FINAL REPORT

INTERACTION OF EFFECTS OF THROUGH-BORING AND BOULTONIZING ON DOUGLAS-FIR SAPWOOD

AUTHOR: FRANZISKA GASTEIGER, BSC

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Supervisor: Prof. Dr. Adam Taylor

UNIVERSITY OF TENNESSEE - KNOXVILLE

AND

SALZBURG UNIVERSITY OF APPLIED SCIENCES - KUCHL

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Abstract

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In the United States particularly, Boultonizing and through-boring are commonly applied to utility poles prior to preservative treatment. Boultonizing – submersion of green wood in hot oil under a vacuum – is used for rapidly drying the wood. Through-boring – drilling small holes through the cross-section – is used to improve the penetration of the preservative, especially in refractory species such as Douglas-fir.

The effect of each of these processes, separately, on wood mechanical properties has been evaluated and is accounted for in relevant standards. However, due to some pole failures, concern has developed that there could be an interaction of through-boring and Boultonizing treatments that causes lower mechanical properties. This project is a small-scale, preliminary experiment to determine if there is an interaction of through-boring and Boultonizing treatment effects.

Small, clear Douglas-fir beams used. Samples were through-bored and/or Boultonized in full factorial design and evaluated for toughness, MOE and MOR. The possibility of an interaction of treatment effects was evaluated using 2-way ANOVA.

The simulated through-boring treatment lowered the mechanical properties (MOR -13%, p=0,003; Toughness -12%, p=0,057) but the Boultonizing process did not. There was no evidence for an interaction of the through-boring and Boultonizing treatments (p=0,114-0,980, 2-way ANOVA).

These data suggest that there is no need for concern about combining through-boring and Boultonizing treatments for Douglas-fir utility poles.

The small-scale test showed no interaction of through-boring and Boultonizing. It addresses concerns in the utility pole industry about the combination of these treatments and problems with uncommon failures of utility poles. The results also suggest that commonly applied mechanical property reductions for Boultonizing treatments are not necessary.

1 Introduction

In the United States, many wood preservation procedures were initiated, beginning with the construction of the railroad tracks at the end of the 19th century. The needs of the railroad industry on wood, for example, intersections, switchover points, or bridge girders were immense. This ultimately led to the development of new processes, which were achieved through cooperation between the chemical and railway industries. For example, creosote, but other preservatives as well, have been used to extend the life of wood products. Even today, some of these processes and chemicals are used to protect the wood. (Cheremisinoff et al. 2008)

During the last decades, new and innovative products were developed from the wood preservation industry. Their methods are used to protect wood, not only against wood-destroying or -staining organisms, but also to combat infestation by these organisms. The goal of modern wood preservation is to ensure a high uniform penetration depth of the wood preservatives with a process which is economical and environmentally friendly.

According to Antwi-Boasiako and Amponsah (2012), the treated samples can reach 5 to 10 times the lifespan of the untreated, depending on which process is used for the required properties, the standard drying methods influence the mechanical properties only slightly to not at all.

Apart from standard wood seasoning, Boultonizing is an alternative drying method, it includes heat and vacuum, which is combined with a non-aqueous solution - mainly creosote. During this procedure, green wood products - recently cut and not dried – are packed into a treating cylinder. The cylinder is enclosed and creosote between 210° F and 220° F is introduced, while at the same time a vacuum is created. Therefore, the boiling point can be reached much earlier than under normal conditions and the drying temperature can be below 212° F. This belongs to the type of wood, or the percentages of the different species. The evaporating steam is directly fed into an equipment outside the cylinder, where it condenses to water.[1]

Another method for a better uptake of the preservative is the through-boring of poles.

But there are not only advantages of these wood treatments, per Thompson and Koch (1981), there is an unfavorable effect on the mechanical properties caused by this seasoning

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[1] http://timber.lk/PRASERVATION/Wood-preservation-process/index.html

method. Elkins *et al.* (2007) demonstrated, that through-boring also induced lower mechanical attributes.

The aim of this project is to find out, if there is an interaction of the effects of Boultonizing and through-boring on Douglas-fir sapwood.

At the beginning, general explanations about the wood species, wood protection, utility poles and the used species are made. Following the used processes and applications are described in general, relevant literature is described and references are shown. In the next part, the material and methods are reported. Then the results are outlined and discussed. At the end, there is a short overview and conclusion.

1.1 Douglas-fir

Douglas-fir is a coniferous and evergreen tree. The common names Douglas fir or Oregon pine are misleading, since it is neither a fir nor a pine species. Although it belongs to the pine family (Pinaceae), the correct botanical name of Douglas fir or Oregon pine is Pseudotsuga menziesii. It naturally occurs in western North America. The American Wood Protection Association (American Wood Protection Association, 2012) distinguishes between Interior Douglas-fir and Coastal Douglas-fir. The first mentioned one referred to “Intermountain Douglas-fir", if it grows east of the top of the Cascade Mountains is and “Douglas-fir, Interior North when growing in Oregon, Washington, Idaho, Wyoming and Montana. The one called “Douglas-fir, Pacific Coast” grows between the Pacific Ocean and the summit of the Cascade Mountains., also called "Coastal Douglas-fir".(American Wood Protection Association, 2012)

According to Encyclopedia Britannica it is also indigenous in eastern Asia, but it was later also introduced into some regions of Europe, because of its good properties (Douglas Fir 2017).

It is very resistant, especially in case of damage to the bark and the trunk, in addition, it is particularly fast-growing contrary to the European native spruce. (Mombächer, 1988, pp. 241–242)

On the west coast of America, trees can reach heights of up to 75 meters. As a rule, however, they are 40 to 50 m high and gain diameter of 1.5 m (measured at a height of 1.3 m). Usually the stem is straight and cylindrical and knot-free up to a length of 20 m. Partly there are forests only with Douglas fir, but more often they are associated with tree species such as hemlock, western red cedar or even redwood. The properties of the wood itself can vary greatly due to climate, location and soil conditions. It is resinous, smells intense and aromatic and shows a clear contrast between early and latewood when looking at the cross section. Regarding fungal infestation, it is mediocre permanently and not easy to impregnate.(Lohmann and Blosen, 2003, pp. 259–260)

The needles are long, greenish-blueish, softish, blunt and they grow separately from the branch (Douglas Fir 2017). They smell like oranges, the male flowers are yellow, female ones are reddish and bloom from April to May, the ripe cones are longish, brown, hanging and oviform (Dreyer, 2010, p. 62).

The wood is versatile, it is an important timber tree for example used as roof structures in some areas. The delicate fragrant twigs of Douglas fir can be used to make tea. Dried and chopped, they find use in herbal salts and root oils. Also for booze and liqueurs male flower buds and cones can be used. Boiled in water, a syrup can be made by adding sugar. Care should be taken not to confuse the tree with the poisonous yew (Taxus baccata). (Dreyer, 2010, p. 62)

Because of its large sizes and the rapid growth, one common application of this species is utility poles made out of the Douglas-fir stems. For the necessary impregnation two treatment processes are combined: Boultonizing and through-boring.

1.2 Wood Protection

For many thousands of years wood has been used for constructions and applications of all kinds. Over time, certain types of wood have been increasingly used because of their specific properties for special utilization purposes. Today one can explain these differences and advantages recognized by empirical values, as for example mechanical properties partly by the different chemical composition and the wooden construction. Due to these disparities among and also within tree species, the natural resistance to external influences as well as the infestation of harmful organisms varies. The different types of wood are therefore divided into performance classes depending on their natural durability. In addition, over time, many new methods and procedures have been developed to make this natural material more resistant and more long-lasting. Consequently, resources, labor and costs can be saved. According to Militz and Mai (2012), adequate wood preservation is not only important from an economic point of view, but also includes a significant ecological component. (Militz and Mai, 2012, p. 457)

Dry wood inside is generally not likely to be infested with parasites. Whereas outdoors, especially with at least a wood moisture content between 20% up to 25%, abiotic infestation, like fungi, insects and bacteria (for wood in contact with soil) increasingly appear. For wood-destroying fungi a moisture content minimum of 30% is necessary. (Militz and Mai, 2012, p. 471)

Actions for wood protection, apart from constructive wood preservation, include for example superficially applied coatings and water-repellent agents or the wood is soaked completely in the preservative.

Different treatments and pre-treatments were used depending on wood species and also application.

1.3 Utility Poles

The American Wood Protection Association, 2012, abbreviated AWPA, shows in “Use Category System” (USC), section U1-12 the “User Specification For Treated Wood”, where amongst others also commodity specifications for poles are described. In general, the Use Category System (UCS) of the American Wood Protection Association (AWPA) indicates which systems can effectively protect wood products under specific exposure conditions. The UCS defines five main categories of use, in which all uses of wood can be arranged. This subdivision describes exactly the permissible fields of application for the individual products during operation. Within these main use categories, further subdivision is made in order to further classify and define certain products and conditions, e.g. with regard to biodegradability and planned product life or also fire-retardant applications. Utility poles belong to UC 4, depending on how much decay divided into A – general use with normal exposure conditions – up to C – heavy duty with high decay and severe exposure. In extreme cases/areas, this represents a very high probability of infestations of insects and fungi with a high biodegradation potential for utility poles. (American Wood Protection Association, 2012)

It is also important to mention, that in areas where cultural landscapes have emerged as a result of changes, for example along the banks of irrigation canals or in residential and agricultural areas that are irrigated, clearer or faster degradation characteristics could occur. Consequently, wood in these modified environments requires a higher level of protection than would be needed under normal conditions of the local natural environment. In addition, it should also be noted that in certain regions, these "deterioration zones" shown in Figure 1 can be overridden by special circumstances in the landscape. Examples of these are river valleys or coastal strips, in which wood deterioration is more likely to happen than in the region as a whole. (American Wood Protection Association, 2012)

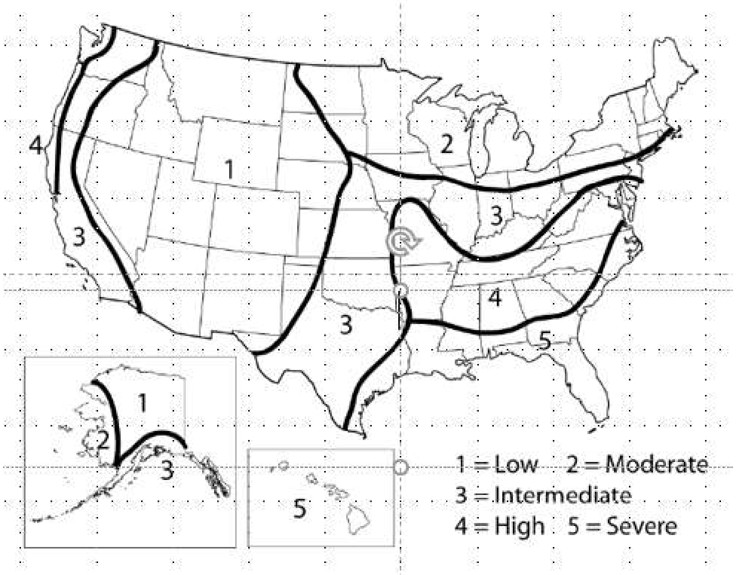


Figure 1: Overview of general regional differences in the US: deterioration potential of wood used in contact with the ground (American Wood Protection Association, 2012)

All these factors lead to inevitability of wood protection and make clear to focus on regional circumstances. As in Figure 1 shown, Tennessee belongs, in general, to zone 4, which mean a high deterioration degree of wood with ground contact. In contrast to other regions of the US, people and also wood-processing companies in these endangered territories have to cope with the topic of wood protection a lot. There are different methods and ways to protect wood and its products, but often you have to balance the assets and drawbacks. For special applications, special reliable types of treatments are increasingly used. In the case of utility poles, the Boultonizing and through-boring process is one common procedure.

2 State of the Art

In this part of the report the treating processes of through-boring and Boultonizing are explained in general first and results of former tests are shown.

2.1 Boultonizing

The Boulton-process can also be called boiling-under-vacuum process. It was patented in England in 1879 and two years later in the United States of America. The original process used coal-tar creosote as boiling medium. Nowadays this method is mainly used for Douglas-fir on the west coast and other suitable preservative oils are used, important features of these oils are non-foaming and insolubility in water. Hunt and Garratt (1938) describe the temperature range to be met between 180°F and 200°F compared with a vacuum about 20 inch of Mercury or more. In a treating cylinder, the wood is treated with hot temperature and vacuum. Because of the negative pressure, the boiling point of water is lower and therefore the drying processes faster than under normal conditions, it needs less energy for heating and damaging of the wood is less than at higher temperatures. The settings of this method stresses the strength and other properties of the wood less than for example most of the steam-pressure-treatments. (Hunt and Garratt, 1938, 12; 172-175)

It is mentioned as a possible seasoning treatment in the American Wood Protection Association, 2012, part T1-12. There are restrictions that only oil-type preservatives are permitted for this kind of seasoning. The negative pressure during the process must be high enough to keep the boiling point of the water in the wood below the temperature of the oil. The process should be done until the moisture content of the wood got low enough through evaporation to allow a good penetration of the preservative. In general, the process is completed when the amount of evaporating water falls below 1.6 kg / m³ / hr. (American Wood Protection Association, 2012)

2.2 Through-boring

The definition in the Glossary of the American Wood Protection Association for through-boring is as follows: "*Holes bored (drilled) from one face of a timber completely through the cross section to the opposite face in a pre-determined pattern, density and angle to the longitudinal axis.*". (American Wood Protection Association, 2012)

It explains only how the holes are drilled, but it is not included why this pre-treatment is carried out. With pressure treatments, most of the wood species can be impregnated with preservatives flawless. If they are treated properly and it was used an appropriate protective substance and method, these types provide great performance. But especially in the case of species, which are difficult to impregnate, like Douglas-fir, larch or Scots pine, additional steps must be taken. For them, it happens easily during the pre-treatments, that the outer parts - the sapwood - is dry, but the heartwood has a moisture content above the fiber saturation point. Therefore, the main impregnation happens only in the dried part of the pole, the sapwood. The heartwood remains wet and little or no penetrated by the preservative. In the case, that these poles are used in service, the inner parts dry slowly during service and drying checks appear. These cracks often extend beyond the outer parts and reach untreated, inner heartwood parts and make it easy for parasites to infest. As a consequence of infestation, maintenance problems arise and shorten the service life. In general, this degradation could be prevented for example by the regular use of fumigants, but pretreatment processing procedures have been developed that can be used in advance and are far more cost-effective. Elkins *et al.* (2007) mentions four different pretreatment techniques for enhancing the performance by making a better drying possible and thus a better penetration by the impregnation agent. The techniques are : kerfing, deep incising, radial drilling, and through boring (Elkins *et al.*, 2007)

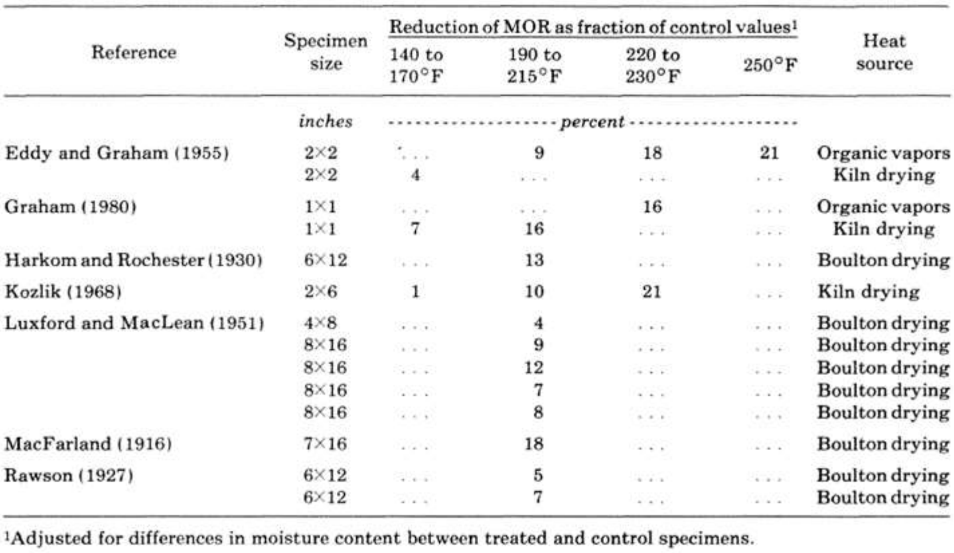
The first mentioned technique implies the cutting of kerfs into the surface of the log. Kerfing itself is not used for gaining a deeper penetration, it should avoid deeper cracks and therefore it minimizes the risk for an invasion of parasites into the pole near the groundline. (Morrell and Schneider, 1994)

For deep incising, which could be used for initializing a deeper impregnation, the log pass a machine with rollers equipped with teeth (about 64 mm long), which puncture the wood (Agriculture, 2011). After this treatment, longitudinal slits can be seen on the lateral surface, but only around the groundline area of the wooden pole.

2.3 Background

Douglas-fir sapwood is proved to be very difficult relating to preservation, both by simple methods for example spraying or dipping and also by pressure methods like vacuum impregnation or pressure treatment (Liese *et al.*, 1982). That is the reason, why the Boultonizing process, a strong process, is used in this case.

Prior research suggests that wood drying via the Boulton process results in modest reductions in the mechanical properties of wood. The effects of the drying processes are shown in Figure 2. There were different sized samples. For the tests with the Boulton-seasoned samples there were used sizes of 4x8, 8x16, 7x16 and 6x12 inches and a temperature between 190° F and 215° F. The reduction of the Modulus of Rupture (MOR) varied from 4% - the smallest sample size - to 18 % at one of the bigger sample sizes (7x16).

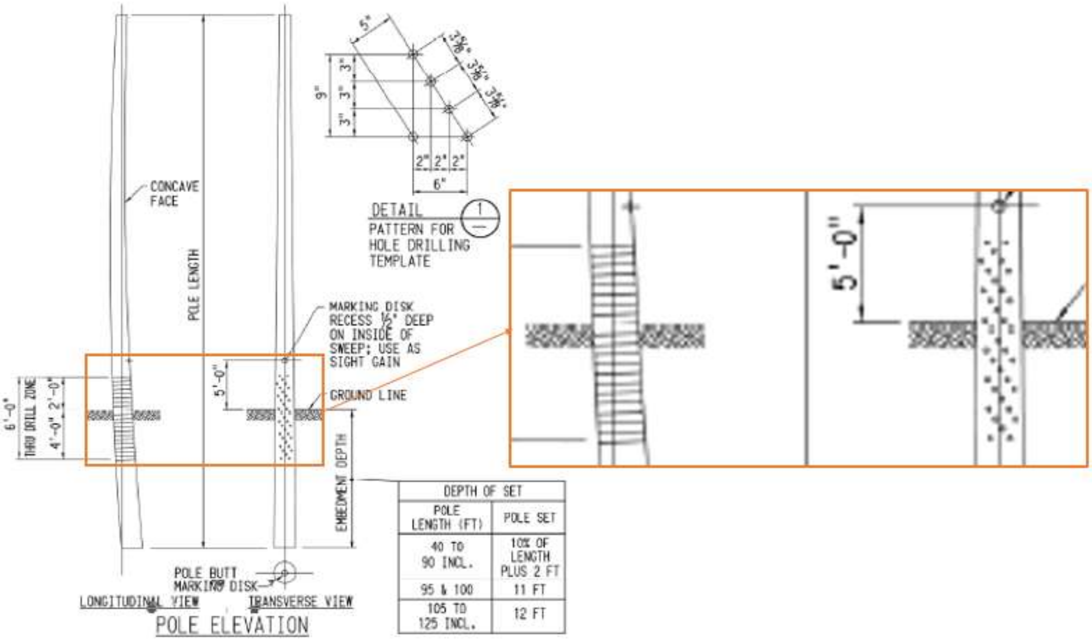


Reference	Specimen size	Reduction of MOR as fraction of control values[1]				Heat source
		140 to 170°F	190 to 215°F	220 to 230°F	250°F	
	inches	*percent*				
Eddy and Graham (1955)	2×2	. . .	9	18	21	Organic vapors
	2×2	4	. . .	. . .	. . .	Kiln drying
Graham (1980)	1×1	. . .	. . .	16	. . .	Organic vapors
	1×1	7	16	. . .	. . .	Kiln drying
Harkom and Rochester (1930)	6×12	. . .	13	. . .	. . .	Boulton drying
Kozlik (1968)	2×6	1	10	21	. . .	Kiln drying
Luxford and MacLean (1951)	4×8	. . .	4	. . .	. . .	Boulton drying
	8×16	. . .	9	. . .	. . .	Boulton drying
	8×16	. . .	12	. . .	. . .	Boulton drying
	8×16	. . .	7	. . .	. . .	Boulton drying
	8×16	. . .	8	. . .	. . .	Boulton drying
MacFarland (1916)	7×16	. . .	18	. . .	. . .	Boulton drying
Rawson (1927)	6×12	. . .	5	. . .	. . .	Boulton drying
	6×12	. . .	7	. . .	. . .	Boulton drying

[1]Adjusted for differences in moisture content between treated and control specimens.

Figure 2:Summary of reported effects of Boulton drying on wood mechanical properties (Thompson and Koch, 1981)

Similarly, through-boring of poles to improve preservative uptake, is considered to have minimal impact on pole structural capacity (American National Standards Institute, 2002). The American Wood Protection Association (AWPA) comprises following advices and rules for the purchaser of such pre-treated poles: By prior consent of the customer, the producer may pre-treat the Douglas-fir poles in the later ground line area by means of deep incising, radial drilling or through-boring. In general, the area for this pretreatment is 0.6 m above and 1.8 m below this baseline. Nevertheless, the treater can change it at his discretion. The first mentioned drilling methods are up to 2.5 mm depth and distances of 150 mm longitudinal and 75 mm in the same plane. The maximum distance in the longitudinal direction is 225 mm, horizontal 100 mm. The through-boring method is done with a diameter of 12.5 mm and the holes are all drilled slightly tilted in the same direction to allow water drainage. Hole distances are again at the discretion of the manufacturer, but Figure 3 shows the given example. It is said, that it has already been displayed that by drilling this way a very good penetration and no negative impact on the flexural properties of the pole arise. (American Wood Protection Association, 2012)



DEPTH OF SET	
POLE LENGTH (FT)	POLE SET
40 TO 90 INCL.	10% OF LENGTH PLUS 2 FT
95 & 100	11 FT
105 TO 125 INCL.	12 FT

Figure 3: through-boring pattern of a utility poles

Apart from that, Elkins *et al.*, 2007 showed that there is a slight decrease of the Modulus of Rupture by increasing the hole size. But for smaller sizes, no significant effect could be seen. There are mentioned also several experiments, which should outline the influence of through-boring on the mechanical properties. Brown and Davidson 1961 are brought up with their results for Douglas-fir. It says they determined strength reductions of less than 10% for the through-bored poles. But the testing with real size models is difficult, the implemented experiments are hard to compare and the results vary. That is why the standards say that both treatments reduce the mechanical properties perhaps for safety reasons. (Elkins *et al.*, 2007)

Figure 4 shows the effect of through-boring on the MOR. The larger the diameter, the lower gets the Modulus of Rupture Each of these processes is accepted in the standard relevant to utility poles, with treatment parameters described therein. (American National Standards Institute, 2002)

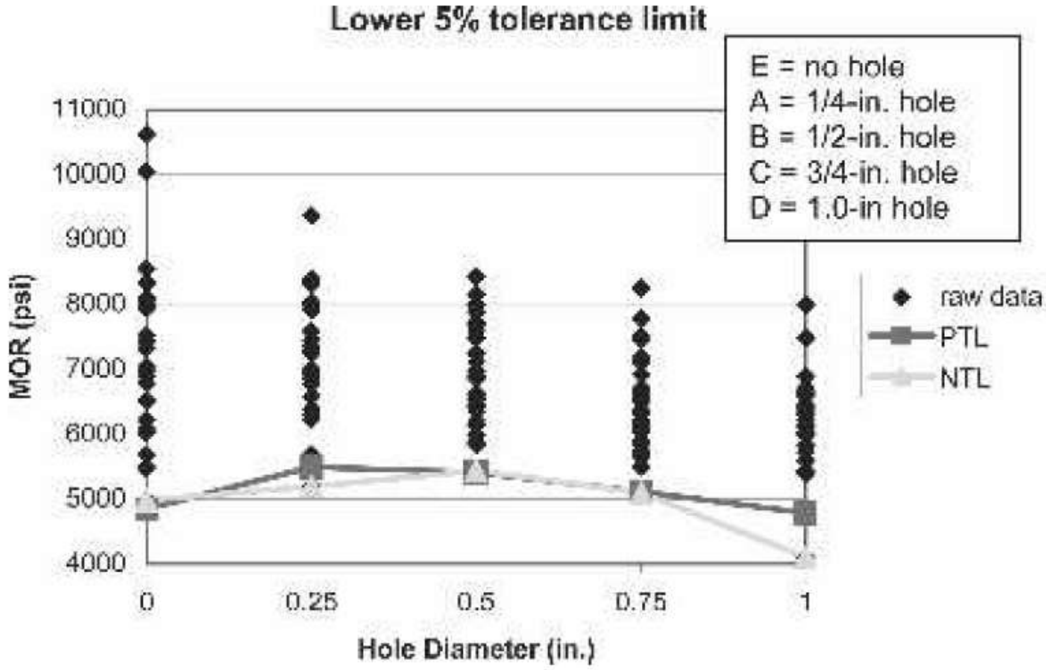


Figure 4: Effect of through boring of various hole diameters on strength, showing parametric- (PTL) and nonparametric-5% tolerance limits (Elkins et al., 2007)

Field failures of Boultonized and through-bored Douglas-fir utility poles have prompted speculation as to whether there may be an interaction of the effects of these two processes; i.e. that the combined effects are more than additive. Furthermore, much of the existing data in support of these treatments results from static bending tests (e.g. MOR and MOE). Toughness properties may be relevant to field exposures such as storms and relevant data are lacking.

2.4 Research question

Is there an interaction effect between the reductions of mechanical properties that result from Boultonizing and through-boring green Douglas-fir sapwood?

2.5 Null hypothesis

While Boultonizing and through-boring treatments separately each reduce the modulus of rupture (MOR), modulus of elasticity (MOE) and toughness of green Douglas-fir sapwood, the combination of these treatments is not more than the sum of their separate effects.

3 Material and Methods

The former proposal of this project included the following considerations regarding the raw material of the experiment. Small, clear samples should be tested, made out of freshly-cut Douglas-fir sapwood from pole stubs. The green dimensions of 5/8” square by 11” long should be sawn.

Furthermore, other variables were included: for the Boultonizing treatment a temperature of 220° F, under vacuum was considered for 60 hours during submerged in P9 oil. The Control samples will be dried at 70° F and 70 % RH to equilibrium (~13% MC).

The through-boring should be simulated by drilling nine holes in the middle of the sample in a special pattern.

The testing procedure included toughness testing using a pendulum-type test machine (Figure 6). In contrast, a static, three-point bending test to failure should determine modulus of rupture (MOR) and modulus of elasticity (MOE) (Figure 5). Samples with through bores should be tested with the holes oriented perpendicular to the direction of force.

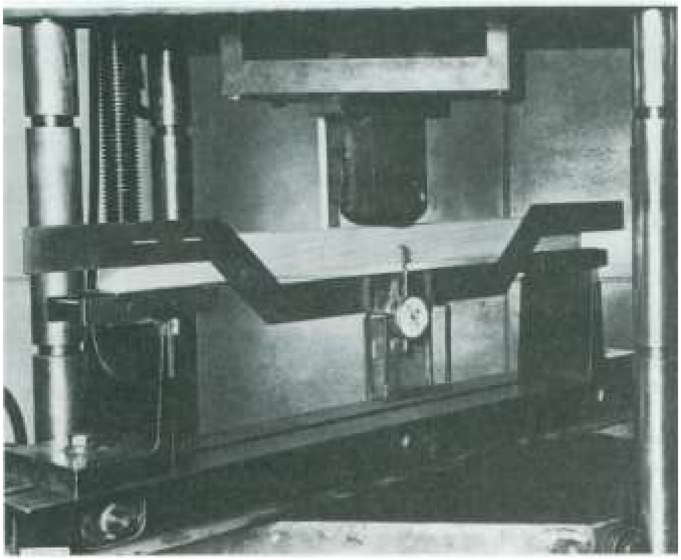


Figure 5: Three-point static bending test set-up (ASTM International, 2000)(ASTM 2000)

Figure 6: Pendulum toughness testing, showing sample ready for testing (left) and lever that is pulled to release pendulum (right). Toughness is calculated as a function of distance travelled by the pendulum after breaking the sample (Forest Products Laboratory, 1961)

Some minor changes were made, but basically the planned structure remained the same.

The following part describes the used material and the implementation in detail.

3.1 The Douglas-fir logs

The logs show features of Douglas-fir for example the difference between heartwood and sapwood. The heartwood color is reddish-brown, the sapwood is yellowish-white, the growth rings are uneven-grained, especially during the cutting of fresh Douglas-fir, pitch pockets and a specific odor appear. (Hoadley, 1999, 69;)

The logs of the Douglas-fir were cut into samples with a cross section of 16x16 mm and a length of 280 mm. Particular emphasis was laid on standing growth rings, no or only small checks or knots and if so solely at the outer parts of the test sticks. This should ensure comparable properties of the untreated single wood sticks. Also, it was used exclusively sapwood, because of its higher moisture content within the stem on the one hand and its importance for pole-strength on the other hand. As described before the moisture content of Douglas-fir green wood varies between heartwood and sapwood, for the coast type between 37% (heartwood) and 115% (sapwood), for the intermediate type between 34% and 154% and the Rocky Mountain Type within 30% and 112% according to Simpson (1991, p. 22). For cantilevers the extreme forces occur in the outer parts, hence the sapwood was considered the more important and interesting part of the tree for this experiment.

It has been taken special care to separate the pieces of the single logs during the cutting, so that it was possible to allocate and divide them equally later.

The size of the samples was adapted to the size of the testing machine. The quadratic cross-section was chosen because of the original round form of Boultonized poles.

For the Boultonizing process in general green wood is used. In this case, the Douglas-fir was not “green” and fresh anymore, because of the long delivery time from. Therefore, all samples were put into water under vacuum first and then under pressure for several times until the samples did not or only slightly float in the water, to at least imitate the usage of green and still wet wood. These samples were split and half of the them were Boultonized.

Due to variability and variation range in properties of wood among the same tree species and even within one tree, it was taken care of with the managed wood that it can later be reassigned to the belonging tree trunk. They were called log 1, log 2 and log 3. For the treating procedures and the individual categories - not treated (0-0); only through-bored (0-1), only Boultonized (1-0) and both treatments (1-1) – particularly emphasis was laid to divide the logs evenly into the groups. Also, this measure was taken to falsify the results as little as possible by potential differences between the supplied Douglas-fir stems.

3.2 Through-boring pattern

The common through-boring procedure was simulated by drilling 1 mm holes. Nine holes were drilled in three rows of three holes, the distance between the holes was 4 mm, as shown in Figure 7. Here the first pattern design was taken over.

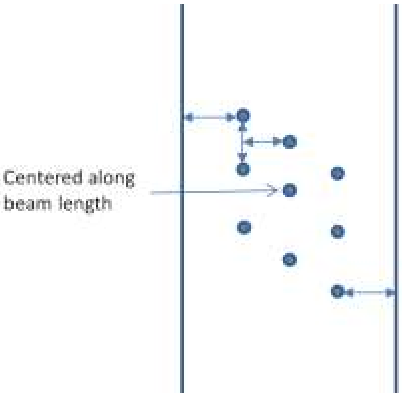


Figure 7: Location of through bores on test beams. All double-ended arrows represent 4 mm distance; the middle hole is centered along the beam length and width

Half of the samples were through-bored perpendicular to the growth rings in the middle of the test models. The drilling was done with a 1-mm-drill on a drilling machine with a jig (cf. Figure 8 and Figure 9), also for preferably equal conditions between the samples. Control samples were not drilled. The diameter of the holes was scaled down to the proportion between pole and borehole used in industrial fabrication. The pattern of the drilling is an attempt to mimic the offset of common through-bored products. Different references and empirical values helped to design the through-boring pattern in this case.

Figure 8: jig for drilling the holes for the through-boring attempt

Figure 9: drilling the 1mm holes for the half of the samples

For drilling the holes, the single rows were drilled one by one. First one row with three bores into every sample, new modification, next row with three drills and once again the same. (cf. Figure 10 to Figure 12)

Figure 10: first row with three drills

Figure 11: second row with three drills

Figure 12: third row with three drills

3.3 Boultonizing process

As mentioned before in 3.1 the received Douglas-fir was not as ordered, not “green” and fresh anymore, probably due to the long period of delivery. The measured moisture content was between 11,67% and 14,20%, which is not as it is used normally for the boiling under vacuum process. Because of that, all samples were first cut and rewetted with a vacuum and pressure cylinder (Binks No.835301). They were put into the cylinder in a bucket filled with water and weighted down with ballast, so that they were completely submerged under water, shown in Figure 13. First a vacuum of 28 inches of Mercury (in Hg) were applied for 1 hour, afterwards a pressure of 80 psi was put on it. This procedure was repeated a few times until the sticks floated no longer or only slightly (cf. Figure 14 and Figure 15). The samples which were Boultonized in the second batch were frozen in order that they don't lose moisture until the boiling-under vacuum-process.

After this effort to produce fresh wood the experiment was implemented as initially planned.

Figure 13: ballast put on the samples in the bucket for a complete submerge

Figure 14: the samples after the first rewetting after the first round, half of the water had "disappeared"

Figure 15: rewetting of the samples, no or only slightly floating at the end

For the Boultonizing itself, sticks were put into pans with Off-Road Diesel. A mesh and a weight (cf. Figure 16) were put on top to assure a full coverage of the samples and moreover a complete drying.

Figure 16: mesh and weight put on top of the samples in the pans as preparation for the Boultonizing process

The pans including the oil and the samples were set in a vacuum oven with a temperature of 82°C (180°F) and a vacuum of 23 inches of mercury for 48 hours to adjust extreme conditions. This applied temperature did not correspond to the former planed temperature of 220°F, 180°F was chosen after new research and conversation with experts. (cf. Figure 17 + Figure 18)

Figure 17: vacuum oven for the Boultonizing process

Figure 18: during the process, condensed water on the glass door, three pans with two layers of samples

After cooling down, these samples and the only rewetted ones were seasoned (25°C, 65% RH) until equilibrium in the seasoning chamber (cf. Figure 19).

Figure 19: seasoning of all samples in the seasoning chamber (25°C, 65% RH)

The Boultonizing process had to be divided into two batches, because of the low capacity of the oven. The pans could not be filled completely with Diesel due to subsequent boiling, that is why only two layers were put in every pan. Hence, the first batch was used for the toughness testing and the other one was used for the bending application.

Figure 20 pictures the pans with the samples after the Boulton process.

Figure 20: The first batch after 48 hours

At the end of the treatments, four different groups were tested to find out if there is an interaction between through-boring and Boultonizing. To minimize and avoid mistakes and inaccuracies, the samples of the logs, named log 1, log 2 and log 3 were divided preferably equally into the four categories, which were:

1	no treatment – only rewetted and seasoned	0 – 0
2	only through-bored – trough-bored, rewetted and seasoned	1 – 0
3	only Boultonized – Boultonized, rewetted and seasoned	0 – 1
4	both treatments - trough-bored, Boultonized, rewetted and seasoned	1 – 1

(cf. Figure 21)

Figure 21: four different kinds of samples

This initial situation with two different treatments and four contrasting particular kinds of samples a full factorial test could be carried out.

3.4 Testing

For getting appropriate results toughness and bending strength was tested. The following section describes these two different methods.

3.4.1 Toughness

The testing machine for the toughness (Wiedemann-Baldwin, impact tester, FPL 1003) can be seen in Figure 6 and Figure 23, this way of testing is generally implemented in the case of fungal deterioration, because it reacts most sensitive and therefore it was also used for this study.

The wooden stick is placed to the allocated space and the pendulum is adjusted in accordance with the range of the approximate strength of the tested material. This adjustment is aligned by using test pieces, which should not include samples of the test setup. For the whole test, the same setting of the pendulum must be used in order to compare the results. Figure 22 shows one of these adjustments, the upper part of the pendulum where the manual lever fixes the deflection of the pendulum is pictured. The other setting can be seen in Figure 23, the position of the round weight of the pendulum on the left side of the picture can be shifted.

Figure 22: adjustment for the prepared samples of the testing machine for toughness (company: Wiedemann, Baldwin); the picture shows the upper part of the pendulum

Figure 23: adjustments for the prepared samples of the testing machine for toughness testing (company: Wiedemann, Baldwin); the deflection of the pendulum can be seen and the hand lever

Attention should be paid that the equipment of the toughness testing machine which causes the break should always have maximal contact to the wooden sample (see Figure 24). Again because of comparability of the results by identical conditions.

Figure 24: sample centered at the allocated place of the toughness testing machine

Through releasing the pendulum, the mechanism breaks the sample, shown in Figure 25 and moves a pointer along a scale pictured in Figure 26). After the procedure, the maximum number can be read from the scale and can be converted into inch-pounds by using a formula.

Figure 25: the sample after breaking

Figure 26: scale for reading the maximal deflection

3.4.2 Bending

For the testing of the modulus of rupture (MOR) and the modulus of elasticity (MOE) a 4-point bending test was used.

Figure 27: testing machine with 4-point bending apparatus and sample

This change from the original plan was made for a variety of reasons. On the one hand, a four-point bending test is commonly used for non-homogenous composites, such as wood. On the other hand, it was utilized to avoid localized reduction. With four points, it is also not so likely to cause artefacts in the middle where the drilled holes are.

The samples were weighted before and the dimensions were measured for the testing program (Instron Bluehill) to calculate the forces immediately after testing. Adjusted and centered on the test bearings of the testing machine (Instron Nvlap 5567Q1466), which were installed with a distance of one third in between (Figure 27 + Figure 28), the sticks were tested one by one. For a more precise analysis of the bending an additional measuring device was used, it can be seen in Figure 29 and Figure 30 under the beam in the middle. Care was taken to adjust this additional equipment so that it touched the beam, but without lifting it from the rest.

Figure 28: boundary for the adjustment on the lower supporting pins

Figure 29: loading pins that apply force on the beam, additional measuring device under the beam

In this case the samples were tested with the holes oriented not perpendicular, but parallel to the direction of the force. The reason of this change in orientation was the intention that it shows clearer and significant differences, because the more stressed direction was now weaker, because of the arrangement of the drilled holes.

Figure 30: additional measuring device

All samples of both types of testing were saved for possible later use. (cf. Figure 31)

Figure 31: labelled samples after breaking by the toughness testing machine

Because of the two different treatments, through-boring and Boultonizing, and four different particular kinds of samples (cf. Figure 21), not treated at all, only through-bored, only Boultonized and both through-bored and Boultonized, a full factorial test on the one side toughness on the other side 4-point bending was carried out. It led to the following results which were used for a 2-way ANOVA.

4 Results and Discussion

The results are also divided into different parts: the results of the toughness testing, the results of the 4-point bending test and the 2-way ANOVA.

4.1 toughness testing

The results for the toughness are for one thing split into the three different logs and then also the average of all is pictured. Their range of variation goes from a minimum of 37.43 in*lb for log 1, through-bored and Boultonized (1-1), the maximum for log 2, through-bored and not Boultonized (1-0) of 138.55 in*lb.

In total log 2 performed best, but also the standard deviation is very high, up to 27.4 in*lb also due to the small size of the samples (n=5). The model of log 3 mirrors the average outcome best because of the high number of samples (n=20). (cf. Figure 32)

The average diagram for toughness (Figure 33: average toughness of all samples togethersFigure 33) shows only small differences. The not TB, not Boultonized (0-0) reached the highest results with 82.79 in*lb, only through-bored (1-0) yielded 72.84 in*lb, which is a reduction of 12%, only Boultonized (0-1) samples showed a value of 80.14 in*lb which corresponds to a percentage of -3% and the samples with both treatments (1-1) revealed a reduction of 1% with 81.72 in*lb. The standard deviation is from 19.53 in*lb (0-0) up to 23.58 in*lb (0-1). (cf. Figure 33)

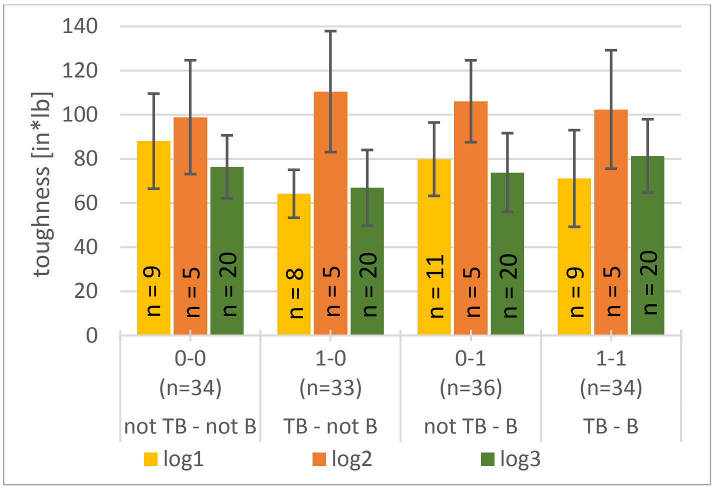


Figure 32: results of the toughness test: average toughness split into the different logs

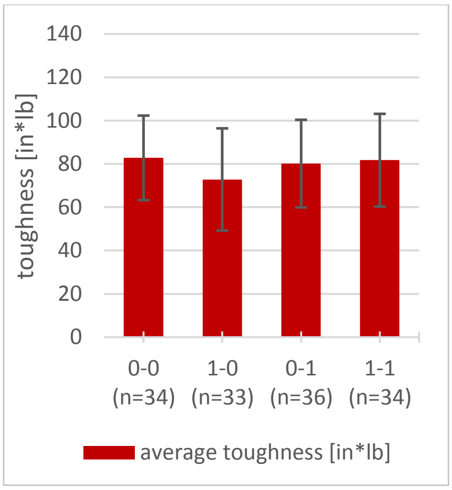


Figure 33: average toughness of all samples togethers

Figure 34 to Figure 37 outline the relation between weight in g and toughness in in*lb of the different samples and logs. The green dots (log 1) are generally lighter, and apart from Figure 36 closer, corresponding a smaller scattering. Log 1 (yellow) are rather heavier than log 3, but not exceptional stronger. In case of log 2 the spread is relatively big, but at least one of those samples is always the toughest.

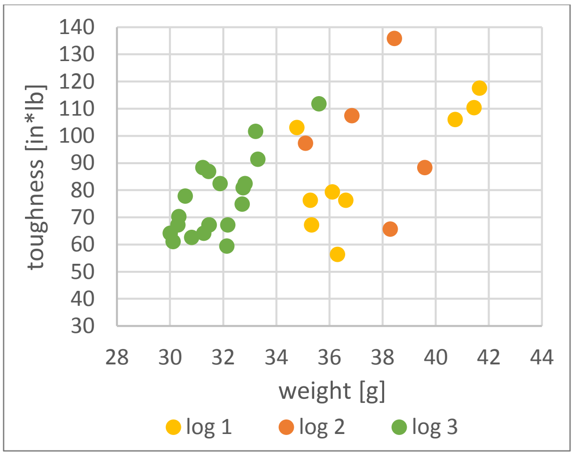


Figure 34: relation of weight and toughness of the different logs for the treatment group not through-bored, not Boultonized (0-0)

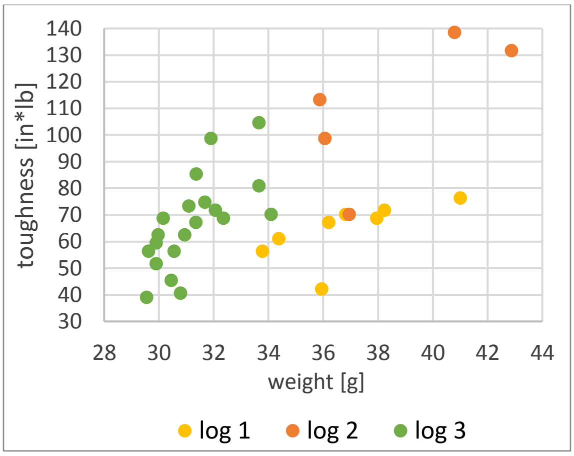


Figure 35: relation of weight and toughness of the different logs for the treatment group through-bored, not Boultonized (1-0)

The charts (Figure 34 - Figure 37) confirm tendencies of varieties between the logs and complement the bar diagrams shown in Figure 32 and Figure 33. There is a divergence from approximately 10 to over 20 grams between the weight of not Boultonized (Figure 34 + Figure 35) and Boultonized (Figure 36 + Figure 37). The figures of the Boultonized show a greater spread than the not Boultonized ones. These differences are determined by the varying absorption capacity of the wood.

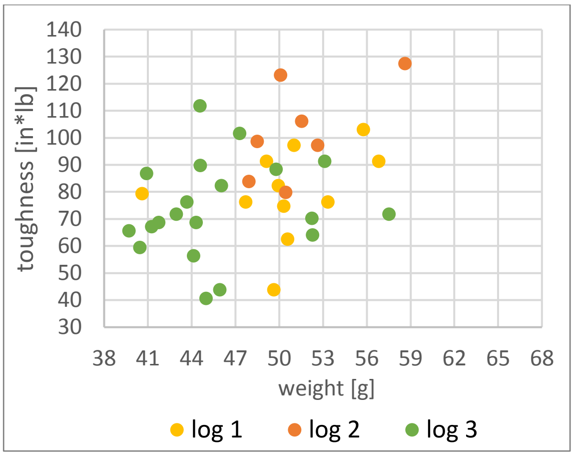


Figure 36: relation of weight and toughness of the different logs for the treatment group not through-bored, Boultonized (0-1)

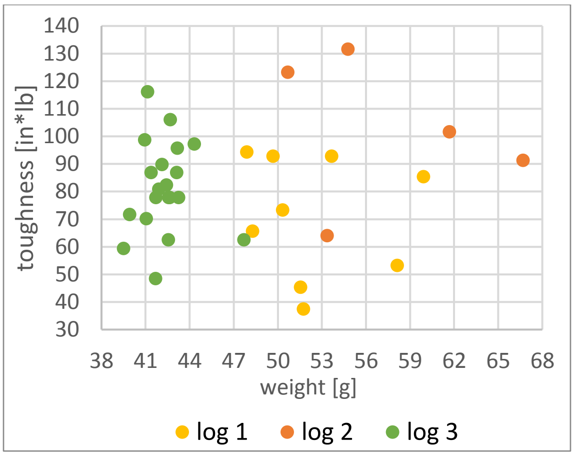


Figure 37: relation of weight and toughness of the different logs for the treatment group through-bored and Boultonized (1-1)

4.2 4-point bending

The series of tests for the Modulus of Elasticity (MOE) are depicted in the same way. The highest outcome for MOE is 13478.75 MPa for one out of the not through-bored, but Boultonized treatment category (0-1) and log 1. The lowest result was 5794.11 MPa for only through-bored (1-0) and log 3. Overall log 2 reached higher scores, followed by log 1 and log 3. The results of the average of all samples show only a small difference between through-bored and not through-bored, but the Boultonized (0-1 + 1-1) achieved better results.

Compared to Haygreen and Bowyer (1996, p. 231) state 1.95 x 10^6 psi for Coast Douglas-fir, which means 13445,25 MPa, the gained result is realistic.

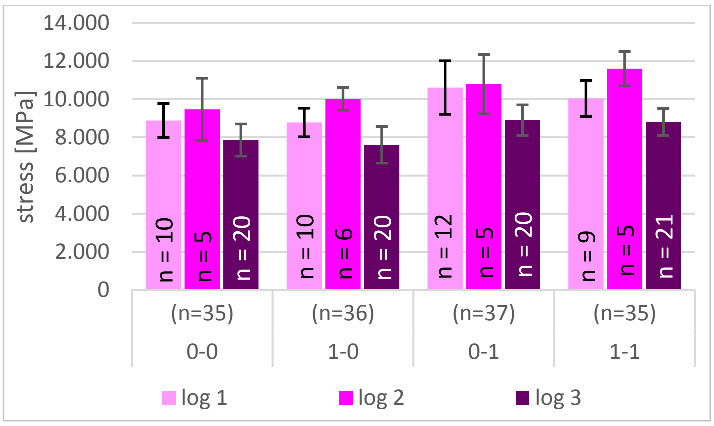


Figure 38: Modulus of Elasticity (MOE) split for every log

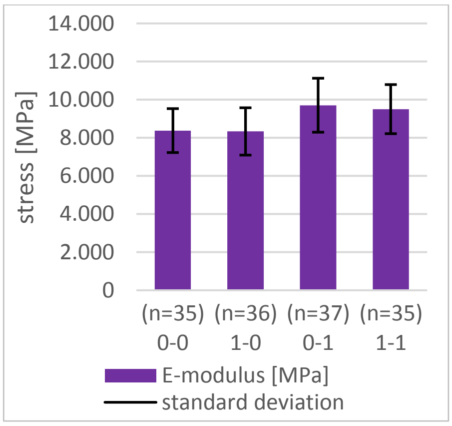


Figure 39: Modulus of Elasticity (MOE) average of all samples

In the case of Figure 40 to Figure 43 the not Boultonized are not as scattered as the treated samples, and again the green dots of log 3 are closer than the values of the other logs. The Boultonized specimens are on average heavier, while log 3 shows generally a lower weight.

The ratio of Figure 40 and Figure 41, the not Boultonized groups, is more linear than the proportion of the under vacuum and heat dried samples.

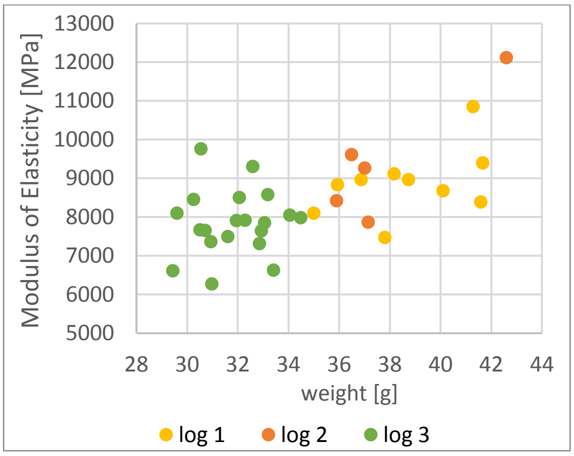


Figure 40: relation of weight and MOE of the different logs for the treatment group not through-bored, not Boultonized (0-0)

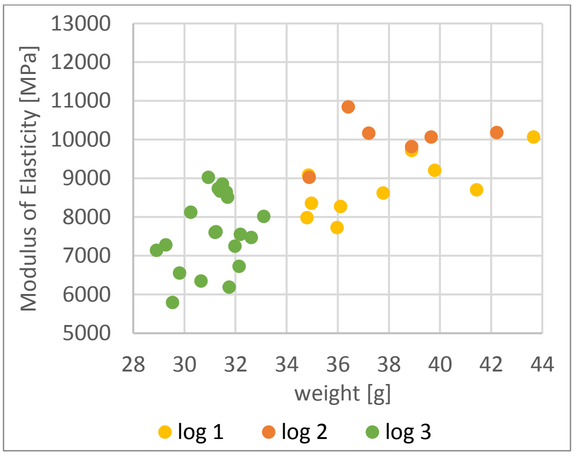


Figure 41: relation of weight and MOE of the different logs for the treatment group through-bored, not Boultonized (1-0)

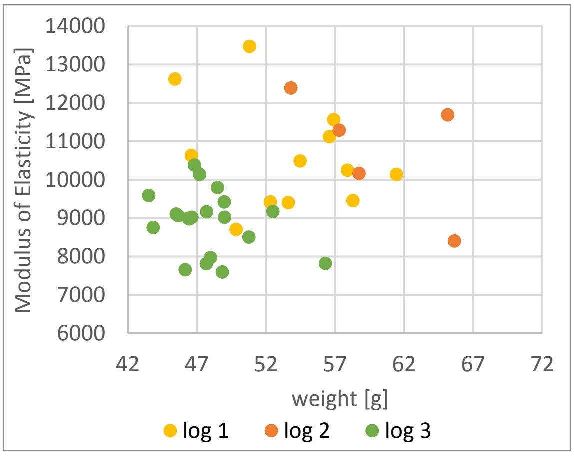


Figure 42: relation of weight and MOE of the different logs for the treatment group not through-bored, Boultonized (0-1)

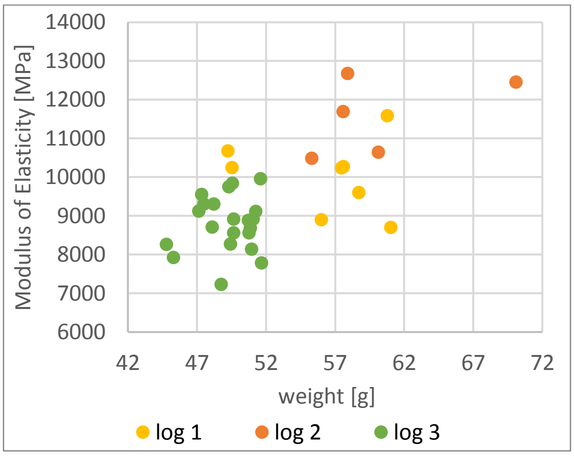


Figure 43: relation of weight and MOE of the different logs for the treatment group through-bored and Boultonized (1-1)

The results for the Modulus of Rupture (MOR) are also split into the three different logs and then also the overall average is shown Figure 45. The minimal and maximal reached values are out of log 3 with 28.04 MPa through-bored and Boultonized (1-1), the maximum of 93.15 MPa for log 1 is through-bored and not Boultonized (0-1). Log 2 performed best with an average of 72.14 MPa, but has also the highest standard deviation. In contrast to that log 3 shows only a small standard deviation, the average maximal stress is only at 56.42 MPa. The model of log 3 mirrors the average outcome best because of the high number of samples (n=20). (cf. Figure 44)

Overall Figure 45 presents differences between Boultonized and not Boultonized as well as varieties between through-bored and not through-bored. Not through-bored, but Boultonized

(0-1) has the highest score with 69.82 MPa, followed by 64.52 MPa for the group without treatment (0-0), through-bored and Boultonized (1-1) yielded 61.35 MPa and only through-bored with 56.14 MPa.

Literature specifies an average value of 12400 psi, 85.498 MPa for the Modulus of Rupture of Coast Douglas-fir. Within the different Douglas-firs the MOR varies between 11900 psi and 13100 psi (82.051 MPa – 90.325 MPa), which is much more than the experiment showed. (Haygreen and Bowyer, 1996, p. 231 + 460)

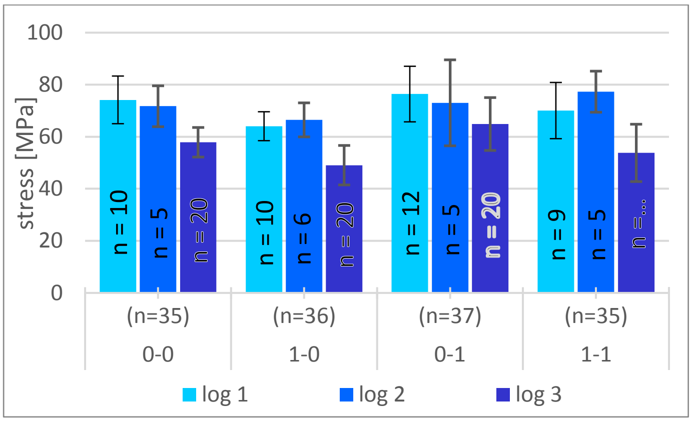


Figure 44: Modulus of Rupture (MOR) for every log

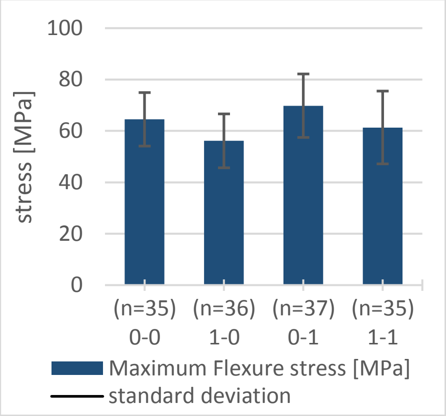


Figure 45: Modulus of Rupture (MOR) average of all samples

The features of the diagrams of the relation of weight and MOR are similar to the ones of the MOE. The not Boultonized categories are not as widely scattered and the ratio between weight and stress looks more linear as the figures of the Boultonized groups and of the testing for Modulus of Elasticity (cf. Figure 46 - Figure 49 and Figure 40 - Figure 43). Log 1 and 2 show higher weights, in average 46.61 g and 49.10 g, log 3 was only 40.02 g.

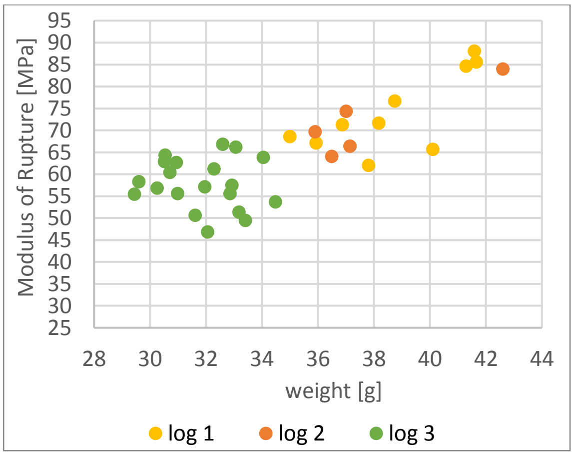


Figure 46: relation of weight and MOR of the different logs for the treatment group not through-bored, not Boultonized (0-0)

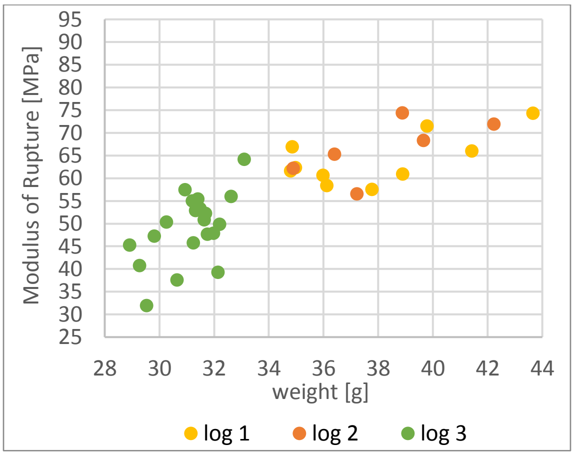


Figure 47: relation of weight and MOR of the different logs for the treatment group through-bored, not Boultonized (1-0)

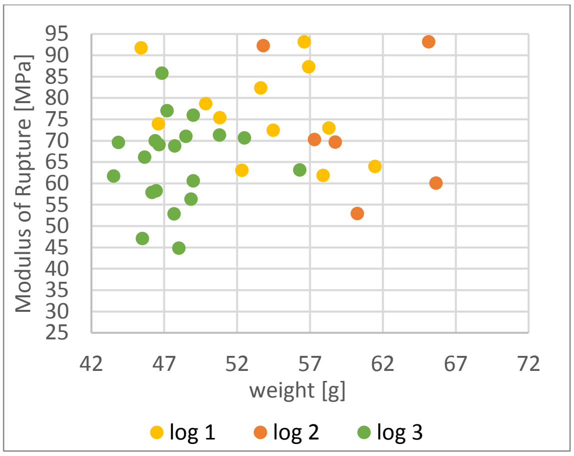


Figure 48: relation of weight and MOR of the different logs for the treatment group not through-bored, Boultonized (0-1)

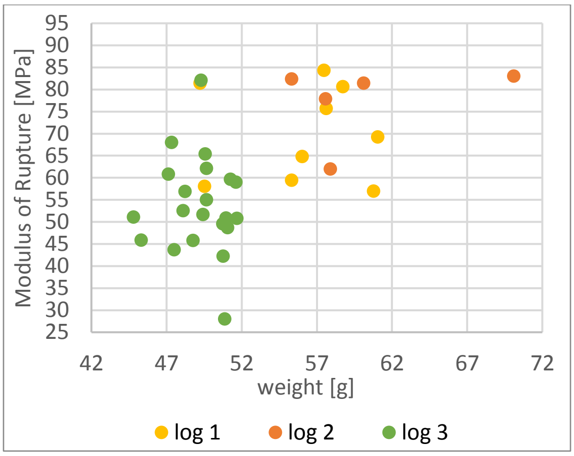


Figure 49: relation of weight and MOR of the different logs for the treatment group through-bored and Boultonized (1-1)

Comparisons of the Boultonized and the not Boultonized categories in the matter of weight and also cross-sectional area are as follows. The overall average of weight is 43.27 g, divided into Boultonized and not Boultonized it is 52.11 g and 34.43 g, that means a difference of 17.68 g. The cross-sectional area is 256.96 mm^2 for the under vacuum dried group, but 259.71 mm^2 for the only seasoned ones.

4.3 additional observations

Figure 50: tension and compression failure during 4-point bending

Figure 51: Diesel comes out of the beam during the testing

Figure 50 shows the failure of one sample, where a tension failure as well as a compression failure can be seen. In general, a tension failure was more common, but also compression failures could be seen, most of the time in combination with tension failures. For the Boultonized samples the Diesel came out of the beam during testing (Figure 51)

4.4 interaction

The generated results were used for a 2-way ANOVA to answer the research question, if there is an interaction of the treatments. The following part describes the findings.

4.4.1 2-way ANOVA for toughness

For the interaction of the effects of the both treatments for toughness the 2-way ANOVA shows a p-value of 0.057, for the Boultonizing it is 0.603 and the interaction of the two is 0.114. (cf. Table 1)

Table 1: 2-way ANOVA; Standardized coefficients for toughness

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
through-bored-1	-0,234	0,122	-1,920	0,057	-0,475	0,007
through-bored-0	0,000	0,000				
Boultonized-1	-0,062	0,119	-0,521	0,603	-0,298	0,174
Boultonized-0	0,000	0,000				
through-bored-1*Boultonized-1	0,234	0,147	1,590	0,114	-0,057	0,526

4.4.2 2-way ANOVA for MOR

Table 2 maps the results for the Standardized coefficients of the 2-way analysis of variance for the Modulus of Rupture. It reaches a p-value of 0.003 for only through-bored samples, 0.069 for only Boultonized ones. The correlation of both is 0.980.

Table 2: 2-way ANOVA; Standardized coefficients for MOR

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Throughbored-0	0,331	0,109	3,025	0,003	0,115	0,547
Throughbored-1	0,000	0,000				
Boltonized-0	-0,203	0,111	-1,833	0,069	-0,422	0,016
Boltonized-1	0,000	0,000				
Throughbored-0*Boltonized-0	-0,003	0,133	-0,025	0,980	-0,267	0,261

4.4.3 2-way ANOVA for MOE

In case of Modulus of Elasticity, the analysis showed results of the single treatments of 0.501 for the through-boring and 0.000 for the Boultonized. Either methods together yielded a p-value of 0.707.

Table 3: 2-way ANOVA; Standardized coefficients for MOE

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Throughbored-0	0,073	0,108	0,674	0,501	-0,140	0,286
Throughbored-1	0,000	0,000				
Boltonized-0	-0,415	0,108	-3,822	0,000	-0,629	-0,200
Boltonized-1	0,000	0,000				
Throughbored-0*Boltonized-0	-0,049	0,131	-0,377	0,707	-0,309	0,210

Apart from the measurements of the Modulus of Elasticity, the through-boring lowered the physical properties. In case of the MOR the influence was very clear with a p-value of 0,003 and a reduction of 13% and for the testing of toughness it was equivocal with a p-value of 0.057 and a reduction of 12%. For these two measurements, there is no evidence for a decrease of physical properties by Boultonizing.

All results tend to show more of an increase by the boiling-under-vacuum process. But here it was noticeable that the average square area was smaller than the one of the not Boulton-dried samples. It is possible that these variations occurred because of the hysteresis effect of wood. The Boultonized samples have been very dry after the boiling-process and were conditioned to a higher moisture content. The other group was seasoned from a high moisture content to a lower one. Because of this the moisture content differ despite of the same relative humidity content.

The Modulus of Elasticity showed different characteristics, probably because its effects on mechanical properties of the moisture content are unlike and it is not as affected by through-boring as the Modulus of Rupture.

No testing result showed proof for an interaction of both treatments with p-values from 0.114 up to 0.980. The Null-hypothesis can not be rejected with the gained results of this project.

In conclusion, these data suggest that there is no need for concern about combining through-boring and Boultonizing treatments for Douglas-fir utility poles. Additionally, the results also bring to mind that commonly applied mechanical property reductions for Boultonizing treatments are not necessary.

5 Outlook

The samples have a quadratic cross-section, they are small-sized and only an attempt to mimic the real poles in a small-sized experiment. The treatments resemble the industrial processes, but there are differences as well. The test structure and arrangement are also only a try to imitate the forces that affect the utility poles in service. Therefore, there are divergences and a laboratory test cannot mirror the problem exactly as it is in real life. Additionally, long-term effects have not been taken into account.

For further research about the utility pole and why they fail it would be interesting to inspect one of these poles. Maybe it gives additional directions why premature flaws occurred and could help to enhance the quality and durability of utility poles in the future.

6 Names and contact details of supervisors in the home and guest institutions

The project supervisor is Adam Taylor of the University of Tennessee, David Harper supported the implementation of the tests. The study is prepared for Brian Flynn of the Southern California Edison Company and for Jeff Lloyd of the Nisus Corporation.

The preparation and trials were carried out in the premises of the University of Tennessee in Knoxville and the toughness-testing was run at the University of Alabama in Auburn.

University of Tennessee:	Salzburg University of Applied Sciences:
Prof. Dr. Adam Taylor *Tennessee Forest Products Center* *2506 Jacob Drive* *Knoxville, Tennessee 37996* *e-mail: AdamTaylor@utk.edu*	*FH-Prof. Univ.-Prof. Dr.-Ing. Dr. Marius-Catalin Barbu* *Campus Kuchl - Raum: Kuchl - 1.01* *Markt 136a* *A-5431 Kuchl* *e-mail: marius.barbu@fh-salzburg.ac.at*
Prof. Dr. Timothy M. Young *Forest Products Center* *Department of Forestry, Wildlife and Fisheries* *University of Tennessee Agricultural Campus* *2506 Jacob Drive* *Knoxville, TN 37996-4750* *e-mail: tmyoung1@utk.edu*	

7 Lists

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7.2 list of figures

7.3 list of tables