Factors Influencing Mechanical Properties of OSB

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ABSTRACT

With more and more buildings built around the world, OSB is an important building material. Learning about its properties can help people make use of the OSB panel effectivity. In this paper, the author will examine the relationship between OSB and these factors by looking at published data. Secondly, the author will introduce the production method of OSB, the structure of OSB, the application of OSB, and the basic properties of OSB. This article describes which factors affect the properties of OSB. It also helps to learn about how the properties of OSB change in a particular case and how to manufacture OSB the most efficiently. People have tested OSB at different densities under the manufacturing process according to the standard of SN EN 300 in order to reduce the experimental error. The results show that the mechanical properties of OSB are better with higher density. Resin is another factor to affect the mechanical properties of OSB. In the experiments, different types and amounts of resin to manufacture OSB are tested. Then OSB mechanical properties are tested for the variations in manufacturing listed above. The results show that the more resin used to a certain degree, the better the OSB mechanical properties. The urea-formaldehyde and the Phenol - formaldehyde resins are two resins normally used in OSB. The result shows that using the Phenol - formaldehyde for OSB displays better mechanical properties than urea-formaldehyde. The species of raw material is another factor affecting the mechanical properties of wood. In the experiment, the mechanical properties of OSB made of pine, hardwood mixture, and aspen were tested. However, there is some error caused by different manufacturing methods. The final factor which can change the mechanical properties is temperature. Experimental results show that the mechanical properties of OSB are reduced by preheating. However, the mechanical properties of OSB preheated at 240°C were better than those of OSB preheated at 200°C. Because the experimental data are not enough,

people need to do more experiments to figure the relationship between the temperature and mechanical properties of OSB. Knots are another factor to affect mechanical properties. The grain which surrounds the knot will become irregular. The grain direction determines to a degree part of the mechanical properties. The last factor is moisture content. The reason for this change is that when the moisture content decreases, there is a strengthening of the hydrogen bonds linking together the microfibrils.

1.0 INTRODUCTION

Oriented strand board (OSB) is a combination of strands and resin produced while under pressure and a set temperature. In recent years, it has replaced plywood in many applications, and has become a prevalent building material (Irle and Barbu, 2010). According to the different end-uses of OSB, the requirements of OSB are very detailed and include many factors. These factors include thickness, density, texture and mechanical strength (Barbuta et al., 2012). The largest producers are the United States and Canada. Their annual production occupies 85 percent of the world market. OSB is becoming increasingly popular in Europe as the construction industry continues to grow. In many countries, housing is a necessity because of population growth. Therefore, the demand for OSB is also increasing day by day (Egger, 2017). Ferro (2018) estimated that until 2020, OSB would occupy 28% of the wood market. With the development of OSB, more and more OSB is used in the building industry. However, is it a reliable building material? What external factors can affect its properties. People need to figure out this question, and it also helps them to make use of the OSB panel more effectively. OSB is a composite structure with a face-core-face layering. The manufacturing process includes debark, wet, dry, mix with the resin, press with heat, and finally trim. The complex manufacturing process differs between different mills based on feedstock and other aspects of manufacturing. This difference causes the OSB product to display different properties. Some groups set many standards for OSB composition to improve the quality of OSB. For example, ASTM standard D 1037-96a specifies the viscosity of PF resins（Okino et al., 2009). However, it is still not understood by all how these factors influence the OSB properties. What happens when people change the factors, the physical or chemical properties of the OSB. Is there some rule when these factors change? Firstly, the paper introduces the structure of OSB in order to give the reader a description of the product. Most properties depend on the structure. Then, the properties of commercially OSB vary, mainly because the different manufacturer will use different standard to make the OSB. So, understanding how to manufacture the OSB is a necessary step to analysis the factors which can affect the mechanical properties of OSB. In recently years, OSB instead of plywood has become more and more popular in the market. Learning knowledge about OSB became necessary in order to use it in suitable applications. People discuss MOE (modulus of elasticity) and MOR (modulus of rupture) as the main mechanical properties of products. According to the literature, factors such as temperature, species, density, resin, thickness, knot, and moisture content will affect the mechanical properties of OSB (Desch and Dinwoodie, 1981). This thesis will look at these factors and how they affect the properties if OSB through a search of the literature.

2.1 STRUCTURE OF OSB

Oriented strand board (OSB) is a multilayer wood particleboard. OSB is divide into three layers, two surface-forming layers, that are oriented oppositely to the one core layer of sandwiched wood strands. The core layers’ strands width is shorter than the length, the fiber element is parallel to the length, and the three layers have their orientation set with the outer layer parallel to outside layers and perpendicular the inside core layer (Wentworth and Park, 1982). The cross-oriented strand pattern is good for stability. When manufacturing OSB, a multilayer mat of adhesive-coated wood particles, with each layer having the wood particle and pattern characteristics described above, is then compressing with the adhesive coated wood particles forming the multilayer mat in a hot platen press (Wentworth and Park, 1982). The coarsest strands are located in opposing layers nearest the core layer while the surface layers are finer materials (Wentworth and Park, 1982). The benefit of OSB over other fibre boards is that the composite board restricts defects such as warping and has better strength properties (Board, 2006). Figure1 describes the manufacturing of OSB.

2.2 MANUFACTURING PROCESS

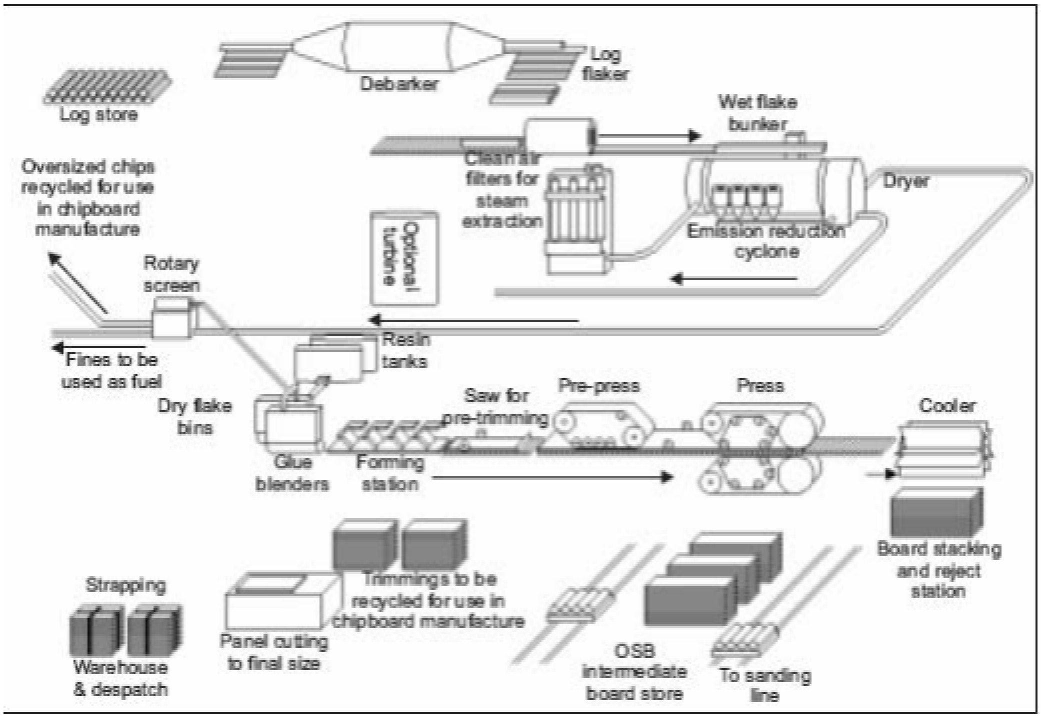


Figure 1. Figure of OSB Manufacture Process (Source: Board, 2006)

OSB is manufactured from trees. With new technology, the manufacturer uses less and less material to manufacture OSB while utilizing a wider variety of tree species.

OSB is made from wood flakes which are processed from logs. After the cut, the log length is around 2.5 meters. Then cut again after debarking, producing a 0.84 m bolt. Those bolts are fed into the flaker. These flakes are pieces of wood 3.8 cm in width, 3 cm in length and 0.07 cm in thickness. These flakes are wet stored to separate the surface flakes and to isolate wood from fungi (Board, 2006).

The next step is drying to control the moisture content of flakes to 4-10%. This is followed by the use of a primary cyclone to remove fines. Then flakes are transported and mixed with resin and any other additives. The resin type used here includes Phenol – formaldehyde resin (PF), pMDI or melamine urea-formaldehyde (MUF). The resin needs to be heated in order to cure it. By means of electrostatic or mechanically, flakes are oriented in the same direction in each layer of the board (Board, 2006). The structure of the OSB is that the flakes in the upper layer must be perpendicular to the flakes in the lower layer (Board, 2006). Therefore, the direction of flakes needs to be changed mechanically. The rough panel is then put through a heated press to form the OSB panel product. This heat press is used to activate the resin and turn the strands into the solid OSB product. The final step is to cool it and cut panels to the desired length and width (Board, 2006).

The properties of OSB are determined by the manufacturing method, the material and the resin. For example, excessive heat causes damage to the properties of the wood, excessive water content results in the resin not adhering to the core material and surface material (Board, 2006). All of these factors and more can affect the properties of the product.

2.3 OSB APPLICATION

OSB has been used in different industries around the world. People prefer the use of OSB due to its versatility in forest products. Some countries have begun widespread use of OSB as a substitute to plywood in manufacturing forest product processes. In recent times, OSB production, production technology and equipment have become more advanced, this has resulted in increased usage in the forest industry. The reason for such is that due to OSB's versatility, the manufacturer can manipulate the proportion and type of resin, moisture, processing parameters, and flake geometry throughout the board to produce products that are tailored for specific applications (Shmulsky et al., 2011). Sheathing grade of OSB is at a density of 640 to 670 kg/m^3, such a grade depends on the individual mill processing parameters (Shmulsky et al., 2011). The wood species used to create OSB have a density range from 370 to 480 kg/m^3 (Shmulsky et al., 2011), with the remaining density of an OSB panel resulting from the resin.

Phenolic resin OSB has high mechanical properties and good water and moisture-proof properties, this is the most widely used structural plate in North American isocyanate vinegar (M D I) because of its superior bonding performance. In addition, it is also used to glue OSB by about 35% of the OSB factories in North America (Shmulsky et al., 2011). The resin can be used alone, or as a core layer glue spray agent and phenolic resin (surface glue agent) (Shmulsky et al., 2011). Together, the product is also used for outdoor materials, Pulse aldehyde resin OSB can only be used for interior applications, a general multi-purpose product in, for example room partition and furniture manufacturing. The mechanical properties and moisture resistance of modified maiden resin OSB can be greatly improved by modifying maiden resin adhesive with melamine (Irvin Wentworth, 1982)

Excellent in-service performance and competitive production costs make OSB superior and a viable replacement for plywood. It is widely used as enveloping material in North American timber structures, used for roof laying, wall envelops, and floor laying (Irvin Wentworth, 1982). In fact, 75% of the homes built in North America each year use OSB as the floor, wall, and roof envelope materials (Shmulsky et al., 2011).

With the development of new technology and new products, value-added processing OSB is used more and more widely in the construction industry, for example: Structural insulated panels, SIPs. SIPs with the best absolute grade and fire performance products can be used as the wall, compartment, and roof system of residential buildings, with the characteristics of light weight, good quality, good insulation, good sound insulation, and simple construction (Engineered wood Association 2009).

2.4 MECHANICAL PROPERTIES

The properties of OSB are dependent upon the process in which manufacturer's produce as well as the raw material (Shmulsky et al., 2011). Density of woody is dependent on the weight and moisture content of the sample (Simpson, 1993). Some of the wood properties density is correlated to are strength properties. (Jaroslav et al., 2009). Generally speaking, the greater the density of wood, the higher the strength and stiffness of the wood (Desch and Dinwoodie, 1981). In contrast, it can also represent the brittleness of the wood. Wood, depends on the cells from which it is made. OSB has different properties depending on the tree species used. Species with higher wood densities can optimize the modulus of rupture and elasticity in the wood (Desch and

Dinwoodie, 1981). The amount of resin in OSB can also change OSB properties. For example, the amount of resin can influence tensile strength perpendicular to the board surface (Hrazsky and Kral, 2009). When the density of OSB decreased and the amount of glue is increased, the bending strength and modulus of elasticity decrease (Hrazsky and Kral, 2009).

In the literature, the mechanical properties of OSB mainly focuses on MOE and MOR. Wood products can display different degrees of stress in parallel and perpendicular directions due to the lumber grain (Desch and Dinwoodie, 1981), therefore it is necessary to test MOE and MOR parallel and perpendicular to the grain. The properties of OSB as a composite board are also related to the manufacturer's processing methods. For example, the strength properties depend on the density of the wood inside, the direction of the strand, and the size of the core center layer (Han et al., 2007). At present, maintaining the relationship between the strength of OSB and the price of raw materials is a common problem for manufacturers.

2.0 FACTORS

This thesis is based on publications that concern the background of OSB research and its impact on the mechanical properties of the product. Due to the voluminous factors that contribute to the properties of OSB, only temperature, species, density, resin, thickness, knots, and moisture content are discussed.

3.1 TEMPERATURE

3.1.1 HEAT TREATMENT OF PARTICLES (PRE-TREATMENT)

Some people want to explore how temperature affects the mechanical properties. Okino et al. (2004) selected four 35-year-old trees from jaguariava-pr (Brazil) species. The density is 0.47g/cm3. A total of 5 groups were set up in this experiment. Heating OSB or particles to figure out difference in change. There is a set of experiments changing Wax emulsion content (%) (Table 1).

The heat treatment of the particles begins by heating the oven from room temperature to 101°C at a rate of 3°C per minute, for a total of about 30 minutes. Thereafter, a heating rate of 1°C per min is applied until the temperature specified for treatment (200°C or 240°C) is reached. The effective heat treatment time of particles at both temperatures is calculated from the moment when the monitored tray interior reaches the specified temperature. However, for 240°C treatment, a further 40 minutes of heating at a rate of 1°C per minute is required to achieve the desired temperature. The difference between pallets is 5°C. The oven was filled with nitrogen to prevent the wood from burning (Mendes et al., 2013).

Table 1. Experimental design for the production of OSB panels

treatment	thermal treatment of particles	Thermal treatment of OSB panels	wax emulsion content (%)
T1			0
T2	200°C		0
T3	240°C		0

T4		220°C /12MIN	0
T5		220°C /12MIN	1

Source: Mendes et al. (2013)

3.1.2 PANEL MANUFACTURING

Phenol formaldehyde adhesive was applied at 6 % (based on the dry mass of the particles) for the production of the panels. The adhesive presented 51.24 % of solid content, the presented pH level was 11.89 with a gel time of 8.41 min, and viscosity of 547 cP. Because of the design of the experiment, wax emulsion in the fifth term should be different from that of other terms. The mass ratio of the face layer to the core layer is 3:4. Only group T2 and T3 contained thermally treated particles (Table 1). When OSB is made, the inner layer of wood is perpendicular to each other. After pressing, OSB board is placed in acclimatized room, the temperature was 22°C and relative humidity of 65 + / - 5%.(Mendes et al., 2013).

3.1.3 HEAT TREATMENT OF OSB PANELS (post-treatment)

A constant mass was reached by heating T4 and T5 of OSB. The wood was then pressurized (0.05Mpa) to allow for temperature transfer. After reaching the required pressure, the OSB was treated at 220°C for 12 minutes. The OSB panel is then cooled at room temperature. After heat treatment, the OSB panel was placed in an environment with a temperature of 22°C and a humidity of 65 (Mendes et al., 2013).

Sample sizes to evaluate particle and panel properties were cut according to ASTM D 1037. Water absorption after two hours and 24 hours of immersion (2 aquarium), thickness speciation (TS) after 2 and 24 h of immersion (2 aquarium), non-return rate in thickness speciation (NRT) (2 specimens) and internal bond (5 specimens) parameters. The next step was to Measure parallel and vertical MOR and MOE, according to DIN 52362 (1982).

3.1.4 HEATING INFLUENCE TO MECHANICAL PROPERTIES

Table 2. Results of the mechanical properties of OSB made with strands of Pinus taeda L.

treatment	moisture content		density apparent(g/cm^3)	thickness(mm)
	particles (%)	Panels (%)		
control	11.25	8.55	0.75	14.95
pre-treatment 200°C	8.37	7.64	0.72	15.61
pre-treatment 240°C	5.73	5.98	0.69	15.96
post-treatment		8.53	0.7	16.14
post-treatment+wax		8.44	0.72	15.26

Source: Mendes et al. (2013)

According to Table 2, the moisture content of OSB particles was low after particles were thermally treated. With the temperature increasing, there are more moisture loss from the OSB. Heating particles not only affects the moisture content of the particles, the moisture content of panels of T2 are lower but T3 are higher. When the heating temperature is higher, the panel's moisture content will decrease. There was no significant difference between the experimental results of T4 and T5 (Mendes et al., 2013). That means wax does not affect moisture content at the wax% tested. Through comparison, thermally treated particle density had a decreasing trend with the increase in temperature. Heating also thickens the wood. The thickness of the experimental group was higher than in the control group.

Table 3. Average internal bond, rupture modulus and elasticity modulus values at static bending of OSB panels

treatment	MOR		MOE		internal bond
	parallel	perpendicular	parallel	perpendicular	
control	57.5	20.8	8061.2	2022.3	0.6
pre-treatment 473.15K	30.8	10.7	5570.4	1293.8	0.23
pre-treatment 513.15K	27.8	13.1	5934.3	1554.1	0.3
post-treatment	49.5	20.7	6665	1694.6	0.63
post-treatment+wax	45.7	19	7366	1608.4	0.75

Source: Mendes et al. (2013)

According to Table 3, after heating the OSB board, all mechanical properties are reduced. Whether it is just heating panels or heating particles and panels. Both of them have different degrees of reduction of MOE and MOR. The IB value of OSB also decreased due to heating (Mendes et al., 2013).

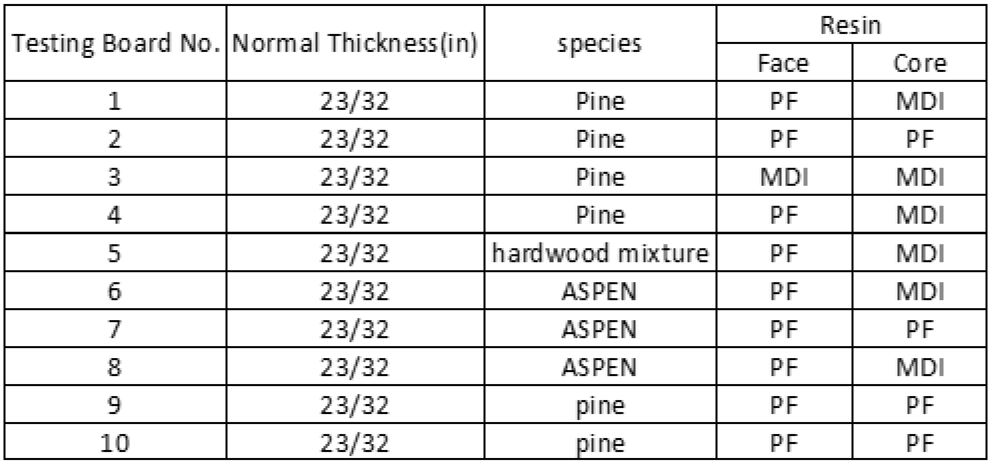
Table 2 shows the relationship between temperature and physical properties. The comparison between T4 and T5 shows that the wax (tested at the given %) does not affect the average panel moisture content. This directly correlates to the explanation by Maloney (1993) that states that wax resists moisture absorption. However, it cannot resist the absorption of water vapour. After heating, the thickness of OSB increases. The phenomenon is due to partial relaxation of the compression stress that remained in the panel generated during the pressing of the particle mat at a pressure of 3.51 MPa in the production phase (Mendes et al. 2013). This is also called spring-back, and because it was thermally treated it caused an increase in the size of the particle (reference needed here). This is another cause of OSB panel thickening. Density is the weight of wood per unit volume, the volume of the OSB increases, but the weight does not change, which means the density of the wood decreases. Irle (2009) believed that the decrease in density during heating was due to the loss of some organic compounds during heating. Paul (2007) has done the research and found that losing the mass of wood polymers happens during the heating process, especially the polyose, which causes the density to go down.

In table 3, heating causes a decrease in the mechanical properties of wood. Sernek (2004) thinks it may be the movement of extractives to the surface of particles and the inactivation of the wood surface. All the numbers are down, however, as mentioned before, some countries even use heat treatment to increase the mechanical properties of wood. This contradicts the results of this experiment. The details can be found from table 3 that wood heated to 240°C display mechanical properties that are greater than wood heated at 200°C. The authors speculate that this may be because some mechanical properties may improve as the wood's temperature rises.

3.2 SPECIES USED IN OSB

The common physical and mechanical properties of OSB include MOR/MOE, Internal Bond (IB), Density and Thickness Swell (TS). Commercially oriented strand boards from 14 mills were procured either directly from the mill or the local market. OSB panels are made from different timber species. Table 4 displays the 14 OSBs raw materials. Table 5 displays the property results from the OSB produced.

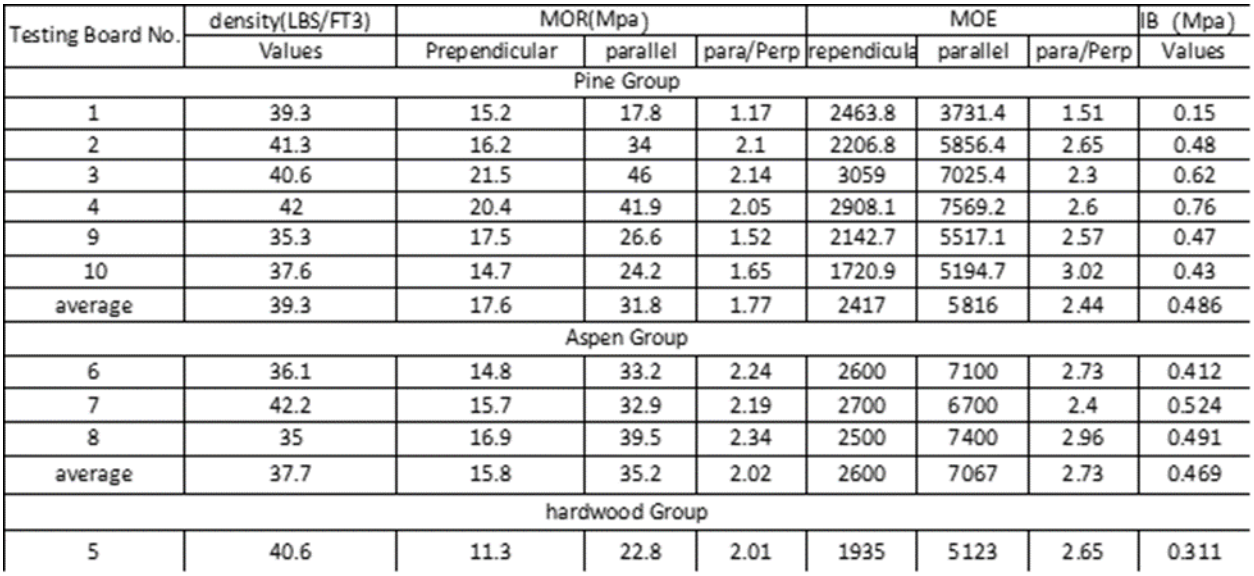
Table 4. Test OSB specifications.



Testing Board No.	Normal Thickness(in)	species	Resin	
			Face	Core
1	23/32	Pine	PF	MDI
2	23/32	Pine	PF	PF
3	23/32	Pine	MDI	MDI
4	23/32	Pine	PF	MDI
5	23/32	hardwood mixture	PF	MDI
6	23/32	ASPEN	PF	MDI
7	23/32	ASPEN	PF	PF
8	23/32	ASPEN	PF	MDI
9	23/32	pine	PF	PF
10	23/32	pine	PF	PF

Source: Wang et al. (2014)

Table 5. The mechanical properties of commercial 23/32" OSB testing panels arranged by panel species.



Testing Board No.	density(LBS/FT3)	MOR(Mpa)			MOE			IB (Mpa)
	Values	Prependicular	parallel	para/Perp	rependicula	parallel	para/Perp	Values
Pine Group								
1	39.3	15.2	17.8	1.17	2463.8	3731.4	1.51	0.15
2	41.3	16.2	34	2.1	2206.8	5856.4	2.65	0.48
3	40.6	21.5	46	2.14	3059	7025.4	2.3	0.62
4	42	20.4	41.9	2.05	2908.1	7569.2	2.6	0.76
9	35.3	17.5	26.6	1.52	2142.7	5517.1	2.57	0.47
10	37.6	14.7	24.2	1.65	1720.9	5194.7	3.02	0.43
average	39.3	17.6	31.8	1.77	2417	5816	2.44	0.486
Aspen Group								
6	36.1	14.8	33.2	2.24	2600	7100	2.73	0.412
7	42.2	15.7	32.9	2.19	2700	6700	2.4	0.524
8	35	16.9	39.5	2.34	2500	7400	2.96	0.491
average	37.7	15.8	35.2	2.02	2600	7067	2.73	0.469
hardwood Group								
5	40.6	11.3	22.8	2.01	1935	5123	2.65	0.311

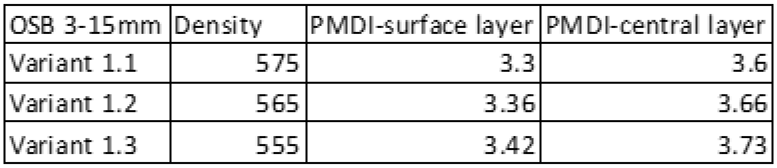
Source: Wang et al. (2014)

This study by Wang et al. (2014) examined the relationship between OSB properties and species. Variables included not only species but also resin type. PF is representative of phenol-formaldehyde, pMDI is representative of diphenylmethane diisocyanate. These two different resins were used in the face layer or core layer. The study species included Pine, hardwood mixture and aspen as they are often used as raw materials for OSB. The experimental result shows that the ratio of aspen group of parallel to vertical direction was the highest (Table 5). This result is because an OSB panel made by aspen has a good strand shape and orientation. The values of MOE and MOR in the parallel and vertical directions of the hardwood group are relatively low. However, the ratio of parallel to the vertical direction is similar to that of aspen. The result suggests that the mechanical properties of the OSB can load more external forces (Wang et al., 2014). The ratio of Pine was the lowest, indicating that there was little difference in the ability to withstand external forces between the parallel and perpendicular directions. The different species, resin, and process result in different properties of OSB can all be seen in table 5. Depending on the situation, a manufacturer needs to choose different species, resins and process methods. It can be concluded that the difference of OSB panels in mechanical performance is partly the result of different vertical density profiles that are developed by different manufacturing mechanisms (Wang et al., 2014). Tables 4 and 5 express the relationship between species and mechanical properties. However, changing the species results in a change of density. Table 3 also shows the density of each testing board. Although the OSB thickness was 23/32in. Due to the fact that manufacturers produce product with different wood species, the associated process also affects the properties of the OSB. Results from the literature indicate that the denser the species, the better the mechanical properties of the OSB panels (Wang et al., 2014).

3.3 DENSITY

A well-known composite board manufacturer in the Czech Republic tested the mechanical properties of OSB. The main contents of the test included MOR and MOE tensile strength in the main and secondary direction. In order to reduce the variable OSB production process, strictly following the standard of SN EN 300 is required. The density was also determined following the standard SN EN 323. At the same time, range of thickness is divided into various ranges, including: 6 to 10, 10 to 18 and 18 to 25mm (Jaroslav et al., 2009). This helps explore the relationship between thickness and mechanical properties. The density of wood is another important factor affecting the mechanical properties of wood. As previously mentioned, OSB thickness affects mechanical properties. In terms of this experiment, OSB thickness of 15mm was tested (Jaroslav et al., 2009). Table 6 displays the density of the subjects, PMDI-surface layer and PMDI-central layer. Although the values of the PMDI-surface layer and central layer are inconsistent, the difference between the two adjacent variables is only 0.06, therefore, the difference here is deemed insignificant. The result is that both MOR and MOE decrease as density decreases. However, the tensile strength perpendicular to the reduction of density was increased (Jaroslav et al., 2009). All the data obtained in Table 7 are averages, which is the result of a large number of experimental data. By conducting further experiments that calculate the average, this allows for less inconsistencies and brings about a larger body of work related to this topic. These experiments aid to identify the relationship between density and mechanical properties.

Table 6. Variants of density in OSB, 15 mm thick,



OSB 3-15mm	Density	PMDI-surface layer	PMDI-central layer
Variant 1.1	575	3.3	3.6
Variant 1.2	565	3.36	3.66
Variant 1.3	555	3.42	3.73

Source: Jaroslav et al. (2009)

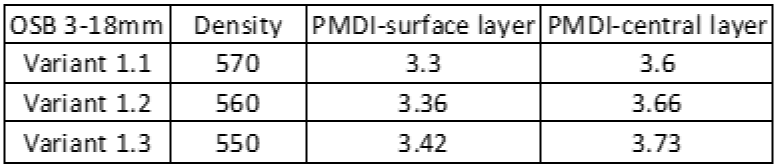
Table 7. Values of density, bending strength, modulus of elasticity and tensile strength perpendicular for variants 1.1 – 1.3, OSB 15 mm thick

		parallel		vertical		
OSB ECO 3 15mm	density	Bending strength	Modulus of elasticity	Bending strength	modulus of elasticity	Tensile strength perpendicular
Variant 2.1	576	25.44	5102	16.46	2409	0.32
Variant 2.2	564	24.73	5090	15.35	2313	0.33
Variant 2.3	553	22.413	4788	14.22	2252	0.35

Source: Jaroslav et al. (2009)

A second experiment was to observe the relationship between density of wood and mechanical properties. Jaroslav et al. (2009) observed OSB at a thickness of 18mm (table 8), demonstrated that their efforts did not show a clear relationship between density and mechanical properties. According to table 9, with the decrease in wood density, MOR shows a trend of decreasing first and then increasing (a U-shaped curve). The MOE in the vertical direction also decreases first and then increases. Only the MOE in parallel direction shows a steady downward trend. Perpendicular tensile strength and the experimental results for the first time demonstrate that with the reduction of density, perpendicular tensile strength results are improved (Jaroslav et al. 2009).

Table 8. Variants of density in OSB, 18 mm thick



OSB 3-18mm	Density	PMDI-surface layer	PMDI-central layer
Variant 1.1	570	3.3	3.6
Variant 1.2	560	3.36	3.66
Variant 1.3	550	3.42	3.73

Source: Jaroslav et al. (2009)

Table 9. Values of density, bending strength, modulus of elasticity and tensile strength perpendicular for variants 1.1 – 1.3, OSB 18 mm thick

OSB ECO 3 18mm	density	Bending strength parallel	Modulus of elasticity	Bending strength vertical	modulus of elasticity	Tensile strength perpendicular
Variant 1.1	571	24.78	5011	14.69	2297	0.32
Variant 1.2	563	23.84	4826	13.99	2187	0.35
Variant 1.3	552	24.26	4781	14.27	2240	0.37

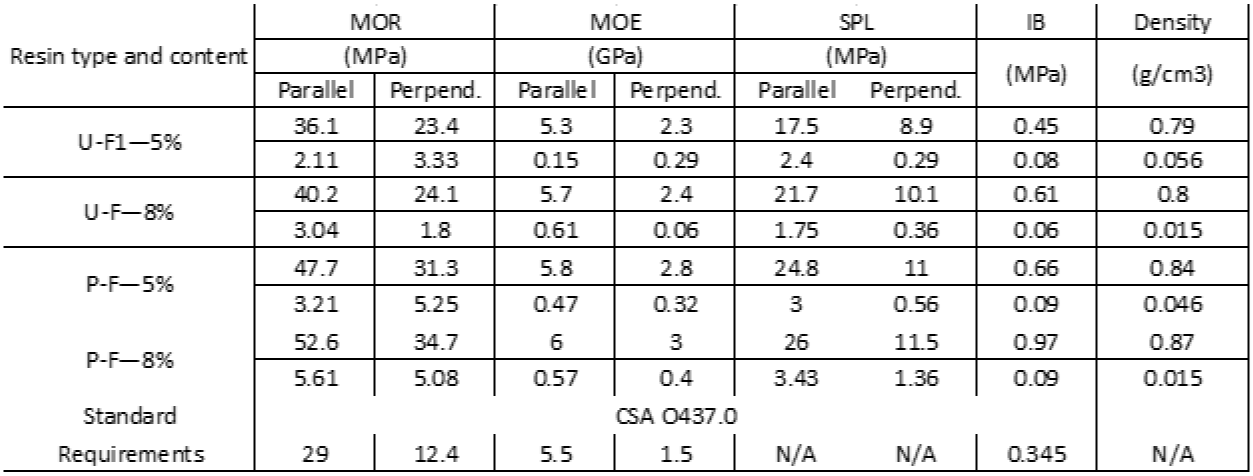
Source: Jaroslav et al. (2009)

According to table 6 and table 7, the higher the density of OSB, the better the mechanical properties. However, it also means that the weight of the wood will be increased. The high-density OSB panels have excellent mechanical properties, but the drawback is their weight. It is not suitable in many situations. The choice of the wood's density may be decided upon by the manufacturer based on the final use of the product. The mechanical properties of 18mm OSB shown in table 9 are inconsistent with the previous experimental results. In table 9, as the density increases, the mechanical properties of OSB decrease and then rise show as a U- shape. The author suggests that there was a measurement error during the density measurement of variant of 1.2. The density of Variant 1.2 may display a lower density than 552 kg/m^3. This suggestion conforms the relationship between density and mechanical properties of OSB.

3.4.1 RESIN

The type of resin also has a significant impact on OSB. Okino et al. (2009) conducted a set of experiments where they changed the type and content of resin to determine the influence of resin on mechanical properties. In order to reduce the experimental error, the raw materials of the experiment were all *Pinus taeda* L. with density maintained at 0.43g/cm^3. A high-speed disk-cut flaker was used to cut the log into flakes. The four experiments used different resin that contained 5% and 8% urea-formaldehyde (UF) and 5% and 8% phenol-formaldehyde (PF). The process of production remains precisely the same. The viscosity of the P- resin is 467MPa. The viscosity of the UF is 267MPa. Mechanical properties MOR and MOE of the test OSB were then measured and are presented in table 10 (Okino et al., 2009).

Table 10. Results of the mechanical properties of OSB made with strands of *Pinus taeda* L.



Resin type and content	MOR (MPa)		MOE (GPa)		SPL (MPa)		IB (MPa)	Density (g/cm3)
	Parallel	Perpend.	Parallel	Perpend.	Parallel	Perpend.		
U-F1—5%	36.1	23.4	5.3	2.3	17.5	8.9	0.45	0.79
	2.11	3.33	0.15	0.29	2.4	0.29	0.08	0.056
U-F—8%	40.2	24.1	5.7	2.4	21.7	10.1	0.61	0.8
	3.04	1.8	0.61	0.06	1.75	0.36	0.06	0.015
P-F—5%	47.7	31.3	5.8	2.8	24.8	11	0.66	0.84
	3.21	5.25	0.47	0.32	3	0.56	0.09	0.046
P-F—8%	52.6	34.7	6	3	26	11.5	0.97	0.87
	5.61	5.08	0.57	0.4	3.43	1.36	0.09	0.015
Standard				CSA O437.0				
Requirements	29	12.4	5.5	1.5	N/A	N/A	0.345	N/A

Source: Okino et al. (2009)

This experiment explored the relationship between resin types, content and the mechanical properties of OSB. U - F represents the urea-formaldehyde, P-F represents the Phenol - formaldehyde. These OSBs exceed the CSA O437 standard. This means that the mechanical properties of the wood are excellent. SPL stands for values that represent the maximum force that the wood can accept without permanent deformation of the wood. The value of the internal bend is an indicator of adhesion. The results were the same as before, in that as the amount of resin increased, the values of MOR, MOE, and SPL all increased. Comparing U-F with P-F, the mechanical properties of P-F are higher than U-F in both the parallel and vertical directions. This indicates that p-f is suitable for use as the raw material of OSBs (Okino et al., 2009).

Table 10 studies the relationship between different types of resins and the mechanical properties of wood. All mechanical properties are better than the CSA O437.0 standard. Because the resin contains a higher mass than the water. Therefore, when the concentration of the resin is higher, the density of the resin is also higher. The ratio of the parallel to perpendicular values of SPL ranged from 2-2.3. It means that OSB can withstand more force in a parallel direction. No matter the MOR, MOE or IB values, the attribute of OSB using p-f is higher than that of u-f (Okino et al., 2009). Therefore, compared to u-f, p-f is suitable for the production of OSB panels without considering the economic factors such as price.

3.4.2 QUANTITY OF RESIN

In the second set of experiments, the experimental variable was the quantity of resin. There were three experiments. The OSB density of each group was 570kg/m^3, and the manufacturing method of the three groups of OSB was also consistent (Table 11). It also changed the OSB widths of the three experiments in order to understand the relationship between OSB width and mechanical properties (Jaroslav et al., 2009).

In Table 11 and Table 13, the thickness of 15mm and 18mm OSB were selected for the experiment. The content of the test is still consistent with the previous experiments conducted. However, the two experiments kept the same density, but the amount of resin is different. There were three experimental groups, and the difference in the average amount of resin between the two adjacent groups was 0.3. The experimental results show that the MOR and MOE in both parallel and vertical directions decrease with the amount of resin decreasing (Jaroslav et al., 2009).

Table 13 and Table 14 show that the mechanical properties have decreased with the decrease in the amount of resin. The result proves that the resin not only connects the face layer to the core layer in OSB but also enhances the mechanical properties of OSB. The experimental object of table 10 is also the 18mm OSB panels. In the vertical direction, MOR and MOE still did not show a clear relationship between the amount of resin and mechanical properties. The reason may be errors in variant 2.2 measurements. Although the resin will increase the mechanical properties of wood, the increase may be in a range. After reaching this maximum, the addition of resin may not increase the mechanical properties of OSB or even decrease it (Jaroslav et al., 2009).

Table 11. Variants of amount of glue in OSB, 15 mm thick

OSB 3-18mm	Density	PMDI-surface layer	PMDI-central layer
Variant 2.1	570	3.3	3.6
Variant 2.2	570	3	3.3
Variant 2.3	570	2.7	3

Source: Jaroslav et al. (2009)

Table 12.Values of density, bending strength, modulus of elasticity and tensile strength perpendicular for variants 2.1 – 2.3, OSB 15 mm thick

OSB ECO 3 18mm	density	Bending strength parallel	Modulus of elasticity parallel	Bending strength	modulus of elasticity vertical	Tensile strength perpendicular
Variant 2.1	571	24.78	5011	14.69	2298	0.32

Variant 2.2	571	20.87	4768	12.81	2102	0.28
Variant 2.3	571	20.15	4564	13.44	2150	0.26

Source: Jaroslav et al. (2009)

Table 13. Variants of amount of glue in OSB, 18 mm thick

OSB 3-15mm	Density	PMDI-surface layer	PMDI-central layer
Variant 2.1	575	3.3	3.6
Variant 2.2	575	3	3.3
Variant 2.3	575	2.7	3

Source: Jaroslav et al. (2009)

Table 14. Values of density, bending strength, modulus of elasticity and tensile strength perpendicular for variants 2.1 - 2.3, OSB 18 mm thick

OSB ECO 3 15mm	density	Bending strength parallel	Modulus of elasticity parallel	Bending strength vertical	modulus of elasticity	Tensile strength perpendicular
Variant 2.1	576	25.44	5102	16.46	2409	0.33
Variant 2.2	575	24.73	5090	15.35	2313	0.31

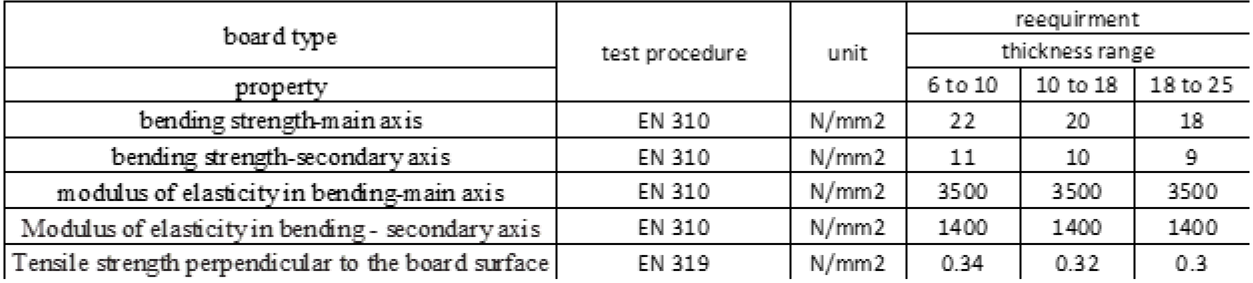
Variant 2.3	577	22.413	4788	14.22	2252	0.28

Source: Jaroslav et al. (2009)

3.5 THICKNESS

Thickness is an important factor affecting the mechanical properties of OSB. In order to reduce other variables, the experiment by Jaroslav et al. (2009) follows the criteria of EN 323 standard. This standard strives to ensure that the density of the test sample, the experimental procedure and other factors are all consistent throughout the experiment. The OSB mechanical properties were then measured using the EN 310 standard. The thickness range is divided into three categories: 6 to 10mm, 10 to 18mm, and 18 to 25mm. Mechanical properties measured include the bending strength of the main axis and the secondary axis (Jaroslav et al., 2009). Elasticity is defined by the property being able to withstand external forces to which it may return to its original form once such forces are removed without losing the original shape of the wood (Desch and Dinwoodie, 1981). However, wood can bear external pressure in a specific range and when the external force exceeds this range, the plastic deformation or failure will occur (Desch and Dinwoodie, 2009). The modulus of elasticity is used to describe wood's elastic properties. Bending strength is also called modulus of rigidity (MOR). Similar to MOE, it is a ratio used to describe the shear stress per unit sample length (Desch and Dinwoodie, 2009). As displayed in table 15, when thickness increases, bending strength decreases. In spite of this change, there tends to be no change in the MOE. Tensile strength perpendicular to the board surface gradually decreased with the increase of thickness. The thickness of 6 to 10mm is a great choice because of its better mechanical properties (Jaroslav et al., 2009). Density is an essential indicator of the mechanical properties of materials.

Table 15. Represents the relationship between thickness and mechanical properties.



board type	test procedure	unit	reequirment		
			thickness range		
property			6 to 10	10 to 18	18 to 25
bending strength-main axis	EN 310	N/mm2	22	20	18
bending strength-secondary axis	EN 310	N/mm2	11	10	9
modulus of elasticity in bending-main axis	EN 310	N/mm2	3500	3500	3500
Modulus of elasticity in bending - secondary axis	EN 310	N/mm2	1400	1400	1400
Tensile strength perpendicular to the board surface	EN 319	N/mm2	0.34	0.32	0.3

Source: Jaroslav et al. (2009)

3.6 KNOTS

The knot has some negative effects on the mechanical properties of the wood. Therefore, it should also affect the mechanical properties of the OSB. In fact, the knot does not directly affect mechanical properties as it is surrounded by irregular grain, and the grain direction affects the mechanical properties of wood (Desch and Dinwoodie, 1981). There are different degrees to which a knot affects mechanical properties. In the vertical direction of shear strength and compression strength, MOE will slightly decrease due to the occurrence of a knot. However, in the parallel direction of compression strength, the bending strength decreases greatly when the knot appears (Desch and Dinwoodie, 1981).

The degree of the impact of the knot on the wood depends on the size, position and type of the knot. The effect of the size of a knot is proportional to its cross-sectional area. If the knot appears in the compression edge, the impact on the mechanical properties of wood is less than that of the knot in the tension edge. In contrast, the knot in the center has minimal impact on mechanical properties（Desch and Dinwoodie, 1981）

3.7 MOISTURE CONTENT

Moisture content has a significate effect on the mechanical properties of wood. According to the data, strength values for more than 400 species were much higher at 16% than at 28% (Desch and Dinwoodie, 1981). After drying wood, the longitudinal compressive strength is three times that of timber at the fibre saturation point (Desch and Dinwoodie, 1981).

When moisture content changes, different mechanical properties change to different degrees. MOR, like longitudinal compression strength, showed significant changes when the water content decreased by 1%. However, side hardness does not change significantly (Desch and Dinwoodie, 1981).

A main reason for this change is that when the moisture content decreases, this strengthens the hydrogen bonds linking together the microfibrils (Desch and Dinwoodie, 1981). Table 14 shows how the mechanical properties of wood change when the moisture content of wood changes.

Table 16. Percentage change in strength of scots pine timber per 1 percent change in moisture content

	mositure range（percent）		
property	6- 10	12- 16	20-24
MOE	0.21	0.18	0.15
MOR	4.2	3.3	2.4
Compression perpendicular	2.7	2	1.4
Hardness	0.058	0.053	0.045
Shear parallel	0.7	0.53	0.36

Source: Desch and Dinwoodie (1981)

3.0 DISCUSSION

OSB is used more and more frequently. The higher the mechanical properties of OSB panels the higher the value. The influencing factors include temperature, species, density, resin, thickness, knot and moisture content. These factors affect the mechanical properties of OSB in varying degrees. The literature suggests that these factors can be divided into two groups. The first group is that raw materials affect the mechanical properties of OSB (Wang et al., 2014; Jaroslav et al., 2009; Desch and Dinwoodie, 1981). These effects include species, knots, and density. OSB is made of wood panels or chips and these factors affect the mechanical properties of the OSB by affecting the mechanical properties of the board. These factors influence the different mechanical properties of OSB. For example, density affects MOE and MOR of OSB in both parallel and vertical grain directions (Jaroslav et al., 2009). According to the previous conclusions, the higher the density, MOE and MOR of OSB will be (Jaroslav et al., 2009). However, the effect of species on the mechanical properties of OSB focuses on the ratio of parallel to and perpendicular to the grain direction of MOE and MOR (Wang et al., 2014). When the pressure parallel to the direction of the grain is the same, changing the species can allow more pressure on the OSB in the direction perpendicular to the grain (Wang et al., 2014). Because species have different densities, species changes also have an impact on MOE and MOR (Wang et al., 2014; Jaroslav et al., 2009). The appearance of a knot changes the direction of the surrounding grain, which is the main reason it can affect the mechanical properties of the OSB (Desch and Dinwoodie, 1981).

The second group of influencing factors is the manufacturing method. This group of factors includes temperature, resin, thickness and moisture content. There is a strong correlation between temperature and moisture content (Mendes et al., 2013; Desch and Dinwoodie, 1981; Okino et al., 2009). As the temperature around the OSB increases, the moisture content of the wood decreases. Dry OSBs tend to increase the mechanical properties of the wood (Desch and Dinwoodie, 1981). However, when the temperature reaches a certain value, increasing the temperature further will reduce the mechanical properties of OSB (Desch and Dinwoodie, 1981). At this point, the moisture content has reached a very low value and cannot change too much when improving temperature. So, the effect on the mechanical properties of wood is negligible (Desch and Dinwoodie, 1981). The influence of resin on OSB is divided into types and quantities of resin. According to the literature, the higher the quantity, the better the mechanical properties (Okino et al., 2009). An OSB made from p-f has better mechanical properties than one made from u-f (Okino et al., 2009). However, it is also denser, and maybe denser has an effect on mechanical properties. Thickness is the final factor explored in this article. As the thickness increases, the bending strength becomes smaller, but there was no obvious change in MOE (Jaroslav et al., 2009).

4.0 CONCLUSION

This paper introduces the background of OSB and its production process. The OSB board is a particleboard product of flakes bonded by resin. This means that the mechanical properties of the OSB are complex. Because of its complex structure, different manufacturers make products with different qualities. OSB density is a measure of the mechanical properties of wood. It was found by comparing different experimental groups, the denser the wood, the better mechanical properties it displays. OSB species were investigated, including hardwood, pine, and aspen, all three being common species used as raw materials for OSB. This reflects the relationship between density and mechanical properties. Because OSB comes from different manufacturers, there are differences in their properties. Comparison are made by means of following standard testing methods where the product is essential standardized. Their ratio in relation to numerical directions also reflects their mechanical properties. Aspen has the highest ratio, which means that aspen can withstand more force in parallel directions. The ratio of Pine is the smallest, which means that the OSB made from Pine has a similar ability to bear external forces in different directions. At the same time, the type and quantity of resin were changed. OSBs made with p-f are of better quality than those made with u-f. The higher the amount of resin, the better the mechanical properties of OSB. At the same time, temperature tends to play a role in the wood product. If the wood is pre-heated before production, the moisture content of the wood is also significantly reduced, in addition density would also decrease. The higher the temperature, the lower the density, which results in increased thickness. Such effects are due to the spring-back effect. Preheating reduces the mechanical properties of the wood, either MOE or MOR. Heat also affects the resin, the IB value of OSB also decreased due to heating. Knots also change the mechanical properties of OSB, because of the changing grains which surround the knots. Timber can load more force in the parallel to the grain direction. With the occurrence of knots, it negatively affects the mechanical properties of OSB. Moisture content also influences the mechanical properties of OSB. With the moisture content decreasing, the mechanical properties of OSB increases. This is one of the reasons why people dry wood before manufacturing it into forest products like OSB, it can improve the mechanical properties.

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