ORIGINAL ARTICLE

Mechanical properties of rubberwood oriented strand lumber (OSL): The effect of strand length

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Abstract

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Mechanical properties of rubberwood oriented strand lumber (OSL): The effect of strand length

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Effect of strand length on mechanical properties (tension, compression and bending) of oriented strand lumber (OSL) made of rubberwood (*Hevea brasiliensis* Muell. Arg.) was reported. Three strand lengths of 50 mm, 100 mm, and 150 mm with 1 mm thickness and 15 mm width were used. The strands were mixed with 5% pMDI glue (weight basis) in a tumble mixer. The OSL specimens were formed by hot pressing process of unidirectionally aligned strands. Average specific gravity and moisture content were 0.76 and 8.34%, respectively. Tension and compression tests were carried out for directions both parallel and perpendicular to grain while bending test was performed only in parallel direction. Ultimate stresses and moduli of elasticity were examined from the stress-strain curves. It was found that for the parallel-to-grain direction, the longer strand OSL gave higher strength. The role of the strand length did not appear for the direction normal to the grain. The relationship between the mechanical properties of OSL and strand length was well described by the modified Hankinson formula.

Key words : rubberwood, oriented strand lumber, composite wood, strand length, mechanical properties

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สมบัติเชิงกลของแถบไม้อัดเรียงเสี้ยนจากไม้ยางพารา: ผลกระทบของความยาวแถบไม้

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งานวิจัยได้ศึกษาผลของความยาวแถบไม้ที่มีต่อสมบัติเชิงกล (การดึง การอัด และการดัด) ของแถบไม้อัดเรียงเสี้ยนจากไม้ยางพารา ชิ้นทดสอบทำจากแถบไม้ยาว 50 มม. 100 มม. และ 150 มม. กว้าง 15 มม. และหนา 1 มม. ผสมด้วยกาว pMDI ในปริมาณ 5% โดยน้ำหนัก ค่าเฉลี่ยความถ่วงจำเพาะและปริมาณความชื้นของชิ้นทดสอบคือ 0.76 และ 8.34% ตามลำดับ การทดสอบการดึงและการอัดทำทั้งในทิศทางตามเสี้ยนและตั้งฉากเสี้ยน แต่การทดสอบการดัดทำเฉพาะทิศทางตามเสี้ยนเท่านั้น ผลการศึกษาพบว่า เมื่อความยาวแถบไม้มากขึ้นสมบัติเชิงกลในทิศทางตามเสี้ยนจะมีค่าสูงขึ้น ในขณะที่สมบัติเชิงกลในทิศทางตั้งฉากเสี้ยนไม่มีอิทธิพลจากความยาวแถบไม้ ความสัมพันธ์ระหว่างสมบัติเชิงกลของแถบไม้อัดเรียงเสี้ยนและความยาวแถบไม้สามารถอธิบายได้ด้วยสมการดัดแปลงจากสูตรแฮนคินสัน

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The quantity of discarded rubberwood (*Hevea brasilliensis* Muell. Arg.) from the replantation scheme was estimated to a figure of 11,875 tons annually (Prasertsan and Krukanont, 2003). Thailand importation of timber and wood product was estimated at around 15,000 million Baht a year (Royal Forest Department of Thailand, 2002). There is an opportunity for rubberwood residue to fill the demand-supply gap, if it is properly engineered. Engineered wood commonly appears in the form of wood composite. Wood composite products are manufactured by gluing small pieces of wood together. Typical commercial products are plywood, oriented strand board (OSB) and the likes.

Oriented strand lumber (OSL) is similar to OSB, but, instead of board formation, the technology gives structural lumber from strands. MacMillan Bloedel, Ltd. developed an OSL product marketed as TimberStrand® LSL in North America and Intrallam LSL in Europe. Being used as structural timber, the required mechanical properties are substantially different from those of the boards. It can be anticipated that the strand length plays an important role in governing the mechanical properties of the lumber. In general, the OSL is manufactured from longer strands in comparison to the OSB and orientation has significant effect on the strength. Many research works revealed that increasing of the strand length has resulted in the increase of the strength and modulus of composite wood products (Post, 1958; Brumbaugh, 1960; Badejo, 1988; Barnes, 2000), but none has reported product from rubberwood. This article reports the study leading to an understanding of the effect of strand length on the properties of rubberwood OSL.

Materials and Methods

Strands used in this study were cut from rubberwood veneer of 1 mm thickness. The width was 15 mm and the lengths were 50 mm, 100 mm and 150 mm (in grain direction). The strands were dried and conditioned in an oven for 24 hours, then mixed with 5% pMDI (by weight) and a predetermined quantity water to attain 12% moisture content. Mat of uni-directional orientated strands was formed manually. The amount of the laid strands was targeted for a lumber having density of 800 kg/m^3 (rubberwood density is 680 kg/m^3) at 20 mm thickness. Hot pressing was performed in 3 steps following well-known references (Moslemi, 1974; Barnes, 1979; Smith, 1980; Maloney, 1993). The mat was pressed to 9 MPa within 90 seconds and kept at this maximum pressure for 8 minutes. The press then released pressure to 6 MPa and 3.5 MPa, with the holding time at each pressure again being 8 minutes. The working temperature was 150ºC.

Specimens were cut from the hot-pressed panels (400 mm x 400 mm) Altogether, 27 specimens of dimension 38 mm x 7 mm x 254 mm (width x thickness x length) were cut in dog bone shape for tension test. The gauge length was 51 mm for tension. The dimensions of the compression specimen were 20 mm x 20 mm x 80 mm (width x thickness x length). The corresponding dimensions for the bending test were 50 mm (width) x 20 mm (depth) x 350 mm (length). The experiments were conducted on a Lloyd Universal Testing Machine (150kN) at 25ºC and 67%RH. Three replications of specimens with three different strand lengths were performed for each test. Prior to the tests the specimens were conditioned at 20±1ºC, 65%RH for at least 24 hours. ASTM D 1037-99 procedure was applied for tension and compression tests, and JIS A5908-1994 was used for bending tests. The mechanical properties were normalized by quantifying in specific values (per specific gravity).

The modified Hankinson formula (Barnes, 2001) commonly used to describe properties of OSL, POSL, as a function of slenderness ratio (strand length per *in situ* strand thickness, ζ) was represented by

$$P_{OSL} = \frac{P_{SW}}{20 \cdot \sin^n(\arctan(2/\zeta)) + \cos^n(\arctan(2/\zeta))} \quad (1)$$

where P_{sw} is the parallel-to-grain property (strength) of solid wood and n is the experimentally determined exponent. For this study, *in situ* strand thickness was 1 mm; thus, the slenderness ratio is

Table 1. Specific gravity (SG) and moisture content (%MC) of specimens (oven-dried weight basis)

Strand length of OSL (mm)	Tension		Compression		Bending	
	Parallel to grain					
	SG [%CV]	%MC [%CV]	SG [%CV]	%MC [%CV]	SG [%CV]	%MC [%CV]
50	0.78	8.41	0.76	8.36	0.76	8.34
	[2.46]	[0.49]	[1.46]	[1.41]	[4.51]	[1.92]
100	0.74	8.53	0.76	8.31	0.70	8.34
	[7.12]	[0.41]	[5.73]	[2.73]	[3.44]	[0.63]
150	0.73	8.65	0.78	8.14	0.72	8.41
	[11.21]	[2.94]	[6.61]	[3.74]	[6.42]	[0.54]
	Perpendicular to grain					
50	0.84	8.38	0.76	8.38	n/a	n/a
	[7.22]	[1.77]	[8.25]	[1.53]	n/a	n/a
100	0.72	8.41	0.76	8.27	n/a	n/a
	[6.48]	[3.80]	[6.27]	[1.87]	n/a	n/a
150	0.74	8.32	0.83	7.87	n/a	n/a
	[14.50]	[2.66]	[10.68]	[10.92]	n/a	n/a

n/a : data not available

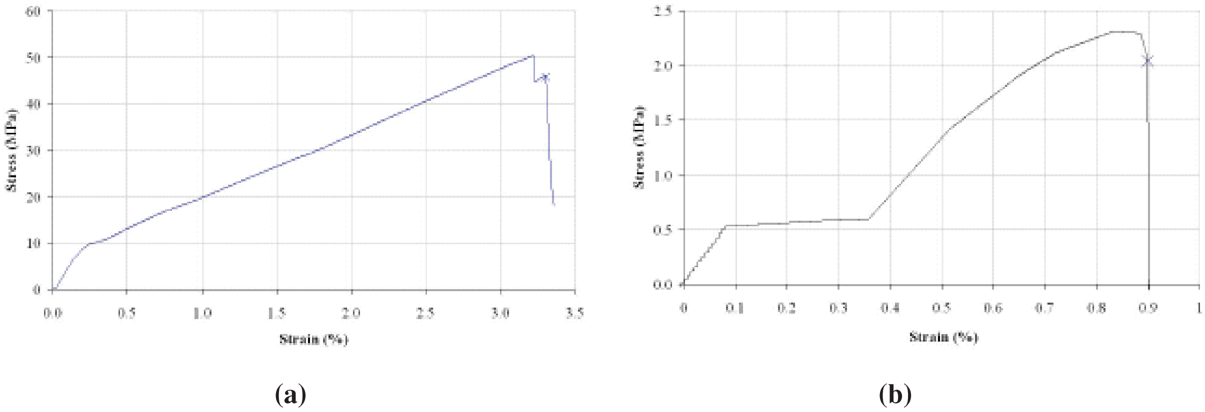


Figure 1. Typical tensile stress-strain curves of OSL specimens (sample of 150 mm strand length) (a) parallel to grain, (b) perpendicular to grain.

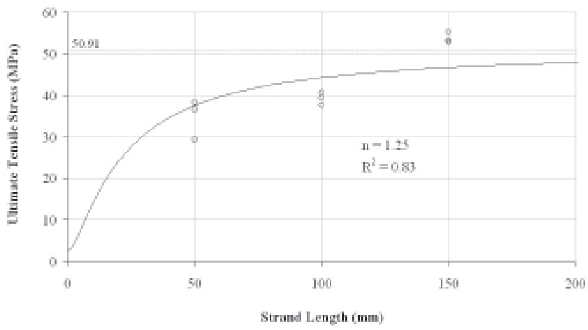


Figure 2. Ultimate tensile stress (UTS) parallel to grain fitted by the modified Hankinson formula.

the strand length (in mm). Mathematically, P_{SW} was the possible maximum value of P_{OSL}.

Results and Discussion

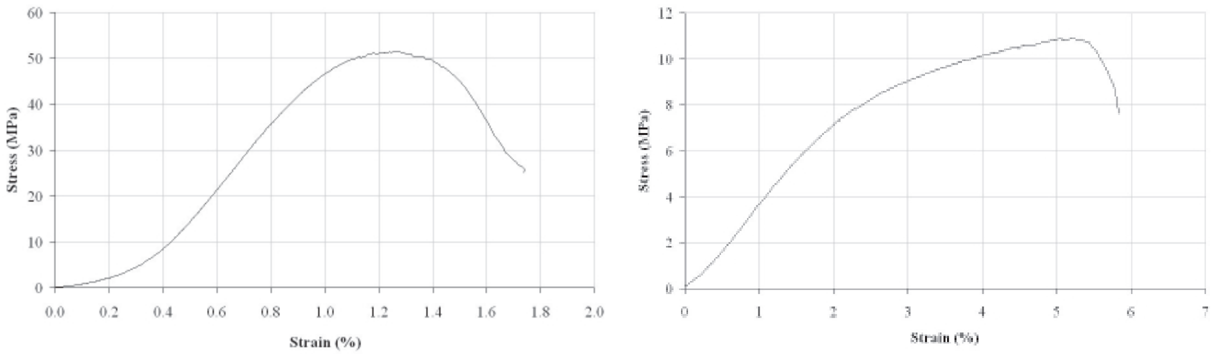
Specimen Physical Properties

The specific gravity and moisture content of the specimens are shown in Table 1, which gives the average values of 0.76 and 8.34%, respectively.

Tensile properties

Typical stress-strain curves of specimens tested in tension parallel and perpendicular to grain are shown in Figure 1. The ultimate tensile stress is the maximum stress appearing on the stress-strain curve and the modulus of elasticity is the slope of the secant drawn from the original to the maximum stress (ASTM E111, 1978). For the parallel-to-grain test, it was found that the OSL failed like brittle materials. The maximum stress and strain tested in the direction parallel to grain was substantially higher than that of perpendicular to grain. The OSL is relatively weak in the direction perpendicular to the grain. In some cases, a slip occurred (as appears in Figure 1b) before the self-tightening grips firmly hold the specimens. This did not have an effect on the mechanical property evaluation since the modulus was determined from the slope after the slip.

Figure 2 illustrates the data fitting by the modified Hankinson formula, which subsequently gives equation (2)



(a) **(b)**

Figure 3. Typical compressive stress-strain curves of OSL specimens. (sample of 150 mm strand length) (a) parallel to grain, (b) perpendicular to grain

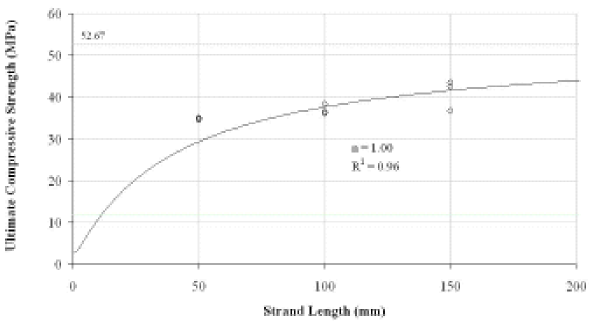


Figure 4. Ultimate compressive stress (UCS) parallel to grain fitted by the modified Hankinson formula with n = 1.25, SG = 0.7 and UCS_{SW} = 52.67 MPa.

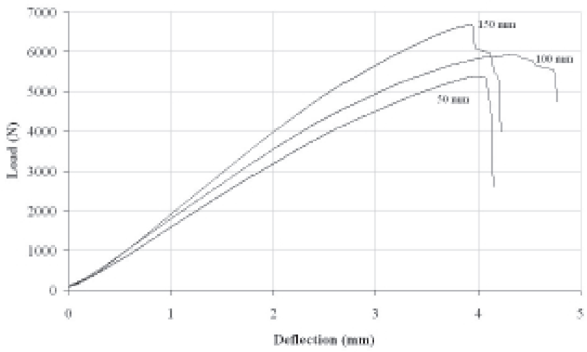


Figure 5. Typical load-deflection curves of specimens tested in bending parallel to grain of various strand lengths.

$$UTS_{OSL} = UTS_{SW}\left(\frac{1}{20\cdot\sin^{1.25}(\arctan(2/\zeta)) + \cos^{1.25}(\arctan(2/\zeta))}\right) \quad (2)$$

where UTS_{SW} parallel to grain of solid wood was 50.91 MPa interpolated to SG = 0.7 (Puajindanetr and Wisuttipaet, 2003). The coefficient of determination, R^2, was 0.83. The longer strand length (or larger slenderness ratio) has resulted in a decreasing of stress transfer angle and, hence, increase in the strength. UTS_{OSL} is about 90% of UTS_{SW} as the slenderness ratio is 360.

Compressive properties

Typical stress-strain curves of compression tests are shown in Figure 3. The failure was accompanied by specimen delamination. The specimens in direction both parallel and perpendicular to grain split out in the direction normal to load direction and failed.

Similar to Figure 2, the modified Hankinson formula describing the compressive strength parallel to grain is obtained as shown in equation (3) with R^2 = 0.96 (Figure 4)

$$UCS_{OSL} = UCS_{SW}\left(\frac{1}{20\cdot\sin(\arctan(2/\zeta)) + \cos(\arctan(2/\zeta))}\right) \quad (3)$$

where UCS_{SW} = 52.67 interpolated to SG = 0.7 (Puajindanetr and Wisuttipaet, 2003). Longer strand length withstands higher compressive load due to smaller stress transfer angle. UCS_{OSL} is about 90% of UCS_{sw} as the slenderness ratio is 360.

Bending Properties

Typical load-deflection curves of OSL tested in static bending were plotted at 3 different strand lengths and are given in Figure 5. The bending modulus of elasticity is the slope of a chord in the linear region, which is the slope of a line drawn from 10% to 40% of the maximum stress (BS EN 310, 1993). Specimens failed under tension at the bottom surface.

The modified Hankinson formula, represented by equation (4), is used to describe the bending strength.

$$UBS_{OSL} = UBS_{SW}\left(\frac{1}{20\cdot\sin(\arctan(2/\zeta))+\cos(\arctan(2/\zeta))}\right) \quad (4)$$

where UBS_{sw} 95.45MPa interpolated to SG 0.7 (Dhonanon and Cheuwichitchan, 1980). Equation (4) is plotted in Figure 6 with R^2 of 0.89. UBS_{OSL} at 150 mm strand length was about 70% of UBS_{sw}. According to this equation, UBS_{OSL} would approach 90% of the maximum value (UBS_{sw}) for the strand length of 360 mm (1 mm thickness).

BMOE at any given slenderness ratio, was represented by

$$UMOE_{OSL} = UMOE_{SW}\left(\frac{1}{20\cdot\sin^{0.95}(\arctan(2/\zeta))+\cos^{0.95}(\arctan(2/\zeta))}\right) \quad (5)$$

where $BMOE_{sw}$ = 9.42 GPa interpolated at SG = 0.7. The data fit well with the equation as indicated by $R^2 = 0.92$ (Figure 7). Predicting by the equation, OSL with 360 mm of strand length and 1 mm of thickness yields modulus of elasticity in bending of 90% of $BMOE_{sw}$.

Effects of Strand Length

Specific mean values and coefficients of variation of mechanical properties tested in tension, compression and bending are given in Table 2. The coefficients of variation, although seeming relatively high (0% - 35%), are in the same range of solid wood reported at 14% - 34% (Wood Handbook, 1999).

For tension parallel to grain, the OSL made of longer strands exhibited higher sUTS. Statistical analysis showed that the results are highly significant (Pr < 0.01). However, for the perpendicular to grain direction there was no obvious effect of the strand length on the sUTS. This is explained by the very weak cohesive force (of wood itself) in this direction. As a result, the sUTS parallel to grain is about 35 times higher than that of perpendicular to grain. The sTMOE parallel to

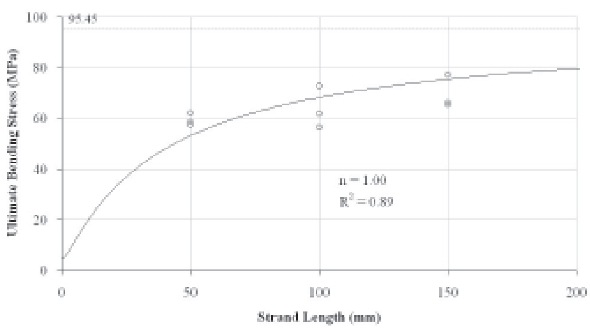


Figure 6. Ultimate bending stress (UBS) parallel to grain fitted by the modified Hankinson formula with n = 1.00, SG = 0.7 and UBS_{SW} = 95.45 MPa.

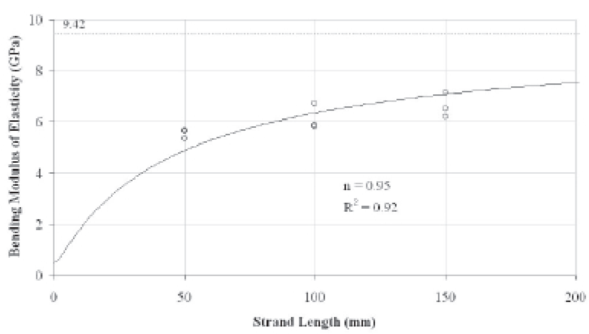


Figure 7. Bending modulus of elasticity (BMOE) parallel to grain fitted by the modified Hankinson formula with n = 0.95, SG = 0.7 and $BMOE_{SW}$ 9.42 GPa.

Table 2. Specific mean value and coefficients of variation (CV) of OSL mechanical properties.

Strand length of OSL (mm)	Tension		Compression		Bending	
	Parallel to grain					
	sUTS (MPa)	sTMOE (MPa)	sUCS (MPa)	sCMOE (MPa)	sUBS (MPa)	sBMOE (GPa)
50	49.58	2073	49.65	5692	84.59	7.92
	[13.56]	[4.39]	[0.51]	[7.82]	[4.08]	[3.26]
100	55.98	2116	52.74	6036	90.88	8.78
	[4.01]	[11.76]	[3.31]	[8.68]	[13.04]	[8.19]
150	76.82	2340	58.36	6193	99.23	9.42
	[2.37]	[16.27]	[98.00]	[12.41]	[9.51]	[7.29]
	Perpendicular to grain					
50	2.65	385.8	13.50	324.6	n/a	n/a
	[13.06]	[15.18]	[20.15]	[6.99]	n/a	n/a
100	1.58	270.8	13.03	315.1	n/a	n/a
	[25.54]	[32.52]	[18.03]	[6.21]	n/a	n/a
150	1.50	352.2	15.78	340.3	n/a	n/a
	[14.10]	[35.36]	[19.57]	[28.59]	n/a	n/a

n/a : data not available; Coefficients of variation (CV) are given in brackets [], unit in %

Table 3. Mechanical properties of rubberwood (solid wood) and the average properties of OSL made from rubberwood compared at SG = 0.7

Mechanical property	Solid wood	OSL @ 50 mm	OSL @ 100 mm	OSL @ 150 mm
UTS parallel to grain (MPa)	50.91[1]	34.07	39.19	53.77
UTS perpendicular to grain (MPa)	2.80[2]	1.86	0.78	1.05
UCS parallel to grain (MPa)	52.67[1]	34.76	36.92	40.82
UCS perpendicular to grain (MPa)	11.87[3]	9.45	9.21	11.05
UBS	95.45[4]	59.21	63.62	69.46
BMOE	9.42[4]	7.76	8.39	9.23

[1] Puajindanetr and Wisuttipeat, 2003
[2] Chunwarin, 1980
[3] Kasemset *et al.*, 2000
[4] Dhonanon and Cheuwichitchan, 1980.

grain is about 6.5 times higher than that of the other direction. There is no significant evidence of the role of the strand length in either direction.

It was found that sUCS and sCMOE parallel to grain increased as the strand length increased ($Pr < 0.05$), but were statistically insignificant for the perpendicular-to-grain direction. The sCMOE parallel to grain was about 18 times of that perpendicular to grain. The OSL with longer strand was significantly stronger than the shorter one in terms of sUBS and sBMOE.

The mechanical properties of rubberwood (solid wood) and the average properties of OSL were compared at SG = 0.7 and given in Table 3. UTS parallel to grain of OSL with strand length 150 mm was slightly higher than that of the solid wood, while UTS perpendicular to grain was only 50% of the solid wood. Voids have weakened the tensile properties of the OSL, especially for direction perpendicular to grain in which the glue lines were relatively short. UCSs of OSL were less than that of the solid wood because of the delamination. Bending properties, UBS and BMOE of the OSL were not as strong as the solid wood. However, the properties follow the modified Hankinson equation. Therefore, it is anticipated that the mechanical properties of OSL could be improved if manufactured front longer and thinner strands. The slenderness ratio (ζ) of 360 could give OSL strength appoach 90% of the solid wood. Industrial stranding machine could produce strands as thin as 0.6 mm (Lowood, 1997), which would increase the slenderness ratio and, hence, the properties of the OSL.

Conclusions

1. The longer strands increase UTS UCS UBS and BMOE parallel to grain of OSL. Mathematically, OSL properties approach the solid wood properties as the strand length increases. OSL made from longer strands will be beneficially stronger.

2. Hankinson formula can be used to determine the mechanical properties of OSL provided that the mechanical properties of the solid wood and the slenderness ratio are known.

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Nomenclature

n	:	The experimentally determined exponent in equation (1)
ζ	:	Slenderness ratio in equation (1)
%MC	:	Moisture content
OSB	:	Oriented strand board
OSL	:	Oriented strand lumber
R^2	:	Coefficient of determination
SG	:	Specific gravity
SCL	:	Structural composite lumber
SW	:	Solid wood
sUTS	:	Specific ultimate tensile stress
sTMOE	:	Specific tensile modulus of elasticity
sUCS	:	Specific ultimate compressive stress
sCMOE	:	Specific compressive modulus of elasticity
sUBS	:	Specific ultimate bending stress
sBMOE	:	Specific bending modulus of elasticity