINING PROPERTIES OF *Melia dubia* WOOD

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ABSTRACT

In this paper result of working quality of *Melia dubia i*s reported after testing them under six major wood working operations namely - planing, sanding, turning, shaping, boring and mortising based on Indian Standard. The wood performed extremely well under planing. In shaping, the performance was good enough. Though all the other operations yielded poor results, the composite rating factor which is an overall performance indicator was 35 % more than that of *Tectona grandis*. The ease of working is only 93 % compared to teak. The working quality index which was based on the composite rating factor and ease of working worked out to 107 taking *Tectona grandis* as 100 mainly because of the high performance under planing and shaping and good performance under sanding.

Keywords: Ease factor, planing, sanding, shaping, turning, working quality.

INTRODUCTION

Like the physical and mechanical properties, the working quality (or machining quality) of a timber also plays an important role in its utilization. Knowledge of working quality of timber is therefore necessary for its efficient utilization. Necessity of data on working quality of more and more native timbers is being felt. It is influenced by density, fibre structure, presence of interlocked grains, tension wood etc. Proper knowledge of working quality of lesser used timber species is becoming important day by day as traditional timbers are becoming scarce and beyond the reach of common man.

Many Indian species have been studied at Forest Research Institute, Dehradun for their working quality indices (WQI) and it has been reported that the working qualities ranged from poorer than to comparable to and better than that of Teak. For instance, the working properties of *Jaonessia principes* and *Populus ciliata* were reported to be poorer than that of teak (Pant *et al.* 1992).

Many species like *Albizzia, Dalbergia sissoo* and eucalypts had WQI (90-96) approaching or comparable to that of teak (Shukla *et al.* 1991). Performances of *Acacia tortilis, Leucaena leucocephala* and *Picea smithiana* were also comparable to teak (Pant *et al.* 2002). Jaitly *et al*. (1983) reported more than 90 % WQI for *Eucalyptus camaldulensis* and *Eucalyptus* hybrid. *E. camaldulensis* responded better to planing with 20° cutting angle. This species also gave clear and acceptable bores and mortises.

Araucaria cunninghamii, Azadirachta indica, Jakaranda acutifolia (jacaranda), were studied by Pant *et al.* (1992). Overall performance was better for *A. cunninghamia, A. indica* and *J. acutifolia* compared to teak. Pant *et al.* (2002) reported that *Paulownia* species and *Ulmuswallichiana* performed better than teak after subjecting them to the six wood working operations.

Working qualities of six Indian timbers obtained from a Northern State of India were reported by Pant *et*

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al. (1989). The species tested were maple (*Acer oblongum*), cypress (*Cupressus torulosa*), shisham (*Dalbergia sissoo*), vern-gair-Garhwal (*Daphniphyllum himalayense*), Indian olive (*Olea glandulifera*) and Indian oak (*Quercus serrata*). The results indicated that all the six species could be worked to an acceptable smooth surface though responses to operations were different for the six species.

Shukla *et al.* (1991) gave a review on the working qualities of 74 Indian timbers. They reported that some of the harder species could be planed to smooth surfaces with planer cutters having 25° cutting angles**.** However, a few other species required a cutting angle of 30°. Whereas less harder woods of Mango and *Pinus roxburghii* required only a lesser cutting angle of 15°. Some timbers like that of *Cinnamomum camphora* and *Araucaria araucana* responded well to multiple cutting angles.

Against this background, a study was conducted to understand the machining qualities of *Melia dubia* (Synonym: *Melia composita).* This wood species is yet to be studied thoroughly from the utilization point of view. The wood of *M. dubia* belongs to the diffuse porous category (Saravanan *et al.* 2013a). Saravanan *et al*. (2013b) found this species suitable for paper pulp production and recommended a five year rotation for use in this sector. Another study showed that apart from paper industry, this species has mechanical properties suitable for plywood industry and energy values required for biomass based power generation (Saravanan *et al.* 2014). Studies on the gluing and bonding properties on the veneers of this species showed that panels made using urea formaldehyde and phenol formaldehyde adhesives meet the requirements of interior Grade (general purpose) and exterior grade (general purpose) plywoods (Uday *et al.* 2012). The finishing qualities of this species also have been recently reported with respect to the lusture and moisture inhibiting capacities provided by various commercial wood finishes (Gupta *et al.* 2016a, Gupta *et al.* 2016b).

MATERIALS AND METHODS

Fifteen kiln-dried (10-12 % moisture content) planks of size 1200x100x25 mm^3 were prepared from plain-sawn 25 mm thick material of a *M. dubia* tree of 15 years of age felled from the Forest Research Institute's campus to prepare samples for various tests. This mature tree had hardly any sapwood. The planks were sawn out from the main stem of the tree. The mean density of the wood thus obtained was 0,39 kg/m^3 (Kumar *et al.* 2018). From these planks, samples of sizes mentioned in Table 1 were prepared for various tests and wood working tests were carried out as per methods given in IS-8292 (BIS IS-8292 1992).

Table 1: Specimen sizes for each wood working operation.

Sl. No.	Working operation	No. of samples	Size of each specimen (mm x mm x mm)
1	Planing	15	900 x 100 x 25 (Both these operations were carried out on each of the fifteen samples in the order of sanding after planing)
2	Sanding		
3	Shaping	15	300 x 75 x 25 (These three operations were carried out on each of the fifteen samples in the order of shaping followed by boring followed by Mortising)
4	Boring		
5	Mortising		
6	Turning	15	150 x 25 x 25

A schematic diagram of the samples cut for various tests is given in Figure 1.

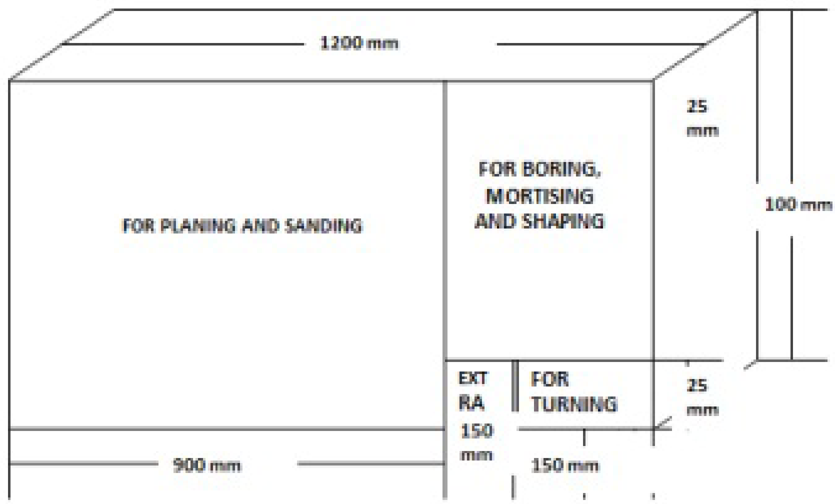

Figure 1: Plan for preparing samples from one plank.

The following were the machines used and their procedure for performing the six wood working operations:

Planing: A DC planer cum thicknesser machine (make Dominion) fitted with two knives diametrically opposite on a circular cutter block was used. Four sets of blades with cutting angles of 15°, 20°, 25° and 30° were used in that order. The grinding angle for the 25° blade was 30° and clearance angle was 15°. Speed of cutter block of diameter 100 mm was kept at 5000 rpm and feed rate was 8,4 m/min. The cutting speed was 26,1 m/s.

Every specimen was passed two times through this machine, once along the grain and then the other face opposite to it. Immediately after each pass, the specimen was visually examined for planing defects. This was carried out with all the four sets of blades. A depth of cut of 1 mm was maintained for each pass so that in effect there was a total depth of cut of 2 mm after two passes. Power requirement in each planing operation was also recorded with the help of a wattmeter. Average value of power required per cm width of cut of the specimen was worked out and values were noted.

Sanding: Three drum endless belt sander (make Smith) with drum motors of 15 hp each at 1725 rpm was used in which drums carried sand papers of grit sizes 60, 80 and 100 progressively. The same specimens used in planing were used for studying the sanding behavior. Each specimen was passed through the three drum sander at a feed rate of 3,6 mm/min with a depth of 1 mm on each side. The cutting speed was 22,9 m/sec.

Shaping: A two-cutter spindle moulding machine (make Sonex Pelican 2840 rpm) mounted with cutters of quarter round profile capable of giving 2 mm deep sweep was used in this test. Fifteen specimen of size 300 x 75 x 25 mm^3 were cut from the original plank. The edges of the specimen were shaped with the help of shaping cutter mounted on the moulding machine.

Boring: A single spindle electric boring machine (make Rockwell - hand feed type) having 3400 rpm and a drill bit of carbon steel with single twist profile pointed type having 25 mm diameter was used in this test. The fifteen shaped specimen were used for this test. Each specimen was held in a suitable position and two holes were made through them near to one end. For the visual examination of the specimen, the four bored holes were cut in two directions, one along the grain and another across the grain.

Mortising: The same fifteen shaped and bored samples were used in this test. The test was done on a hollow chisel type single spindle electric mortising machine (make Oliver) running at 3000 rpm. The square chisel was of 12,5 mm in size. Each specimen was held in a suitable position and two mortises were made on them extending through into a hardwood backing. These mortises were made near the other end of the samples on which holes were bored previously. For the visual examination of the specimen, the mortises were cut along the grain and another across the grain.

Turning: 15 specimens of size 150 x 25 x 25 mm^3 were used for this test. An auto-tool turnery lathe machine (make Crompton) of 3000 rpm which turns samples into uniform shape and size was used for this test.

Immediately after each test, the specimens were visually examined for defects like raised grain, torn grain, fuzzy grain, chip mark and charring effect and were noted depending on the intensity of each defect. Defect values depending on the severity (visual assessment of how a defect can be rectified by subsequent operations like sanding, finishing etc.) from 1 to 5 were assigned as given in Table 2.

Defect grading

Table 2: Assignment of defect values.

Defect severity	Assigned Value
No defect (defect-free)	0
Excellent	1
Very Good	2
Good	3
Fair	4
Poor	5

The calculations of various factors involved in arriving at the working quality index were carried out according to BIS IS-8292 1992 as explained by Shukla *et al.* (1991).

The defect values were compiled for each operation. The total defect values were then calculated for each sample (or surface) as the case may be. These were then grouped into five Grades of 1 to 5 according to the scheme shown in Table 3.

Table 3: Grading of samples/surfaces.

Grade	Definition of grading
1	Defect Value 0 (defect-free)
2	Total Defect Value 1
3	Total Defect Value 2
4	Total Defect Value 3 & 4
5	Total Defect Value 5 & Above

After this, the numbers of samples/surfaces falling into each grade were counted from the compiled data for each operation and their percentages were calculated as follows:

- Let, Total number of samples/surfaces in an operation = N
- Let the number of samples/surfaces falling in grade 1 = n
- Then, % of samples/surfaces falling in grade 1 = (n x 100)/N

Rating factor

After calculating the percentage of number of samples/surfaces falling in each grade, the next step was to arrive at the rating factors (R_i) for each operation which are calculated as given in Table 4.

Table 4: Method of calculating the rating factors.

Operation	Definition of Rating factor
Planing	Percentage of grade 1 specimens
Sanding	Percentage of grade 1 specimens
Shaping	Total Percentage of grade 1&2 specimens
Boring	Total Percentage of grade 1&2 specimens
Mortising	Total Percentage of grade 1,2&3 specimens
Turning	Total Percentage of grade 1,2&3 specimens

Once rating factors have been estimated, the Adjustment factor (A_i) needs to be calculated which is based on the magnitude of the best planing values for teak species. These values can either be generated in the laboratory or taken from literature. In the present study, the values for teak were taken from the literature (Pant *et al.* 2002). For this, the percentage value of a particular operation for teak is divided by the percentage value of teak for its planing operation. For instance, the adjustment factor for planing of teak would be 1.

Various operations are given due weightages (W_i) as per the importance of the operation in working with wood (BIS IS-8292 1992). The weightage for sanding is the highest (5) because this operation is required in almost every type of wood products. This is followed by planing (4), Shaping (2), Boring (1), Mortising (1) and Turning (2). It is to mention that the ASTM standard though did not specify weightages to individual operations, it was stressed that the depth of a defect is more important than its area covered (ASTM D-1666 1987).

In the next step, the weighted averages for teak and the species under investigation would be calculated as Equation 1:

$$Weighted\ average = \frac{\sum RiAiWi}{\sum Wi} \quad (1)$$

Where Ri is the rating factor for each operation, Ai is the adjustment factor and Wi is the weightage for each operation.

BIS IS-8292 1992 defines a figure indicative of the overall performance of a species under all wood working tests relative to teak which serves as an index which is termed as the Composite Rating Factor (CRF). This is calculated as Equation 2:

$$CRF = \frac{\text{Weighted average of species under investigation}}{\text{Weighted average of teak}} \text{ x } 100 \quad (2)$$

The next step is to calculate the Ease factor (EF) which is an indication of ease of working of the species under study relative to teak in wood working tests (BIS IS-8292 1992). It is evaluated by measuring power requirements per cm width of the species studied to achieve a cutting depth of 1,6 mm under planing operation. The power requirement is calculated as Equation 3:

$$Power\ requirement = Power\ requirement\ in\ cutting\ condition\ (kW/cm) - Power\ requirement\ in\ the\ idle\ running\ condition \quad (3)$$

These are noted during the planing operation by reading the power on a wattmeter in idle running condition and when planing samples is in progress Equation 4.

$$EF = \frac{\text{Power requirement of teak}}{\text{Power requirement of species}} \text{ x } 100 \quad (4)$$

Here also the value for teak can be tested in the laboratory or taken from literature. In the present case, value given by Pant *et al.* (2002) was adopted for the purpose.

Estimation of working quality index (WQI)

According to BIS IS-8292 1992, besides the physical and mechanical properties of a timber, its working quality under different wood working operations also form an important consideration for determining its suitability for the manufacture of timber products. Towards this, the BIS IS-8292 1992 formulated the working quality index (WQI) which is calculated by combining the composite rating factor and ease factor which are discussed above. According to the standard, in the calculation of WQI, the CRF or overall performance is given a weightage of "one" whereas the ease factor or the reflection of power requirements is given a weightage of "two". WQI is calculated as Equation 5:

$$WQI = \frac{CRF + 2EF}{3} \qquad (5)$$

RESULTS AND DISCUSSION

Since planing was done on the fifteen samples using four different cutting angles, the rating factors for this operation are given separately. These are given in Table 5.

Table 5: Percentage of *M. dubia* planed surfaces lying in different grades.

Cutting Angle	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Total %
15°	50	40	10	0	0	100
20°	47	23	30	0	0	100
25°	60	3	30	7	0	100
30°	57	13	20	10	0	100

A close observation of different defects that occurred in the species indicated that raised and torn grains were most common followed by chipped grain. In some specimens, roughness was also observed. Koehler (1929) defines raised grains as the corrugated appearance of a planed surface. This is mainly caused by the effect of the planer knives crushing the hard summerwood into the softer springwood beneath it. In this process, the springwood cells underneath gradually try to regain their original shape to some extent causing the summerwood to rise up. In the present case, edge sharpness could not have caused the defects related with grains as freshly ground blades were used in the study. The not too high density may be one reason. However, Bustos *et al.* (2010) clearly found that the cutting edge-recession increased with increasing use of planer blades.

Table 5 reveals that most of the samples lie in the grade 1 (defect-free) category when planed with different cutting angles. It can also be seen that the 25° gives the highest defect free surfaces (60 %) closely followed by 30° which gives 57 % defect-free surfaces. This means that for this species, it is better to keep the cutting angle on the higher side. Hence, a cutting angle of 25°-30° is recommended for *M. dubia* species. For further calculations, the value of 60 % was adopted. The Corresponding grade factor for *Tectona grandis* in planing with a cutting angle of 25° is 20 % (Pant *et al.* 2003). Thus, as far as planing is concerned, *M. dubia* performs much better than Teak. It is worth mentioning that *Azadirachta indica*, *Albizzia* and *Chukrasia tabularis* (belonging to *Meliaceae* family) were reported to be planed to smooth surfaces with planer cutters having 25° cutting angles whereas species like *Acacia nilotica, A. catechu, Cedrus deodara* etc. required a cutting angle of 30° (Shukla *et al.* 1991).

The percent grade values obtained for the other operations are given in Table 6. The values reported for *T. grandis* by Pant *et al.* (2002) also are included in the Table 6.

Table 6: Percentage of different Grades of *M. dubia* along with those for *T. grandis.*

Operation	Grades	*M. dubia*	*T. grandis* (Pant *et al.* 2002)
	1	33	56
Sanding	2	10	44
	3	40	0
	4	17	0
	5	0	0
	1	50	10
Shaping	2	30	20
	3	13	35
	4	07	35
	5	0	0
	1	0	43
Boring	2	0	30
	3	03	23
	4	37	04
	5	60	0
	1	0	34
Mortising	2	10	50
	3	07	16
	4	37	0
	5	46	0
	1	13	36
Turning	2	0	26
	3	0	22
	4	0	14
	5	87	02

From grading data reported in Table 5 and Table 6, Rating factors for each operation were calculated for the species under study and are presented in Table 7 along with those reported for *T. grandis* (Pant *et al.* 2002).

Table 7: Rating factors of and *M. dubia* evaluated from percentage of defects along with those of *T. grandis.*

Species	Planing	Sanding	Shaping	Boring	Mortising	Turning
Tectona grandis (Pant *et al.* 2002)	20	56	33	73	100	84
Melia dubia	60	33	80	00	17	13

Rating factors indicate the extent to which a wood worker can tolerate defects in finishing operation. It can be seen from Table 7 that *M. dubia* shows a much better performance than teak as far as planing and shaping operations are concerned. However, it would be interesting to mention that the wear of the planing blade increases with increasing length of planing (Bustos *et al.* 2010). They used planer blades which had undergone wear due to planing four levels of lengths ranging from 200 to 30000 m. The tensile shear strength of lap joints made with radiata pine was reported to decrease significantly with planing length and the resulting knife wear. Careful sanding has been reported to remove defects caused during planing in the case of *Eucalyptus* hybrid

(Jaitly *et al.* 1983).

In shaping, the most common defects found were raised and torn grains. The defect that was most prevalent in five species of Eucalyptus was torn grain in shaping trials (Belleville *et al.* 2016). During moulding of plantation-grown *Picea glauca* also torn grain was reported as the main defect (Hernández *et al.* 2001).

Scratching (caused by uneven grits) and snake (spiral) marks were not observed in any specimen after sanding. However, fuzziness or woolly surface and torn grain were noticed on the specimen. Sanding is already reported to cause more fuzziness than planing since the grits on the sand papers tear up parts of fibers, whereas the planer blade usually cuts through the fibres resulting in lesser numbers of loose ends sticking up (USDA 1955). The surface finish produced for eucalyptus spp. was very smooth when Belleville *et al.* (2016) used higher grit sized sand papers. Hazir *et al.* (2017) cites the report of Varanda *et al.* (2010) which reveals that smaller abrasive grains resulted in higher surface roughness of the samples of *Eucalyptus grandis.* Roughness parameters of samples sanded with 180 grit were lower in contrast to samples planned or sanded with 60 grit (Relaño *et al.* 2017).The occurrence of torn grains in *M. dubia* during sanding may thus be mostly attributed to the tearing of fibres and use of relatively smaller grits used in the test.

The most common defects that were observed during turning were raised grain, torn and chipped grain with charring effects. With a rating factor of just 13 (against 84 for teak) *M. dubia* does not look to be good for turning purpose and therefore cannot be recommended for the small scale or handicraft units making round toys.

Raised, torn, chipped and fuzzy grains were the common defects observed during boring. A close-up view of the bored holes is shown in figure 2. Belleville *et al.* (2016) observed that the denser species of eucalyptus showed better boring performances than lighter timbers. Hernández *et al.* (2001) also reported good boring, planing and shaping performances for higher density *Picea glauca* which were obtained from different provenances. Their sample size for boring was done on the shaped samples which were 305 mm long. A rating factor of zero (Table 7) indicates that *M. dubia* is not at all suitable for the boring operation. This can be attributed to the relatively low density of this species as reported by Kumar *et al.* (2018).

Figure 2: Close up view of bored holes.

The common defects that were noticed during mortising were raised, torn, chipped and fuzzy grains.

Sometimes the wood is completely chipped out. This is a very serious defect as such defects make the product weak from the point of view of a joint. Occurrence of torn grain is usually caused by dull cutting edges and/ or irregular grain direction that tend to extend into the wood (USDA 1955). On the whole, *M. dubia* does not seem to be a good species for the making mortise joints.

The next step is to calculate the weighted averages as described in the methodology. For calculation of this, the adjustment factors for *T. grandis* and weights assigned to each operation needs to be taken into account. Adjustment factors are calculated from Table 7 by dividing the rating factor of planing by the rating factors of each operation for teak. For instance, the rating factor for turning is 84 and that for planing is 20. Hence the adjustment factor of turning would be 20/84. Table 8 gives the adjustment factors and weightages assigned to each operation (Pant *et al.* 2003).

Table 8: Teak adjustment factors and weightages of different operations.

	Planing	Sanding	Shaping	Boring	Mortising	Turning
Adjustment factor (Ai)	1	0,357	0,606	0,274	0,2	0,238
Weights (Wi)	4	5	2	1	1	2

(Pant *et al.* 2003)

Weightages (W_i) are given to each operation as per its importance in working with wood. For example, the weightage for sanding is the highest (5) because sanding is required in almost every type of wood products as described earlier. The total ($\sum$Wi) weight is 15.

The weighted averages were then calculated using Equation 1 with the values in Table 7 and Table 8 which came out to 22,40 for *T. grandis* and 23,74 for *M. dubia*. Using Equation 2, the composite rating factor for *M. dubia* was calculated to be 135,15 %. With a composite rating factor of more than 100 % one can say that the overall performance of *M. dubia* is better than that of teak as far as wood working operations are concerned. This is based only on the results of the defects that were observed on this species. As seen earlier, this result is mainly due to the high performance in planing and shaping and reasonable performance in sanding.

However, the actual working quality involves the calculation of Working Quality Index (WQI) which takes into account the power requirements in addition to the defect pattern. The power requirements are reflected through the ease factor described in the materials and methods section.

Ease factor is an indication of ease of working of the species under study relative to teak in wood working tests. It is quantitatively evaluated by measuring power requirements per cm width of the species studied under planing operation.

It was observed that during planing operation:

- Power requirement in cutting condition measured = 1,25 kW/cm
- Power requirement in idle running condition measured = 0,96 kW/cm
- Thus, the Power requirement of *M. dubia* = 1,25- 0,96= 0,29 kW/cm
- The power requirement reported for planing of *T. grandis* is 0,27 kW/cm (Pant *et al.* 2002).

Hence, the ease factor for *M. dubia* was calculated using Equation 4 as Equation 6:

$$EF = \frac{0,27}{0,29}\ x\ 100 = 93,1\% \quad (6)$$

This indicates that *M. dubia* is not as easy to be worked upon compared to teak. However, we saw that the overall response (CRF) to the working operations were better for *M. dubia.* The actual WQI would include contributions both from CRF and EF of *M. dubia.*

The working quality index (WQI) was calculated by combining the composite rating factor and ease factor using Equation 5 as 107,12. Thus, though in three operations *M. dubia* has not performed well compared to *T. grandis*, due to the very high performance in planing, the species has shown a slightly better WQI.

Figure 3 represents the comparative performance of *M. dubia* with *T. grandis* taken as 100 under easiness of working (EF), overall wood working performance (CRF) and actual calculated Working quality index (WQI) as discussed above.

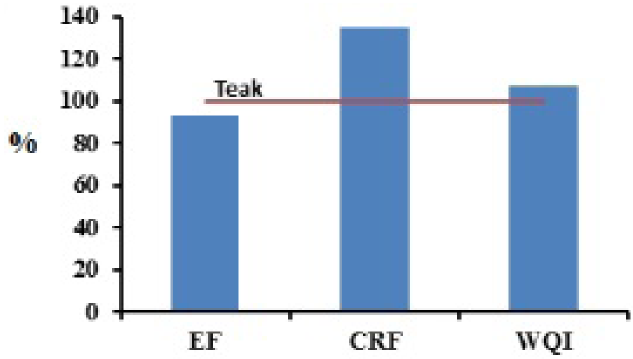

Figure 3: Comparative values of ease of working, overall working performance and working quality index of *M. dubia* taking *T. grandis* as 100.

It is a fact that if a species shows good behavior in one machining quality, then it need not automatically give good results in other machining operations also. This fact can be very much seen with *M. dubia* where the species shows very good performances as far as planing and shaping are concerned but seems to be a poor performer in three other basic operations. This fact in turn benefits the end user in rejecting this species in certain specific uses like turnery products. The composite rating factor and WQI (Working Quality Index) thus present the gross behavior of species in wood machining operations, a property useful in promoting a species for broader end use and substitution of traditional woods by alternate species.

CONCLUSIONS

The study indicates that ease of working of *Melia dubia* is comparable to teak which means that the power requirement is nearly same for the species as that of teak. The overall performance (Composite Rating Factor) is higher than that of teak which indicates its overall behavior under the six different machining operations. Although the overall performance of *M. dubia* is better than teak, when operations are looked at individually, the species shows its best results under planing and shaping operations. The surface of this species showed reasonably good performance in sanding also. Though the other three operations are not good performers, the working quality of *Melia dubia* is just above as that of teak.

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