# Fundamental Wood Properties of Clones Grafted with Plus-Trees of *Abies sachalinensis* MASTERS (II) : Clonal Differences in Some Chemical Components of Thinned Wood from a Seed Orchard in the Forest Tree Breeding Experimental Station of Hokkaido University

by

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# 種々のトドマツ精英樹からつぎ木されたクローンの基礎材質（II）
## ―― 北大林木育種試験場採種園間伐木の化学成分のクローン間変異 ――

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**Abstract**

A comparative investigation was carried out between the chemical composition and physical properties of wood using thinned wood from an *Abies sachalinensis* MASTERS seed orchard in the Forest Tree Breeding Experimental Station of Hokkaido University. The materials used were 225 samples of 46 clones of the heartwood and 58 samples of 12 clones of the sapwood. The following components were investigated : ① hot water solubles, ② 1%NaOH solubles, ③ ethanol-benzene solubles, and ④ ash content. The maximum values of each respective component in the heartwood were as follows : ① 6%, ② 20%, ③ 6%, and ④ 2%. The maximum values of the components in the sapwood were approximately half of those in the heartwood, except for ① and ②. The results of analysis of variance of clonal differences in each the component showed significant differences for ③ and ④ (1% level) in the heartwood, and ①, ③ (0.1% level), and ④ (5% level) in the sapwood. Although there was no significant correlation between the components in the heartwood and sapwood ($r<0.18$), a significant correlation was seen between all the components in the heartwood. As for the moisture content of fresh wood, while a significant correlation was seen between the moisture content and the respective components in the heartwood, no significant correlation was seen in sapwood, although there was a significant correlation between the moisture content in the sapwood and ①, ②, and ④ in the heartwood.

**Key words** : *Abies sachalinensis* MASTERS, Wood properties, Chemical composition, Heartwood, Moisture content, Correlation

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## 1. Introduction

The total area of artificially afforested land in Hokkaido is approximately 1,450,000 ha, with over half occupied by *Abies sachalinensis* MASTERS, which is native to Hokkaido. The wood of *A. sachalinensis* MASTERS is soft, both the sapwood and heartwood are yellow, and the grain is straight. Although the wood is an important material for construction, there are limitations in its use due to several defects in the quality of the wood.

Seed orchards have been set up in Japan since 1956, with the aim of producing genetically superior seeds. The process of new seed development, based on "Forest Tree Breeding Operational Guidelines" (7), involves the selection of plus-trees, and then grafting the plus-trees. The aim of forest tree breeding operations is to develop the trees with improved growth and improved resistance to damage by blight and noxious insects, as well as improved wood quality.

Seed orchards have been operating for many years, and thinning operations have been carried out. There have been several reports on the characteristics of plus-tree wood based on samples of wood thinned from seed orchards : wood characteristics and genetic variations of *Cryptomeria japonica* D. DON (1), wood characteristics of *Larix kaempferi* LAMBERT (7), and chemical composition of *Pinus densiflora* SIEB. et ZUCC. and *P. thunbergii* PARLATORE (6). However, apart from the reports by KATAYOSE and others (3~5), there have been very few studies on the wood properties of different clones of *A. sachalinensis* MASTERS. KADOMATSU *et al.* (1994) reported on the physical properties of wood, especially the basic density, of clones grafted with plus-trees of *A. sachalinensis* MASTERS, using trees thinned from the seed orchard in the Forest Tree Breeding Experimental Station of Hokkaido University. In the present study, investigation was focused on the chemical properties of trees thinned from the same seed orchard. Although the thinned trees were young trees, and the seed orchard used in this study may be considered different to general artificially afforested land areas due to the focus on fertilization, drainage, soil improvement and the spraying of agricultural chemicals which is necessary for the production of seeds, the samples of grafted tree clones are considered to be genetically identical, and statistical analysis of the wood properties is possible. The purpose of this study is to clarify the clonal difference in the chemical properties of *A. sachalinensis* MASTERS.

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## II. Materials and methods

The wood samples were obtained from the *A. sachalinensis* MASTERS seed orchard in the Tree Breeding Experimental Station of Hokkaido University, located in Nayoro. The experimental station has a total land area of 20 ha, a temperature range of −35.7~34.5°C (mean 5.1°C), a mean annual precipitation of 1,000 mm and a maximum snowfall of 150 cm. The soil is composed of thick peat, but the surface soil has been mixed with river sand. Grafted tree saplings were made from plus-trees selected mainly from the Hokkaido

University Experimental Forests, and after being raised in a nursery for several years, 1,600 trees per ha were planted in a seed orchard in 1971 by the usual 49-tree (7×7) method.

In April 1993, thinning was carried out in every second row. The thinned trees were 28 years old, by calculating from the time they were grafted (Table 1). The materials, as shown in Table 1, included 225 trees (3~5 repetitions of 46 clones), and small disk-shaped samples were taken from each tree at breast height. Data of tree heights and breast height diameters were taken from the study by KADOMATSU *et al.* (2). A total of 225 samples of 46 clones were obtained from all of the heartwood samples (named heartwood simply), and 58 samples of 12 clones were selected from some of the sapwood samples (named sapwood simply) at random, and experiments were carried out in February to September 1994.

**Table 1.** Number of clones and samples of *Abies sachalinensis* MASTERS plus-trees heartwood and sapwood

| Factor | Clones | Samples within clone | Samples |
|---|---|---|---|
| Heartwood | 46 | 3 ~ 5 | 225 |
| Sapwood | 12 | 3 ~ 5 | 58 |

For chemical analysis, the samples were first crushed and divided into 40~80 and 80~100 mesh sizes. For the ash content, 80~100 mesh sized wood particles were burned at 600°C after oven drying at 105°C, and the weight of the residue was measured. For hot water extraction, air-dried wood particles of 40~80 mesh size were boiled in distilled water for 2 hours, and the amount of the extract was measured from the oven-dried weight of the residual wood. For alkali extraction, 40~80 mesh sized wood particles were boiled for in a 1% sodium hydroxide water solution for 1 hour, and the amount of the extract was measured from the oven-dried weight of the residue. For alcohol-benzene extraction, air-dried wood of 40~80 mesh size were extracted with a solution of 1 part ethanol : 2 parts benzene for 6 hours using a Soxhlet extractor, and the amount of the extract was measured from the oven-dried weight of the residue.

## III. Results and discussion

### 1. Percentages of extracts and ash

Table 2 shows a summary of the percentages of extracted components obtained by hot water, alkali, and alcohol-benzene extraction and the ash content for both heartwood and sapwood samples according to clone. The mean percentage of hot water extracts in heartwood was 4.11%, with a maximum of 5.92% and minimum of 1.20%. The mean, maximum and minimum percentages of the alkali extracts in heartwood were 16.30%, 20.37% and 10.89% of the total weight of samples, respectively. The mean, maximum and minimum percentages of alcohol-benzene extracts in heartwood were 4.07%, 6.32%, and 1.71%, respectively. The mean, maximum and minimum percentages of the ash content in heartwood were 1.18%, 2.03% and 0.62%, respectively. Except for the alkali solubles (coefficient of variation=11%), the amount of each component extracted from the heartwood samples was small, and the coefficient of variation was around 20%.

Percentages of the extracted components from the randomly selected 58 samples (12 clones) of sapwood are also shown in Table 2. Percentages of hot water extracts were 3.14% (mean), 4.55%(maximum), and 1.78% (minimum), which were slightly smaller than those from heartwood. Percentages of the alkali extracts were 18.07% (mean), 20.44% (maximum) and 15.65% (minimum). The mean percentage was 2% higher than that for

**Table 2.** Chemical components (expressed as percentages of oven-dried wood weights) of clones (Average / Range)

| Factors | Solubles (%) Hot water | SD | CV | Alkali | SD | CV | A.B. | SD | CV | Ash | SD | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heartwood | 4.11 / 1.20~5.92 | 0.78 | 19 | 16.30 / 10.89~20.37 | 1.84 | 11 | 4.07 / 1.71~6.32 | 1.03 | 23 | 1.18 / 0.62~2.03 | 0.29 | 20 |
| Sapwood | 3.14 / 1.78~4.55 | 0.69 | 22 | 18.07 / 15.65~20.44 | 1.13 | 6 | 2.03 / 1.29~2.68 | 0.35 | 17 | 0.68 / 0.39~1.04 | 0.15 | 22 |

Notes : SD=Standard deviation. CV=Coefficient of variation.
Alkali=1% NaOH extracts. A.B.=Ethanol-benzene extracts.
Hot water=Hot water extracts. Ash=Ash (% of oven-dries wood).

heartwood, and the maximum and minimum values were also slightly higher. Percentages of the alcohol-benzene extracts were 2.03% (mean), 2.68% (maximum) and 1.29%(minimum). The mean percentage was only half that of heartwood, and the maximum percentage was approximately 40% that of heartwood. Percentages of the ash content were 0.68% (mean), 1.04%(maximum) and 0.39% (minimum). The mean, maximum and minimum percentages were all approximately only half those of heartwood.

SATONAKA (8) investigated the percentages of extracts and the ash content using these 4 experimental procedures in *A. sachalinensis* MASTERS and *A. sachalinensis* var. *mayriana* MIYABE et KUDO without dividing the samples into clone groups or heartwood and sapwood groups for analysis. His results showed that the mean values of hot water extracts, alkali extracts, alcohol-benzene extracts, and ash were 3.8%, 12.6%, 2.1%, and 0.38%, respectively. The values reported by SATONAKA are lower than those in this study for heartwood but similar to the percentages for sapwood.

## 2. Analysis of variance and repeatability between different clones of each extractive and ash.

Table 3 shows the results of analysis of variance between different clones for the extracts by hot water, alkali and alcohol-benzene extraction, and the ash in heartwood and sapwood. The data were converted to $\mathrm{Sin}^{-1}\sqrt{x}$. The sapwood hot water and alcohol-benzene extracts showed a significant difference at the 1% level among clones, and the sapwood ash content showed a significant difference at the 5% level among clones. Heartwood alcohol-benzene extracts and ash content showed significant differences at the 1% level for each clone. These results show that there is a significant difference between clones for components with a small content such as alcohol-benzene

**Table 3.** Differences in heartwood and sapwood between each clone

| Factors | Variation of clones: Heartwood | Variation of clones: Sapwood | Repeatability ($R^2$): Heartwood | Repeatability ($R^2$): Sapwood |
|---|---|---|---|---|
| d.f | 45 | 11 | | |
| Hot water | ns | *** | 0.10 | 0.44 |
| Alkali | ns | ns | 0.01 | 0.09 |
| A.B. | ** | *** | 0.18 | 0.45 |
| Ash | ** | * | 0.19 | 0.20 |

Notes : Factors are the same as those in Table 2.
*, **, *** =Significant at the level of 5%, 1%, and 0.1%, respectively. ns=Non significant. d.f=Degree of freedom.

extracts and ash, but no significant difference between clones for components with a large content such as alkali extracts.

The repeatability for each extract, which is regarded as the heritability in a broad sense is calculated in Table 3. The repeatability was small in most cases except for those of sapwood hot water and alcohol-benzene extracts, which were 0.44 and 0.45, respectively. The repeatability of alkali extracts in both heartwood and sapwood was very small at 0.01 and 0.09, respectively, suggesting there was little effect from genetic factors. As the main extracts with alkali are thought to be starch and soluble hemicellulose, they may be easily affected by environmental factors.

### 3. Correlation between two selected components

Table 4 shows the correlation between extracted components in heartwood and sapwood. A significant correlation was not seen in any of the extracts and ash between heartwood and sapwood ($r<0.18$). Although, the amount of the alkali extracts were greater in heartwood than in sapwood, there was no significant correlation between those in heartwood and sapwood. Table 5 shows the physical characteristics of the plus-tree clones used in our study (data reported and described in a previous paper by KADOMATSU *et al*, (2)), which show a significant correlation between those in clones. Tables 6 and 7 show the correlation between the physical characteristics of plus-tree clones and the chemical components investigated in this study.

The results in Table 6 show there was a significant correlation between the moisture content in heartwood and the amounts of hot water, alkali, and alcohol-benzene extracts and ash content in heartwood. The trees of *A. sachalinensis* MASTERS contain a great deal of water, and especially a part of the

**Table 4.** Correlations between heartwood and sapwood

| Factors | r |
|---|---|
| Hot water | 0.151 |
| Alkali | 0.031 |
| A.B. | 0.184 |
| Ash | 0.047 |

Notes : Factors are the same as those in Table 2. Number of samples=58.

**Table 5.** Wood properties of each clone (225 samples of 46 clones) $\left(\frac{\text{Average}}{\text{Range}}\right)$

| Factors | Basic density (kg) | Average annual ring width (mm) | Moisture content (%) | YOUNG's modulus (t/cm²) | Height (m) | DBH (cm) |
|---|---|---|---|---|---|---|
| Heartwood | 342 / 275~425 | 3.9 / 2.2~6.4 | 141 / 63~224 | | | |
| Sapwood | 346 / 278~459 | 3.9 / 2.1~6.5 | 189 / 131~252 | | | |
| Total | 342 / 276~427 | 3.9 / 2.4~5.6 | 165 / 63~252 | 86 / 45~136 | 6.9 / 3.5~9.1 | 13.3 / 6.1~20.4 |

Note : DBH=Diameter breast height.

**Table 6.** Correlation between different properties I (225 samples of 46 clones)

| Factors | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Heights | | ** | ** | ** | ** | ** | ** | ** | * | ** | * | ns | ns | ns | ns |
| 2 DBH | | | ** | ** | ** | ** | ** | ** | ns | ** | ns | ns | ns | ns | ns |
| 3 BD-H | | | | ** | ** | ** | * | ** | ** | ** | ns | ns | ns | * | ** |
| 4 BD-S | | | | | ** | ** | ** | ** | ** | ** | ns | ns | ns | ns | ns |
| 5 BD-T | | | | | | ** | ** | ** | ** | ** | ns | ns | ns | ns | ** |
| 6 ARW-H | | | | | | | ** | ** | * | ** | ns | ns | ns | ns | ns |
| 7 ARW-S | | | | | | | | ** | ns | ** | ns | ns | ns | ns | ns |
| 8 ARW-T | | | | | | | | | * | ** | ns | ns | ns | ns | ns |
| 9 MC-H | | | | | | | | | | ** | ns | ** | * | ** | ** |
| 10 MC-S | | | | | | | | | | | ns | ns | ns | ns | ns |
| 11 YOUNG's moduli | | | | | | | | | | | | ns | ns | ns | ns |
| 12 HWS-H | | | | | | | | | | | | | ** | ** | ** |
| 13 AS-H | | | | | | | | | | | | | | ** | ** |
| 14 ABS-H | | | | | | | | | | | | | | | * |
| 15 Ash-H | | | | | | | | | | | | | | | |

Notes : BD=Basic densities. ARW=Annual ring widths. MC=Moisture contents. HWS=Hot water solubles. AS=1% NaOH solution solubles. ABS=Ethanol -benzene solubles. H=Heartwood. S=Sapwood. T=total. *,**,***= Significant at the level of 5%, 1% and 0.1%, respectively. ns=Non significant. DBH=Diameter breast height.

**Table 7.** Correlation between different properties II (58 samples of 12 clones)

| Factors | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Heights | | ** | ns | ns | ns | ** | ** | ** | ns | ns | ns | ns | ns | * | ns | ns | ns | ns | ns |
| 2 DBH | | | ns | * | ns | ** | ** | ** | ns | ns | ns | ns | * | ns | ns | ns | ns | ns | ns |
| 3 BD-H | | | | ** | ** | ns | ns | ns | * | ** | ns | ns | ns | ns | ns | ns | ns | ns | ** |
| 4 BD-S | | | | | ** | * | ** | ** | ns | ** | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| 5 BD-T | | | | | | ns | ns | * | ** | ** | ns | ns | ns | ns | ns | ns | ns | * | ** |
| 6 ARW-H | | | | | | | ** | ** | ns | ns | * | ns | ns | ns | ns | ns | ns | ns | ns |
| 7 ARW-S | | | | | | | | ** | ns | * | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| 8 ARW-T | | | | | | | | | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| 9 MC-H | | | | | | | | | | ** | ns | ** | ns | * | ns | ** | ns | ** | ns |
| 10 MC-S | | | | | | | | | | | ns | * | ns | * | ns | ns | ns | * | ns |
| 11 YOUNG's moduli | | | | | | | | | | | | ns | ns | ns | * | ns | ns | ns | ns |
| 12 HWS-H | | | | | | | | | | | | | ns | ** | ns | ** | ns | ns | ns |
| 13 HWS-S | | | | | | | | | | | | | | ns | ns | ns | * | ns | ns |
| 14 AS-H | | | | | | | | | | | | | | | ns | ** | ns | ns | ns |
| 15 AS-S | | | | | | | | | | | | | | | | * | ns | ns | ns |
| 16 ABS-H | | | | | | | | | | | | | | | | | ns | * | ns |
| 17 ABS-S | | | | | | | | | | | | | | | | | | ** | ns |
| 18 Ash-H | | | | | | | | | | | | | | | | | | | ns |
| 19 Ash-S | | | | | | | | | | | | | | | | | | | |

Note : Factors are the same as those in Table 6.

trunk has a very high moisture content, called wetwood, which has a low basic density and the wood is weak. The fact that there is a significant correlation between the moisture content and ash content in heartwood (r=0.5422) suggests that the wood with a large amount of water has a high ash content.

## 4. Discussion

It is thought that trees which have a high moisture content in heartwood contain reading water-soluble components in the surrounding regions. The materials are extracted with hot water. While inorganic substances in the tree are absorbed from the soil through the roots, the main hot water extracts are composed of starch, resin and essential oil, the main alkali extracts are a part of hemicellulose, starch, and resin and essential oil, and the main alcohol-benzene extracts are resin, and essential oil, flavonoidos, and so forth. These materials are all closely inter related, and the moisture content in heartwood is significantly correlated with heartwood hot water, alkali and alcohol-benzene extracts, and heartwood ash content. Heartwood hot water extracts are significantly correlated with heartwood alkali and alcohol-benzene extracts, and its ash. Significant correlations are also seen between each of the heartwood alkali extracts, heartwood alcohol-benzene extracts, and heartwood ash content, and between heartwood alcohol and benzene extracts and heartwood ash content. Thus, there are clear correlations between all the extracted components in heartwood.

The correlations shown in Table 6 can also be seen in Table 7. Significant correlations were seen between the moisture content in heartwood and each extracted component in heartwood in the 58 samples of 12 clones. However, significant correlations were not seen between the moisture content in sapwood and each extracted component in sapwood. Also, few significant correlations were seen between each extracted component in sapwood.

Thus, the results of this study have clarified that the moisture content is closely related to each extracted component and ash content in heartwood but not in sapwood.

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## 要　　約

北海道大学演習林のトドマツ採種園間伐材を用いて，木材の抽出成分の収率を物理的性質と比較検討した。材料は 46 クローン 225 個体の心材と，12 クローン 58 個体の辺材で，①温水抽出物，②アルカリ抽出物，③アルコール・ベンゼン抽出物，④灰分の 4 つについて調査した。心材の各抽出物の収率の最大値をみると，②は 20%と大きく，①は 6 %，③は 6 %，④は 2 %であった。辺材は①②を除いて，心材の約 1/2 であった。各抽出物収率のクローン間変異の分散分析では，心材で③④が 1 %水準，辺材では①③が 0.1%，④が 5%水準で有意であった。心材と辺材の抽出成分の相関は r＝0.18 以下で，有意な相関はみられなかった。心材の抽出成分は互いに有意な相関があり，心材含水率は心材の①～④と有意な相関があったが，辺材含水率は辺材の①～④と有意な相関はなく，心材の①②④と有意な相関があった。