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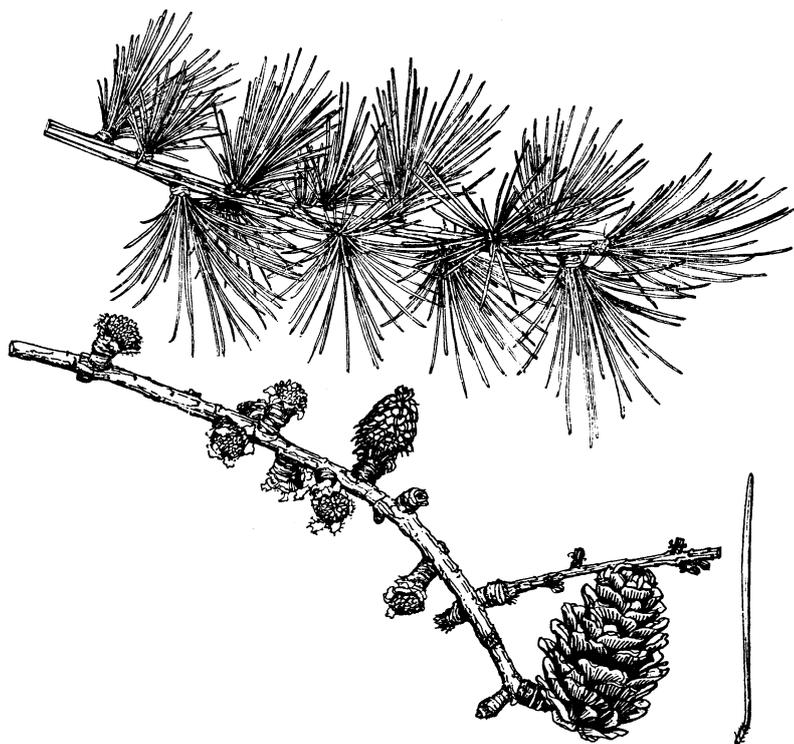
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LARCH WOOD



a literature review conducted for
The Nordic Forest Research Co-operation Committee (SNS)

Project no. SNS 80, March 2003

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1:

Use and availability of Larch wood in Northern Europe

- a literature review

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1. Introduction

During 2003-2005 a research project with the title: “The potential of Larch wood for exterior use” is being conducted, with financial support from the The Nordic Forest Research Co-operation Committee (SNS). The participating countries in the research project are Denmark, Finland, Iceland, Lithuania, Norway and Sweden. The experimental work in the research project is divided into two main tasks. One task is concerned with the assessment of basic properties of non-weathered small wood samples. The second task deals with the weathering properties of structural size boards in exterior use, primarily the water uptake. In all the participating countries, some research and experiments with larch wood have been performed recently. However, the efforts are scattered and the results are difficult to compare for the following reasons:

- Different species of larch have been studied.
- The trees have been grown and used under very different conditions.
- Many of the results have been obtained, interpreted and published locally and are not easily accessible.

As a precursor of the joint Nordic/Baltic research project, the present literature survey has been conducted. The purpose of this preliminary project is to create a common basis for the research project by gathering the literature available on larch wood and make a review of the most relevant information concerning the use of larch in northern Europe.

The research project will be focusing on larch wood in exterior use above ground, but in order to describe the complexity within the genus *Larix*, information on larch in ground contact will be presented in this study as well.

1.1 Background

Larches comprise one of the most abundant genera in the boreal forest areas on the northern hemisphere. They are dominating in Siberia, very common in the rest of Russia and furthermore naturally distributed in China, Mongolia, Japan, North America and Central Europe.

Several species of larch have the ability to grow at high altitudes and far north. Actually, Dahurian larch is the wood-species in the world that grows on the highest degree of latitude. Furthermore, larch is fast growing, at least in the juvenile stage, but the growth culminates rather early. The growth potential of larch will be examined thoroughly in a later chapter.

Although larch is widespread in Northern Europe, it makes up only a small percentage of the total forest area. But why is larch not used and grown to a larger extent in northern Europe? According to Dansk Skovforening (1997), some of the reasons are:

- The red heartwood makes the wood look different, compared to Norway spruce or pine.
- The by-product (wood chips) from the processing sells at a lower price to the pulp industry, because of the coloured heartwood.
- The working properties differ from the primary species (Norway spruce), and the drying process is different, which means that it cannot be processed together with Norway spruce.

Other reasons could be:

- Foresters consider the growth to be too slow.
- Bad stem-form, growth stresses and checking.
- Deformations during drying.
- Root rot (*Heterobasidion annosum*)

Recently, more interest has been taken in larch because of a larger focusing in general on environmental properties. Larch wood is an environmentally compatible product, which in many uses can function as an alternative to chemically treated wood. Its natural durability has come even more in focus, as many of the wood preservatives have been taken off the market.

Larch is a pioneer-species. It is very easy to grow and reaches fairly large dimensions very quickly. The formation of heartwood begins at a very early age, and Larch has therefore, even at a relatively young age, a large proportion of heartwood, which makes it useable at places where chemically treated wood earlier was used. These properties make larch superior to many alternative species.

What in particular makes larch interesting is:

- The strength and durability of the wood
- A high volume production in the juvenile phase and a potential for continued production even in very long rotations.
- A positive effect on the soil
- A positive effect on the landscape
- A high resistance to root rot (*Heterobasidion annosum*)

This study will primarily be focusing on the use and the technical properties of larch wood and less on the methods of cultivation and the effect on soil and landscape. However, since these subjects are difficult to separate completely, some information on growth will be presented in the study.

The good technical properties of larch have been known and appreciated for many years. Dahll (1892) wrote about the highly esteemed technical properties of the European larch and referred to its durability, strength, toughness and especially its fast growth. Still, Dahll believed that there was an even greater potential in the Siberian larch, and that bringing in such a fast growing species of extremely good quality would be a good way to get a higher yield from the forest. These statements are today more relevant than ever.

1.2 The need for research

Since the 1930's a good deal of effort has been put into provenance selection and breeding of larch, especially in Denmark and France. Still, larch is only being used on a very limited scale in the Nordic forestry, and among the European countries only France seems to have continued the breeding work. But new provenance trials with Siberian larch are under way, following import of seed from a variety of sites after the cease of the Soviet Union. Together with results of older and ongoing breeding work, those new efforts probably will ensure the availability of valuable planting stock in the future.

Larch wood, however, is still relatively unknown in the Nordic and Baltic countries, and research has concentrated on silvicultural issues. The wood properties and their range of variation are relatively unknown, and among users the properties of larch are often mixed up with those of similar heartwood forming conifers, e.g. Douglas fir or Scots pine. Therefore, more research on the technical properties of larch is needed, especially on two areas:

1. Form stability / deformations of the wood during sawing and drying, in relation to species, provenance and processing technology.
2. The durability of the wood when used above ground.

Borsholt et al. (1995) in their report on the influence of building design upon wood durability, summarized the literature available in Sweden, Germany, Switzerland, Holland, Norway and England, but found very little documentation on durability of wood above ground. Although some experiments have been initiated during recent years, more research is needed in this field, in particular if larch wood is going to be used extensively as an alternative to pressure impregnated wood.

2. Taxonomy of larch

It is known that larch was present in Scandinavia just after the last Ice Age. Though, for natural reasons larch disappeared from Scandinavia in prehistoric time, only to be reintroduced by humans in the middle of the 18th century. Since then several larch species have been introduced in the Nordic countries by humans.

Larch is a pioneer tree. It grows mostly in mixture with other species and does not reproduce itself in closed forests. The rejuvenation is adjusted to forest fires – therefore the thick bark. In East Siberia trees with thin bark adjusted to permanent frost can be found (*L. gmelinii* and *L. cajanderii*).

Over the years there have been different opinions of how many larch species the genus comprises, and to some extent there still are. Though, today it is accepted that the genus consists of at least 10, probably 11, species. It is found relevant to list all the larch species below although only some of them are of importance or potential future relevance to the northern European market. Although *Larix x eurolepis* is not a species, it is an interesting, relevant and rather successful hybrid worth mentioning in this context, and it is therefore included in the list as well. A couple of varieties (*Larix sukaczewii* Dyl. and *Larix cajanderi* Mayr.) are also included, as these represent the matters of disagreement.

2.1 Description of the larch species

Table 2.1 The different species in the genus *Larix*

Name in Latin:	Synonym:	Name in English	Distribution:
<i>Larix decidua</i> Mill	<i>Larix europaea</i> Lam. et D. C.	European larch	Central Europe
<i>Larix sibirica</i> Ledeb. <i>Larix sukaczewii</i> Dyl.	<i>Larix russica</i> (Endl.) Sabine	Siberian larch Russian larch	NE Russia to Siberia, C Asia
<i>Larix gmelinii</i> (Rupr.) Rupr. <i>Larix cajanderi</i> Mayr.	<i>Larix dahurica</i> Trautv.	Asian larch	Siberia, China, Mongolia
<i>Larix laricina</i> (Du Roi) K. Koch	<i>Larix americana</i> Michx.	Tamarack	North America
<i>Larix kaempferi</i> (Lamb.) Carr.	<i>Larix leptolepis</i> (Sieb & Zucc) E.	Japanese larch	Japan - Central Honshu
<i>Larix griffithiana</i> Carr.		Sikkim larch	E Himalayas
<i>Larix potaninii</i> Batalin	<i>Larix chinensis</i> Beissn.	Chinese larch	China
<i>Larix mastersiana</i> R. et W.		Masters larch	Western China
<i>Larix lyallii</i> Parl.		Subalpine larch	NW America
<i>Larix occidentalis</i> Nutt.		Western larch	NW America
<i>Larix x eurolepis</i> A. Henry	<i>Larix decidua x kaempferi</i>	Dunkeld larch	



Fig 2.1 Natural area of distribution of the ten species:
 1=*L. laricina*, 2=*L. occidentalis*, 3=*L. decidua*, 4=*L. sibirica*, 5=*L. gmelinii*,
 6=*L. potanii*, 7=*L. griffithiana*, 8=*L. kaempferi*, 9=*L. mastersiana*, 10=*L. lyallii*

2.1.1 *Larix decidua* (European larch):

The natural area of distribution of *L. decidua* is rather small (Fig. 2.2). The largest connected area is found in the Alps and smaller areas in the Carpathians, the Sudeten Mountains and the south-west of Poland. Most studies agree that European larch includes five geographical races, often considered to be subspecies or varieties;

- I. *Larix decidua* var. *decidua* – Alpine larch
- II. *Larix decidua* var. *sudetica* – Sudetic larch
- III. *Larix decidua* var. *tatrensis* – Slovakian larch
- IV. *Larix decidua* var. *polonica* – Polish larch
- V. *Larix decidua* var. *pendula*

Others as Farjon (1990) divide it into only three varieties; var. *decidua*, var. *polonica* and var. *carpatica*.

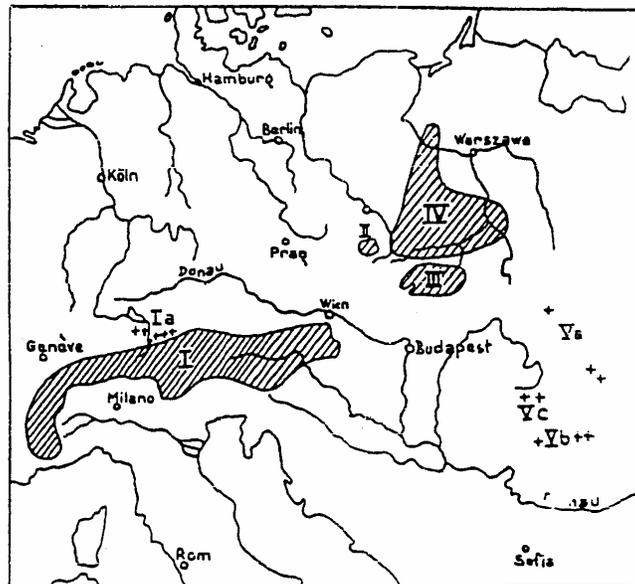


Figure 2.2 Natural area of distribution of *Larix decidua*

The Alpine larch has the largest area of distribution: from France in the West to Slovenia in the East, and is therefore in some literature referred to as the common European larch. *Larix decidua* var. *polonica* is distinguished from the Alpine larch by smaller and shorter cones with more rounded seed scales. Its natural area of distribution is between Krakow and Warsaw and towards north-east (Farjon 1990). It is a lowland tree and is by some looked upon as a species of its own (Bornebusch 1948). There seems to be a big difference between the alpine larches south of the Donau and the larches north of the Donau; the latter being more resistant both to larch canker and frost damages (Bornebusch 1948).

In some literature the Scottish larch is mentioned. It is believed that this originally comes from the western part of the alpine origin, and that it is adapted to the Scottish growth conditions. It is resistant to neither hard frost nor larch canker, why Bornebusch (1948) recommends not using the larch from Scotland, at least not in Denmark. One should instead stick to seeds from the area of the Carpathians and the Sudeten Mountains or the Polish provenance.

The international Larch Provenance trial of 1944/45 in West-Norway showed that the larches from the Sudetian and Tatra areas have the widest potential culture area, but they needed sheltered sites to ensure a straight stem (Robak 1982a).

Danish researches show that the best results are provided by the provenances from Poland and the Sudeten Mountains, as well as second-generation Danish sources (Brandt 1977; Bornebusch 1948). Especially the provenance from Blizyn (Brandt 1977) and Sarzysko areas combine good growth and form with good resistance towards larch canker, while the Chelmowa Góra in Poland as well as in Denmark shows rather poor stem form (Bornebusch 1948).

2.1.2 *Larix sibirica* (Siberian larch):

L. sibirica has a large distribution, from the White Sea in NE Russia to Lake Baikal in Siberia, N to 69° - 70°15' near the mouth of the Yenisei, S to the Altei Mountains (45° - 46° N), as well as in N Mongolia and NW China (Farjon 1990) (Fig. 2.3).

There is an element of uncertainty whether or not *L. sukaczewii* is a separate species of *L. sibirica*. The two show great similarities, but Dylis (1947) suggested after intense cone-morphological studies that *Larix sukaczewii* should be considered a separate species (Blomqvist 1988; Karlman 1998). However, Farjon (1990) does not describe *L. sukaczewii* as a separate species, and we therefore choose to describe it only as a geographical variety of *L. sibirica*. *L. sukaczewii* has its natural area of distribution in the northern part of Russia and Asia between the Ural Mountains and the river Ob, and from the latitude 52°-68°N. It is also known as Russian Larch, or if grown in Finland as "Raivola" larch.

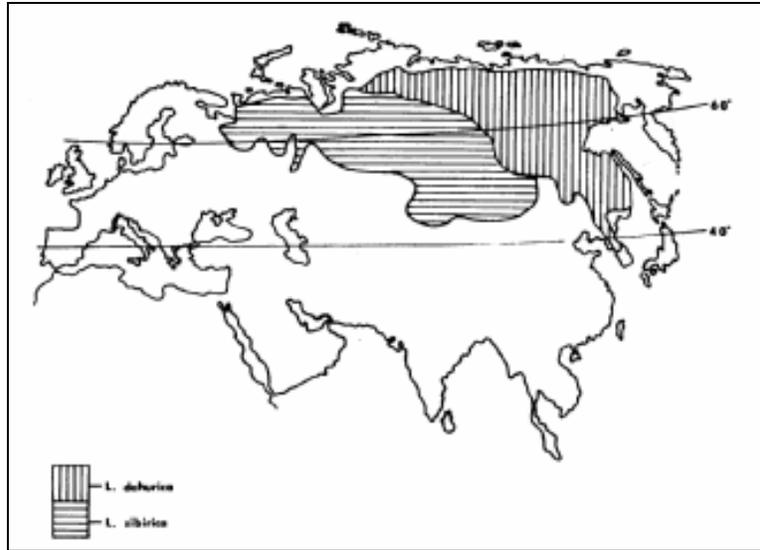


Figure 2.3 Natural area of distribution of *Larix sibirica* and *Larix gmelinii* (*L. dahurica*) (Hakkila & Winter 1973)

2.1.3 *Larix gmelinii* (Asian larch):

L. gmelinii is a typical continental species (Børset 1957). It is also known as *Larix dahurica*, or in English as Dahurian larch or Asian larch. It is said to be the most variable species in the genus. Its natural area of distribution is in E Siberia, NE Mongolia, NE China, and an isolated population in Kamchatka (Fig. 2.3).

It is the most cold-tolerant species in the genus and the soils are affected by permafrost over much of its range (Farjon 1990). Since it occupies such a large area, a wide range of habitats occur, as well as several varieties of the species.

2.1.4 *Larix laricina* (Tamarack):

L. laricina, also known as eastern larch or locally as hackmatack, is a small tree, which may grow well on swampy soil, where other larch species are not doing well (Børset 1957).

It occupies a vast range across boreal North America, from Newfoundland and the New England States to British Columbia and Yukon Territory, from the tree limit in the north to SE of Lake Michigan in the South. A separate population occurs in interior Alaska. In Canada it reaches 70° N (Farjon 1990) (Fig. 2.4.)

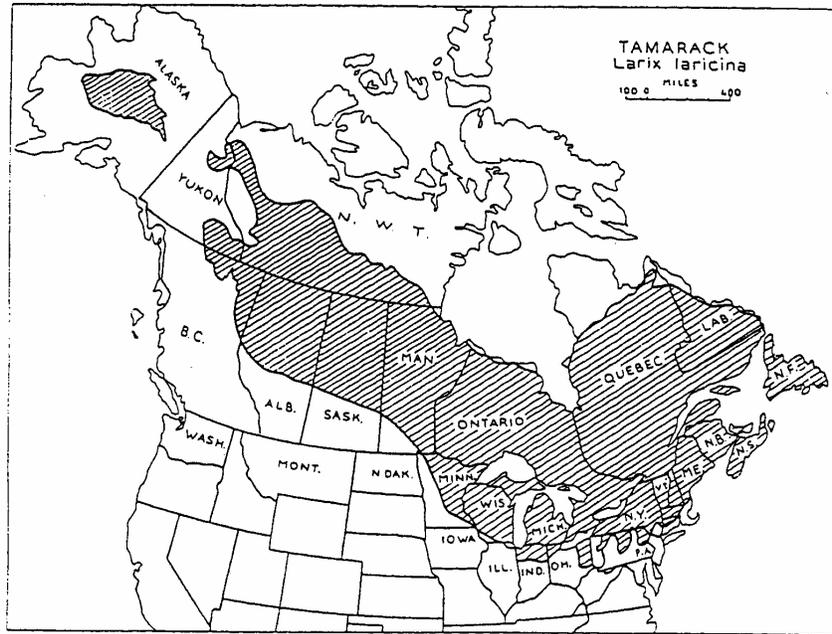


Figure 2.4 Natural area of distribution of *Larix laricina* (Simak, 1971)

2.1.5 *Larix kaempferi* (Japanese larch):

L. kaempferi grows within a small area in the central part of Honshu – the Japanese main island (Fig. 2.5). It grows from the hills to high up in the mountains. Unlike the other NE Asiatic larches it occupies better soils, often of recent volcanic origin, and it is never found on peat (Farjon 1990).

The species is used a lot in Scotland in areas with high precipitation, where it (surprisingly) has shown very good growth on peat soil. The stem form in general is not as straight as that of European or Siberian larch, but the species is almost immune to larch canker (Børset 1957).

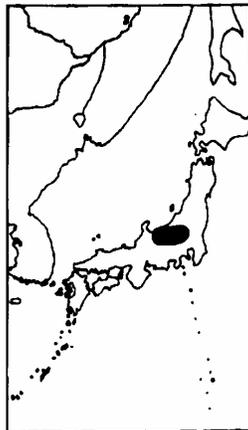


Figure 2.5 Natural area of distribution of *Larix kaempferi* (Farjon, 1990)

2.1.6 *Larix griffithiana* (Sikkim larch):

L. griffithiana is a small tree, compared to the other larch species. It grows at very high elevations in the Eastern Himalayas from E Nepal into Arunachal Pradesh (India), in the Chumbi Valley it reaches into Xisang (Tibet) and China. The exact eastward extent of the typical variety is presently unknown (Fig 2.1). It can be found on very rocky moraines, where the climate is moist to wet (summer monsoon), with annual precipitation exceeding 2000 mm. (Farjon 1990).

2.1.7 *Larix potaninii* (Chinese larch):

L. potaninii and its varieties are high mountain larches occurring between 2350 and 4300 meter elevation. It grows on acidic mountain podzols, in a cold climate with precipitation varying between 800 and 2000 millimeter. Its natural area of distribution is China and the typical variety is found in the S Ganshu, S Shaanxi, W Sichuan, NW Yunnan and E Xisang provinces (Farjon 1990) (Fig. 2.1). It is also known under the name *L. chinensis* or Chinese larch.

2.1.8 *Larix mastersiana* (Masters larch):

L. mastersiana is a high mountain species of rare occurrence (altitude range 2000-3500 meter). It grows on podzolic mountain soils, usually on steep slopes with good drainage. Its natural area of distribution is W China, in a limited area near Guanxian, West of the Min River (Farjon 1990) (Fig. 2.1).

2.1.9 *Larix lyallii* (Subalpine larch):

L. lyallii occurs at or near the tree line and grows normally on shallow, rocky mountain soils. It is a rare species with two main areas of distribution: the Cascade Mountains in the West and the Rocky Mountains in the East. It is furthermore found scattered in SE British Columbia, SW Alberta, W Montana, N Idaho and N Washington (Farjon 1990) (Fig. 2.1).

2.1.10 *Larix occidentalis* (Western larch):

L. occidentalis has its natural area of distribution in the mountains of the Upper Columbia River Basin, in SE British Columbia, NW Montana, N Idaho, on the eastern slope of the Cascade Mountains in Washington and N & NE Oregon (Anonymous 1987; Farjon 1990) (Fig. 2.1). It grows at elevations from 600 to 2100 meter, usually on grey-brown, well-drained podzolic soils. The climate is cold, with cool summers and moist winters, and an annual precipitation from 450 to 875mm. (Farjon 1990). Up till now the experiences with this species in Europe have not been very good (Børset 1957; Simak 1971), but it might

be an interesting species under good growing conditions, for instance in the south of Norway (Børset 1957).

2.1.11 *Larix x eurolepis* (Hybrid larch):

L. x eurolepis was discovered for the first time in 1902. The duke of Atholl planted in 1885 some Japanese larches at the Dunkeld House in Scotland. Nearby stood some European larches and when seeds from the Japanese larches were collected in 1902, a hybrid of the two was discovered. An intense breeding work followed, and today this hybrid is widespread in Scotland (Børset 1957), as well as in other countries.

It is a common experience that the growth is more vigorous, compared to the pure species (heterosis) and that it is more resistant to draught. Measurements show that the hybrid, at least in the youth, grows much faster than the Japanese larch. The resistance to larch canker is furthermore very high compared to European larch. Concerning growth vigour, stem form as well as resistance to canker large differences are found, depending on the different parent combinations. For the use in sandy heath-land areas the Polish parents give hybrids which combine headiness, growth-energy and good form. Hybrid larch is not as exposed to draught-damage as the Japanese, but caution still has to be taken. On the other hand, Japanese larch seems to be able to accept more shadow. It has been tried to gather seeds from stands with hybrid larch, but this can not be recommended (Brandt 1977).

2.2 Concluding remarks

Above the ten different larch species have been described. Most of the species appear in mixed forests together with other species in their natural range of distribution, which may be important to bear in mind when considering planting them outside these areas. Not all species mentioned above will be treated in detail below. Focus will be on European larch, Siberian larch, Asian larch and Japanese larch. Furthermore, the North American species will be mentioned where it is found relevant to the study.

3. The use of larch wood in the past and in the present

In this chapter the past and the present uses of larch will be presented together with a description of the specific use in each of the Nordic countries and other countries relevant.

3.1 Applications of larch wood

It is known that larch has had and still has many valuable uses within its natural range of growth in Asia, Central Europe and North America. In northern Europe consumers are now paying more attention to larch wood, especially with a large supply of high quality wood becoming available from Russia.

Larch wood is used when high strength, hardness and durability are asked for, like in building of mines, bridges, and heavy constructions. Although not in the same amount as pine and spruce, it is used for structural work in some central European countries. A striking example is the Stefansdom in Wien. For indoor uses, larch is today primarily used where esthetic has high priority, for instance in visible roof-structures, and it is furthermore used for ceilings, walls, doors, stairs and floors (Bosshard 1982; Boutelje & Rydell 1986; Grosser & Teetz, 1985). Often is it used for special purposes like for instance floors in railway wagons (FPRL 1969), where it is very suitable because it is hard-wearing.

For outdoor uses larch is for instance usable for building bridges – spectacular examples of this can be found in both Germany and Italy and probably in several other countries. For this purpose the three forces of larch: high strength, natural durability and decorative appearance, are combined. But larch has many other outdoor uses: outer doors, external wooden paneling, balconies, fences and constructions in gardens, barrier-constructions against avalanche, etc. (Grosser & Teetz 1985). Larch is also very suitable for boatbuilding, although not many boats are built out of wood anymore. However, only the best qualities are in demand for this use (Grosser & Teetz 1985; Harding 1988).

In the past it was often used for furniture, but today other species have mostly taken over. Earlier larch was also used for containers for chemical solvents, because of its resistance to acid and its durability. It could compete with containers of both steel and artificial materials because of its ability to isolate, which is important when using temperate liquids (Geyer 1979).

Larch wood is not equally advantageous for all the uses mentioned above. This will be treated in the chapters to follow. Likewise, larches are not preferred pulpwood species due to the coloured heartwood and a high content of resin and extractives.

3.2. The use of larch in the Nordic countries

Among the Nordic countries, Denmark probably has the largest production of larch timber. It is used mainly as structural timber and for packaging, but increasing amounts are in demand for external cladding, playgrounds, fencing and garden equipment. Other uses include noise barriers along the main roads. Small amounts of special quality wood are in demand for restoration of old wooden ships.

In Norway larch is used for exterior cladding, outdoor furniture, noise barriers, stairs, doors, boatbuilding and poles for maritime purposes (Vadla 2002; Lutdal 1997).

In Iceland larch is used for poles, exterior panelling, outdoor furniture, floors and governmental offices (when Icelandic grown wood is asked for) (Eggertson 2002).

In Sweden larch is for example used for kitchen furniture and flooring, and furthermore for outdoor playgrounds and for outdoor panelling e.g. in carports.

In Norway and Finland larch has to some extent been sold to production of sulfate pulp (Børset 1957), but probably not in large amounts, since the resource in these countries is rather small.

3.3. The use of larch in other European countries

Although Britain does not belong to the natural area of distribution of larch, it has been planted over rather large areas and has therefore been available, if not in large quantities, then at least to a larger extent than in the Nordic countries.

Larch is in Britain traditionally regarded as a timber for out-of-door use and for special purposes. Its use in buildings is limited mainly to exterior work such as cladding, gates and sills, and other purposes where something stronger and more durable is asked for. As sawn timber the heartwood is suitable for work where durability is of importance, such as boat planking and exterior work. It is harder and tougher than most conifers and is used where these properties are important factors (BRE 1986). It is a favorite timber for estate work - for farm buildings, fences, poles, footbridges and the like. In the industry it has been used for the floors in railway wagons and for ramps, and it would probably have been used more widely if available in suitable sizes and grades (FPRL 1969). It has been used very much in boat-building and in harbours as well as in mines because of the strength and because it creaks before breaking.

Even though nailing can cause problems, it is used for pallets in both Germany and Great Britain because of its resistance, strength and hardness (Harding 1988).

In Germany small dimensions are used for pit props (mining), fences and industrial wood for particle boards. The stem wood is used for sawn goods for furniture, indoor building, outdoor cladding, frames, structural purposes, parquet floors and special containers. In Germany and France the best qualities of larch are used for veneer for furniture and

indoor use (Grosser & Teetz 1985; Geyer 1979). In the Alpine region larch has been the preferred species for roof and wall shingles in traditional housebuilding.

In the USA Western larch is used mainly for rough dimension wood in building construction, small timbers, planks and boards, railroad crossties and mine timbers, as well as for piles, poles, and posts. Some high-grade material is manufactured into interior woodwork, flooring, sashes, and doors. The properties of western larch are similar to those of Douglas-fir (*Pseudotsuga menziesii*), and these species are sometimes sold mixed (Anonymous 1987). Tamarack (*L. laricina*) is used principally for pulpwood, structural timber, railroad crossties, mine timbers, fuel, fence posts, and poles. Sawn wood is used for framing material, tank construction, boxes, pallets, and crates. The production of tamarack sawn wood has in recent years declined (Anonymous 1987).

In Russia larch has, in the areas short of stone, been used as foundation under houses. As an example of larch's resistance to rot, the research institution in Krasnojarsk showed Sjöström (1938) pieces of larch, which apparently should have been in the ground for more than 1000 years, and the wood was still fresh. Another example, which also illustrates the many uses of larch, is the church in Kirenski. The church is made completely in larch in the year 1756 and was (in 1937), in defiance of the absence of painting, in a very good shape. Larch was furthermore seen as being excellent for fuel. *L. sibirica* is also found excellent, and better than pine, for telephone poles, and is in the eastern part of Siberia the most used species for this purpose. Some 40 year old poles, still in working order, showed that the sapwood was rotten above ground, but surprisingly enough seemed undamaged in the ground (Sjöström 1938).

3.4 Concluding remarks

The uses of larch in northern and central Europe show a picture of a desired product which has only been used for special purposes. There are some indications in the literature that this is primarily due to a limited supply of larch wood - small amounts, few dimensions and varying quality. However, larch has been used for a large number of items, mostly out-of-doors, which shows not only that the durability above ground is well-known, especially in central Europe, but also that larch has actually been preferred for other species in certain above-ground applications. It is not often used in ground contact, except in Russia.

In the Nordic countries larch wood has had a very limited use until now. There is no traditional use and very little experience to lean back to, and for those reasons it is important that it is made clear, for what purposes larch can be used in the Nordic countries. At the same time it is important to keep in mind, that with the introduction of chemically treated wood, we were set back in knowledge about where and especially how to use wood the best way. Furthermore is focus today very much on growth on behalf of the quality and it can not be expected that planted fast grown larch has the same uses as larch has had in the areas where it grows naturally.

4. Availability

The area covered with larch in the Nordic and Baltic countries is very modest but the production is increasing and due to the opening of the markets towards east, large amounts of Siberian larch are now entering the market.

Larch has been planted in Norway, Sweden and Finland since the middle of the 18th century, though in small scale. In Norway and southern Sweden the European larch (*L. decidua*) has been the preferred species, while in northern Sweden and in Finland it has been the Siberian larch (*L. sukaczewii*) (Martinsson 1999).

4.1 Availability in the countries participating in the research project

4.1.1 Denmark:

The area covered with larch is approximately 11 000 ha, or 2.7 % of the total forest area. 83 % of this is to be found in Jylland. The standing volume is estimated at approximately 1.8 Million m³. A Danish survey stated that the annual cutting in 1996 and 20 years ahead could amount to approximately 84 000 m³, or 62 % of the annual growth (Dansk Skovforening 1997).

4.1.2 Finland:

The area of larch plantations in Finland is app. 20,000 ha - 75% *Larix sibirica*, (Venäläinen et al. 2001). Plantations are young and the annual loggings are approximately 1000-2000 m³. However, cuttings are predicted to increase to 10 000-15 000 m³ per year in the near future when the stands get older (Saranpää 2002).

4.1.3 Iceland:

There is about 5000 ha larch forest in Iceland amounting to approximately 10 % of the real forest area and a little more than 4 % of the woodland area. 3000 ha are less than 10 years old and only 115 ha are more than 40 years old. 80 % are Russian larch (*L. sukaczewii*) and 15 % are Siberian larch (*L. sibirica*). The annual increment is estimated to be around 6 m³/ha. (Eggertson 2002)

4.1.4 Lithuania:

The planted larch trees come from Poland, Russia and Finland. The resource is rather small; approximately 850 ha with larch as the main species, and app. 1500 ha mixed with other species – altogether about 136 000 m³ standing volume of larch wood (Saladis 2002).

4.1.5 Norway:

Larch was introduced in Norway in the 1760es, and the first large-scale forest plantations were established in 1789. The activities on planting larch have varied considerably, but it had its maximum between 1950 and 1970. In the last two years around 300 000 plants have been planted each year. The area covered with larch is approximately 4000 ha (0,025 % of the productive forest area), but only 2500 ha are considered as successful. The total standing volume is approximately 250 000 m³, the average annual growth 2-12m³/ha. Total increment is estimated at 12 500 m³ per annum. Harvested volume amounts to app. 3500 m³/year (roundwood). Consumption is app. 6500 m³/year (sawn wood) and 5000 of these are imported. Japanese larch is planted in the East of Norway, European larch in the West, Russian larches in the North and in the mountains. Hybrid larch has a scattered distribution. *L. occidentalis* and Korean larch has also been planted, but in very small numbers. Japanese larch shows a higher increment than European larch. (Vadla 2002).

4.1.6 Sweden:

The standing volume of larch wood in Sweden is estimated to be in the range of one million m³ (0.5 % of the total standing volume of wood in Sweden). Around 2 % of this is processed a year (Martinsson, 1999). The import amounts to 50 000 m³/year (Terziev 2002). Almost half of the total standing volume of larch wood is less than 50 years old (Martinsson 1999), and 60 % of the standing volume is to be found in Götaland. The average annual increment in Skåne is estimated at approximately 13 m³/ha (Alriksson 1992).

4.2 Central European countries and Great Britain

Great Britain: The area covered by larch was in 1996, according to the Forestry Commission, 143 675 ha or 9.4 % of the British coniferous area and rising. Japanese larch and European larch made up 8 % of the total forest area (1995). The production in 1984 was 710 000m³, which in 2000 is believed to have increased to around 930 000 m³ (Dansk Skovforening 1997).

In Germany, larch covers about 1% of the total forest area. It is bought only by sawmills specialised in this species and sold as round wood, sawn wood and veneer (to veneer production it is sold at very high prices if the bole is flawless) (Dansk Skovforening 1997). A distinction must be made between the natural slow grown mountain larch (from the southernmost part of the country) and the planted lowland larch with wide annual rings.

The larch stands of France cover about 100 000 ha. The standing volume is estimated to be 16.5 million m³ or 2% of the coniferous wood resources (Reuling *et al.* 2002). The larch in France has a scattered distribution. It occurs naturally in the Alps, and a few specialised sawmills in the French Alps are buying all larch here.

In Austria, larch covers as much as 26 % of the total forest area (Grosser & Teetz 1985).

4.3. Concluding remarks:

None of the Nordic or Baltic countries can show anything but a very limited larch resource. In the rest of Europe a few countries have considerable resources of larch wood, notably Great Britain, France, Italy, Poland, Austria and the Czech Republic. Most of the countries experience an increase in the area covered by larch, but at least seen over a shorter perspective of time, western Europe will be dependent on importing larch from markets in the east, if the actual trend of consumption is continued.

5. Growth and yield

Growth, and especially differences in growth between species and varieties, is important knowledge when trying to understand the properties of larch wood. This chapter will focus on growth as well as features such as stem form, spiral grain, knots, bark percentage, and the proportion of heartwood.

5.1 Growth of larch

The growth of larches is characterized by a fast development in the juvenile stage, faster than most conifers (Bauger 1985), an early culmination of growth at the age 15-25 years (Grosser & Teetz 1985) followed by a slowing down, with European larch slowing down more than the Japanese. Although both height growth and volume production can be impressive during the juvenile phase, the increment declines over time and can hardly be compared with Norway spruce stands in an older age (Bauger 1985; Kleppe 1994), except maybe in the northern part of Scandinavia, where larch can be superior. As the rapid height growth culminates early, the larches attain their maximum mean annual increment significantly earlier than other conifers in the same yield class.

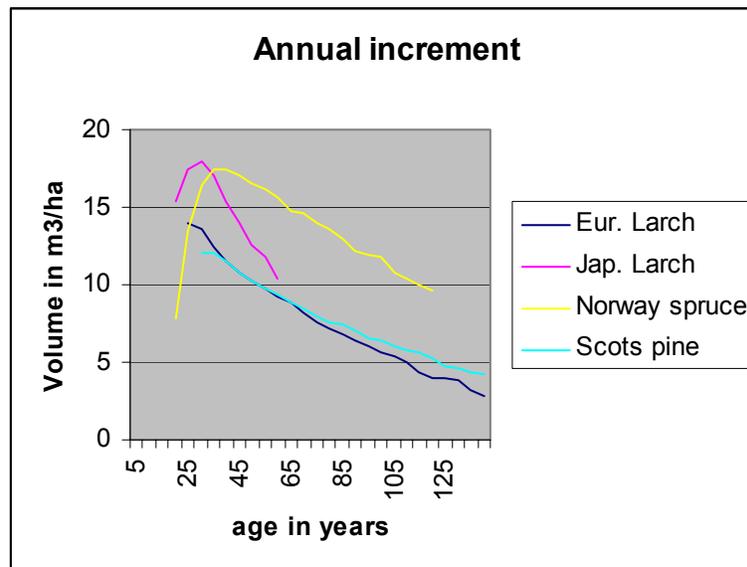


Figure 5.1 Annual increments of European larch, Japanese larch, Norway spruce and Scots pine in Germany (Data from Schober, 1975)

Figure 5.1 shows the development in the annual (current) increment for the four species: European larch, Japanese larch, Norway spruce and Scots pine in Germany, all on the best soil-type and moderately thinned. European larch has already reached its maximum before the age of 25, Japanese larch reaches its maximum around the age of 30, Scots pine at the age of 35 and Norway spruce at the age of 40. Until the age of 35, Japanese larch shows the highest increment. But from the age of 35 Norway spruce takes over and

stays for the rest of the period on a much higher level than the other three species. Scots pine follows the European larch quite closely, but with less increment in the early age and a higher increment after the age of 65. Japanese larch has clearly a higher increment than European larch. However, that the European larch should slow down more than the Japanese larch can not be concluded from figure 5.1.

The fast growth in the juvenile phase makes larch suitable for shelterwood establishment and as a supplement-tree in natural regenerations or in stands with severe losses (Børset 1957).

An aspect in the growth which is difficult to control is the variation in annual ring-width within the tree. According to Hansen (1998) Siberian larch shows a large variation in annual ring-width between years with cool summers and years with hot summers. In the cool years the annual ring-width was reduced with 50% compared to the average annual ring-width. Apart from such climate induced variation, ring width can to some extent be controlled through thinning intensity. Since larch is a light-demander, thinning at an earlier stage than with most other conifers is important in order to maintain diameter growth.

5.1.1 Characteristics/differences between species and provenances:

European larch has been planted all over Europe with varying results, partly because of the wrong choice of provenance. In the IUFRO 1944 provenance experiments, the best growth and development is experienced with provenances from Sudeten mountains and the west Carpathian region. These together with south-central Polish and lowland Austrian larch seem to be the best adaptable among the provenances of European larch when it comes to growth. Performance declines in all directions from the optimal region, particularly westwards, so that west Alpine provenances demonstrate poorest growth (Giertych 1979). Most surveys agree with these results. On this background European larch of alpine origin is believed to have little future in Scandinavia. In Danish experiments larches from the Blizyn/Zagnansk area in Poland have been healthy and fast growing (Göhrn 1957). The Sudeten provenances are possible alternatives, but even these grow more slowly than the Japanese and hybrid larches. The mean annual increment for European larch in Germany is in the range of 5 to 10 m³/ha/year depending on thinning intensity and soil quality (Schober 1975).

Compared to Norway spruce, European larch appears much more sensitive to interactions with the environment. Thus, the correct selection of plant is of utmost importance. Unfortunately, the provenances with the fastest growth are not the ones providing the best wood quality. The fast growth individuals are very often those with heavy branches, and stem form seems to be almost inversely correlated with growth. Therefore, when choosing larch provenances with a straight stem and a fine branching habit, loss in growth potential will follow (Giertych 1979).

The Japanese larch (*L. kaempferi*) is according to Sachsse (1987) the fastest growing of the larch species. Only in drier parts of Great Britain it is reported to be overgrown by the European larch on the best sites, but the Japanese larch is still superior in the moist

uplands and on less fertile sites (FPRL 1969). Sachsse (1990) reports annual ring widths of more than 8 mm, and even more interesting, that the ring width does not decrease significantly later on, as it does in e.g. Scots pine. This statement of sustained growth, however, is supported neither by Schober (1975) nor by Andersen (1950), as shown in figure 5.1 and 5.2.

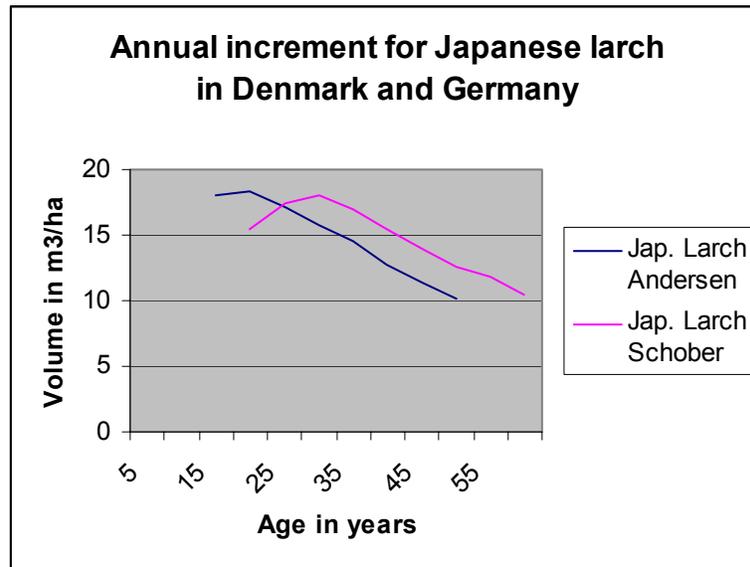


Figure 5.2 Annual increment for Japanese larch in Denmark (Andersen, 1950) and Germany (Schober, 1975)

Based on the measuring of only one stand, Folsach (1948) describes Japanese larch as valuable and easy to work with and fast growing in the young years, producing a yield much faster than Norway spruce and Sitka spruce. The standing volume is at the age of 35 comparable with Norway spruce (yield class II-III), which makes the future growth the more interesting. On the contrary, Schober (1975) shows a much higher standing volume in Japanese larch at the age of 35 compared to Norway spruce, while the annual increment is on the same level (see fig. 5.1). The German yield tables show a mean annual increment between 6 and 13 m³/ha/yr depending on thinning intensity and soil quality (Schober 1975), which is approximately 20% more than the figures for European larch.

From figure 5.1 it is clear that the increment of Japanese larch can only compete with that of Norway spruce in short rotations, but with Scots pine in a much longer rotation. Still, these figures show the situation in Germany, and may be useful in the southern part of the Nordic countries. Moving further north a species like Siberian larch is believed to take over and the yields of the species described may react quite differently.

Yield data from a Canadian research study (Fowler 1988) shows that Japanese larch, managed over short rotations, is capable of producing two to three times more wood than other conifer species commonly planted in the Maritime Region of Canada. The mean annual increment of merchantable wood for trees of the three best provenances of

Japanese larch at age 25 was about 12 m³/ha, while that of the poorest provenance was about the same as for European larch and tamarack, 4 m³/ha. This shows that Japanese larch is a genetically highly variable species regarding volume growth. In average, Japanese larch produced twice as much wood as the European larch or tamarack. The interesting thing about the variance in the Japanese larch is that it appears to be independent of commonly measured geographic and environmental variables. Provenance variation appears to be synonymous with stand variation. Random genetic drift would appear to be the most plausible explanation for the lack of any clear pattern of variation.

According to Fowler (1988) Japanese larch wood sawed, dried and machined well. The wood has a pleasant appearance and the rapid growth and acceptable wood properties of Japanese larch make it attractive from a wood supply perspective. Diameter growth rate, which peaked at 15 years at about 14 cm, suggests this species to be particularly suited for short rotations when grown on appropriate sites. The results support other results showing that opportunities for the utilization of plantation grown larch for solid wood products are excellent.

The Japanese larch can accept more shadow than the European, and the trees can as a result of that stand closer together (Bauger 1985), leading to less thinning and a broader use, also when grown with other species.

The qualities of Siberian larch have been appreciated for many years. Dahll (1892) wrote that the tree develops a high and slender stem, which exceeds the pine in height. He referred to Blomqvist (1887) who described findings of 200 years old house-foundations of Siberian larch which were still fresh, and Dahll (op.cit.) suggested that Siberian larch could be excellent and better than the European larch as a culture tree in Scandinavia, because of its slender and high growth, but especially because of its insensibility to the climate. Blomqvist (1887) also described a visit to a Finnish cultivated forest with Siberian larch which was 110 years old and contained about 800 m³/ha. He described it as being the most beautiful forest in Finland and said that having seen this forest, one had to be convinced of the use and importance of cultivating the Siberian larch in Scandinavia. He foresees that the cultivation of the European larch will end as soon as seeds from Siberian larch can be obtained in the right amount and quality.

Also Hakkila & Winter (1973) think highly of the Siberian larch. In Finland it thrives in a diversity of sites, and its yield in terms of volume per hectare is slightly higher than that of Scots pine and Norway spruce on the best soils. Most likely, this is a pattern seen only far north, as the Norway spruce in general shows a much higher production than larch. However, tests have shown that the Russian larches (*L. sukaczewii*) grown in Norrland, Sweden can give 10-25 percent more wood than pine (measured under bark) during a rotation period of 100 years (Anonymous 1997).

The Raivola provenance, which is a provenance of the Russian larch grown in Finland, is mentioned in the literature. It is known for its extremely good stem form and accepted for its high growth and qualitative properties. Blomqvist (1988) is referring to some plantations made by Skogsvårdsstyrelsen in Sweden in 1947. The stands with Raviola larch show a remarkably high production compared to the stands with pine. In Finland

the height and diameter growth of individual trees is considered to be exceptionally fast (at the expense of the number of stems), which means that certain dimensions may be achieved even in half the time required by pine and spruce. Therefore, if it is desired in Finland to grow large timber trees quickly for certain special purposes, this is best achieved with Siberian larch (Hakkila & Winter, 1973).

Giertych (1979) is more cautious in his optimism concerning the possibilities of Siberian larch, and says that it is of no use except in the northern part of Scandinavia: Finland, northern Sweden and northern Norway. Although it may be an excellent culture tree in some parts of Scandinavia, Siberian larch is adjusted to inland climate, cold winters and short, but relatively warm summers. It doesn't fit into the coastal areas because it is attacked by larch canker, and it is damaged by spring frost because of early bursting (Børset 1957).

The growth potential varies as always when talking about larch, but a research study shows that the mean annual production of Siberian larch in the northern part of Norway varies between 2.8 and 7.6 m³/ha (Hansen 1998). These figures are quite impressive having in mind that it is in the northern part of Scandinavia, which means that they are not to be compared directly to the German figures for European and Japanese larch mentioned earlier.

It is very difficult to compare yield tables for the relevant species in the Nordic countries, but Edlund (1966) claims that in northern Sweden Siberian larch has a higher production than Scots pine on middle-good soil-types during the first 70 years (fig. 5.3). Norway spruce on the other hand is still believed to exceed larch in total production in the long run, although larch can turn out to be a serious competitor far north, maybe exceeding Norway spruce in some areas.

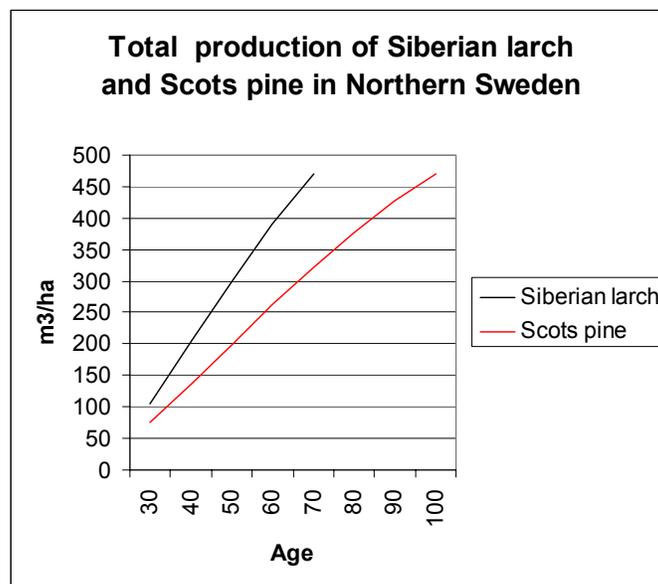


Figure 5.3 Total productions of Siberian larch and Scots pine in Northern Sweden (Edlund 1966)

The hybrid between Japanese and European larch (*L. x eurolepis*) outgrows either parent on all but the very best larch sites, and its superiority becomes very marked under marginal conditions for larches (FPRL 1969). The IUFRO 1944 provenance experiment showed good growth potential in hybrid larch (concerning height), even in further generations, and over a variety of sites. The hybrid larch has on several places in Götaland, Sweden, produced between 300-400 m³ standing volume per hectare within 25 years, or 35-80 percent more than spruce at the same time and place. The wood density in these young larch-stands is between 400 and 500 kg/m³, which means that the production of dry-substance is then on the same level as with willow (*Salix sp.*) grown for energy purposes. This is interesting as larch has many more uses than the energy-forest with *Salix* (Anonymous 1997). The results quoted above are relevant if hybrid larch is planted with a rotation of 25 years in mind. If a longer rotation is wanted it is very likely that the average volume production will diminish, but the notion of growing larch in highly productive short-rotation plantations seems attractive. However, it is important to keep in mind that it may prove difficult to reach a sufficient diameter within the short rotation age if any emphasis is put on wood quality in terms of restricted annual ring width or knot size.

5.1.2 Yield tables:

Yield tables for larch have been elaborated in several of the north European countries, primarily for the European and the Japanese larch:

For Germany the work of Schober (1975) presents figures for European and Japanese larch under different thinning regimes and growth conditions, and for the same species in Great Britain height growth curves by yield class are presented among other species by Hamilton & Christie (1971) and Edwards & Christie (1981). Jansen et al. (1996) compiled yield tables for the important tree species in the Netherlands, i.a. Japanese larch.

Most other yield tables are more limited in their scope. For Danish conditions Andersen (1950) and Brüel (1969) present local growth and yield figures based on measurements from a very limited number of stands. The work of Wielgolaski (1993) is based on a much bigger material, but presents only height growth figures for European and Japanese larch in western Norway.

For the growth of Siberian larch in Sweden, Wiksten (1962) and Edlund (1966) summarized some examples (Fig. 5.2). Growth and yield figures for Siberian larch in Sweden have later been presented by Remröd & Strömberg (1978) and by Martinsson (1990a). For Finnish conditions, the site-index curves of Vuokila *et al.* (1983) apply.

5.2 Stem form

A very optimistic view of the larch tree is presented by the British Building Research Establishment: “if grown in forests, the stem is long, cylindrical and clean for two thirds of its length. When well-grown it is straight-grained and relatively free from knots” (BRE 1986). However, this statement seems very simplified, as the stem form is often a cause for concern among larch growers and breeders. The same goes for the branching habit of the tree.

According to some authors Japanese larch generally exhibits a better stem form than European larch (Mayer-Wegelin, 1955; BRE 1986). Schober (1953) reported Japanese larch to have a better stem form than European larch, but in a later study (Schober 1976) he found that a young stand of Japanese larch had a worse stem form than the European larch. A study by Robak (1982a) placed a Japanese larch provenance approximately in the middle of the range of variance expressed by a number of European larch provenances. Other Norwegian sources disagree on the issue: Børset (1957) reports Japanese larch to have a bad stem form compared to European larch, while Bauger (1985) describes a rather good stem form in older stands of Japanese larch.

Among the European provenances, Børset (1957) states that under Norwegian conditions especially the Scottish grown larch has good stem form. Also larch from the Sudeten mountains has good stem form, while larches from the area of Tyrol are inferior.

Under good growing conditions Siberian larch will normally show a better stem form than European larch, although a weak crookedness may occur (Børset 1957; Edlund 1966).

Large variation between individuals is a prominent feature among larches, and the selection process during breeding work may lead to a marked improvement of stem form. This, together with provenance variation, may explain the varying results found by different authors.

Strong winds frequently cause young larch trees to lean, and those trees will develop a basal sweep as they strive to regain a vertical position of the stem. Basal sweep is commonly present in European larch, although Scottish, Polish and Swiss provenances have shown better properties on this matter (Edlund 1966). In addition to conversion losses the basal sweep is accompanied by the formation of compression wood, which can cause severe problems during the working and drying process.

The basal sweep should be separated from poor stem form in general (“snaking”), which is to a large extent under genetic control, and which can only be diminished through the right choice of species, provenance and breeding material. The importance of choosing the right provenance of larch was known already in the 19th century. Dahll (1892) wrote that it was believed that bad stem form of European larch had to do with the soil and the climate as well as heredity.

Bad stem form can also be caused by larch cancer (*Lachnelulla willkommii*). This fungus can to a great extent be avoided by choosing a resistant species or provenance, and by planting the larch on suitable locations.

5.3 Branches

In general larch has an irregular arrangement of the branches. The branch whorls are not clearly defined and internodal branches are numerous. When pruned at an early age, clear timber is obtained, but much of the timber cut from young trees contains numerous small, irregular scattered and often dead knots (FPRL 1969). Moltesen (1952) sees knots as one of the most serious problems with larch wood, and argues that to get a good quality of the wood, larch must be pruned.

Severe knots lower the strength and impede the working process. Especially the long, black overgrown “nail-knots”, which larch has a tendency to produce, create some problems. The knots are dark, hard and have a tendency to loosen when dried. Japanese larch develops to a larger extent than other larches severe knots far down the stem after a thinning. Furthermore, the natural pruning in Japanese larch is not as good as for the European larch (Mayer-Wegelin 1955), because the Japanese larch in general has thicker branches.

The Finnish research by Hakkila & Winter (1973) showed that the proportion of knot-wood increases from the butt towards the top. It was 0.3 % at the butt and 1.8 % at the top, with an average in the whole stem of 1.0 %. The number of branches was larger in the lower parts of the tree. However, the butt-end branches die young and are self-pruned rapidly, so the volume percentage of knot-wood is always smallest in the butt end of the stem. Young and fast-growing trees contain the most knot-wood. The proportion of knot-wood seemed to be considerably smaller in Japanese larch than in the other larch species (Hakkila & Winter, 1973), which is quite surprising, taken the above-mentioned into consideration. Siberian larch was characterised by a large number of branches of rather thin diameter in the early stages of its development.

In order to benefit from the fast juvenile growth and ensure a good diameter development, young larch stands are often heavily thinned, thus impeding the natural pruning of the trees. Branches that are allowed to stay alive for long enough time to develop heartwood will remain on the tree for many years if not artificially removed. Artificial pruning has been common practice in larch growing, especially in Denmark. Besides improving the wood quality, pruning opens up growing space for the under storey trees when larch is being employed as a shelter species. The branches are brittle and artificial pruning of thin branches proceeds very easily.

5.4 Spiral grain

Spiral grain is very common in larch and causes serious problems in the drying process.

Many conifers start out showing left oriented spiral grain. This left hand spiral of the juvenile phase is over time partly compensated by an outer layer of straight-grained wood or eventually by a right oriented spiral grain, as the tree grows old. However, this outer right oriented spiral grain is not in the same matter present in larch and most trees exhibit a sustained left-hand spiral grain orientation. The spiral grain can cause problems in the drying and working processes (Sachsse 1979). It makes the sawn timber inclined to twist in drying and may give rise to some tearing of the surface in machining operations. British observations indicate that spiral grain is more pronounced in European than in Japanese larch (FPRL 1969).

5.5 Bark

Larches are known to have a thick bark, but it varies a lot depending on species and age. The volume of bark is in European larch 16-24 %, compared to Scots pine with an average on 12 % (Wagenführ & Scheiber 1989). Grammel (1989) found that the bark of larch amounts to 16.4 % in volume, and 12.6 % in weight (336 kg/m^3). For Norway spruce the volume was 9.7 % and for Scots pine 9.1 %.

In 1970 a study was undertaken in Finland (Hakkila & Winter 1973) with the purpose of determining the bark percentage by dry weight, the percentage of heartwood and knotwood by volume and the basic density of wood. In addition, the content of acetone- and hot water-soluble extractives was determined. The study compare the four species Siberian larch, European larch, Dahurian larch and Japanese larch. Except for Siberian larch, it was based on a rather limited amount of material. The mean age of the trees was 49 years.

The results showed that the weight-percentage of bark in Siberian larch is relatively high, 15.5 % on average, which is higher than that of Scots pine and Norway spruce. The proportion of bark decreased from the butt to 1/3 height of the stem and then began to increase again towards the top (see fig. 5.7 and 5.8). The variation in bark percentage was best explained by the tree size. The proportion of bark diminishes with increasing age and size; the faster the growth, the smaller is the proportion of bark. Furthermore, the proportion of bark is considerably higher in the North than in the South. No significant differences were seen between the larch species, but in Siberian and European larch the proportion of bark seemed to be higher than in Dahurian and Japanese larch, which harmonise very well with the findings of other authors. For instance Moltesen (1988) reports Japanese larch to have a considerably thinner bark than the European larch.

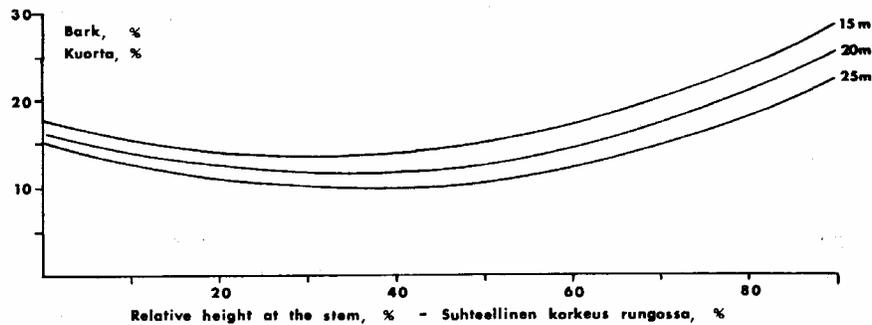


Figure 5.4 Longitudinal variation in bark percentage of 15-, 20- and 25-metre Siberian larch stems. (Hakkila & Winter 1973)

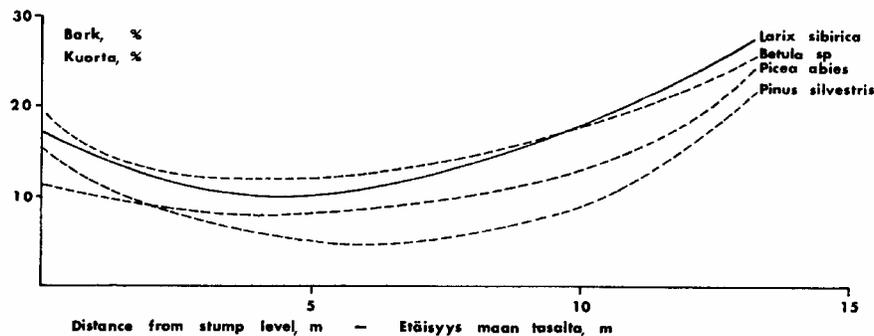


Figure 5.5 The longitudinal variation of bark percentage of a 15-metre Siberian larch stem compared with Scots pine, spruce and birch. (Hakkila & Winter 1973)

5.6 Heartwood development

The formation of heartwood in larch is initiated early. Some authors claim that it starts already after 5-6 years (Mayer-Wegelin 1955), others say 15-20 years (Moltesen 1988). According to Blomqvist (1988) the average number of sapwood rings in larch is 11. Thus, the sapwood is narrow: often around 2 cm, and in old trees often less than 1 cm. (Grosser & Teetz 1985; Boutelje & Rydell 1986). For Western larch and Tamarack the sapwood is generally less than 2.5 cm wide (Anonymous 1987). The proportion of sapwood in larch is therefore lower than in Douglas fir and particularly Scots pine (Mayer-Wegelin 1955). For instance, a research by Gravbrøt (1996) showed twice as much heartwood volume in a 60 years old Siberian larch stand than in a comparable Scots pine stand. Alriksson (1992) found in a 40 year old stand of Japanese larch a heartwood proportion of 50 %, while Hakkila & Winter (1973) in a 53 year old stand found the average heartwood volume percentage of Siberian larch to be 48.7, but with a large variation. Alriksson (1992) quotes a Danish rule of thumb saying that larch with a mean height of 25 meter contains 60 percent heartwood along the bole. As a rule, the more vigorously growing trees have wider sapwood (Anonymous 1987). Dominating trees have more heartwood (due to their bigger size) than the suppressed trees in the same stand and with the same age, though if trees within the same diameter class are compared,

the suppressed trees will show a higher proportion of heartwood (Hakkila & Winter 1973; Gravbrøt 1996).

Larch has the greatest proportion of heartwood in the lower part of the stem; decreasing evenly towards the top of the tree (Fig. 5.6). This is different from Scots pine where the proportion of heartwood increases at first when moving from the butt towards the top and does not begin to diminish until a relative height of 10-30 percent (Hakkila & Winter 1973).

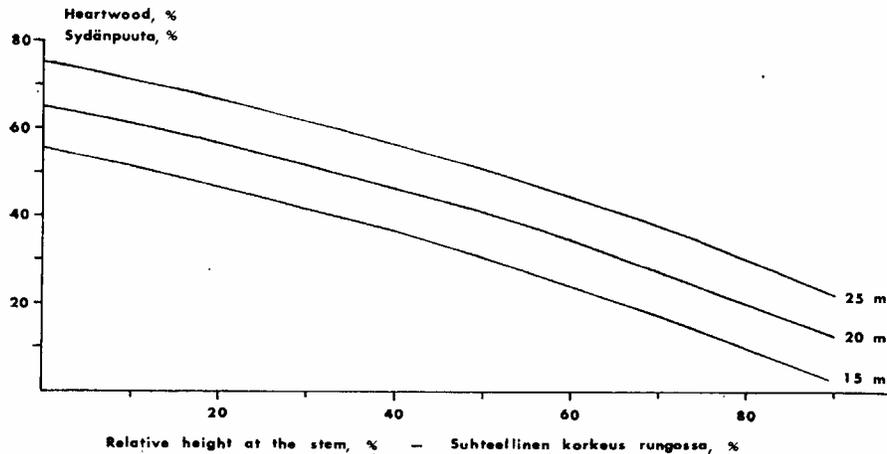


Figure 5.6 The longitudinal variation of the percentage of heartwood in 15-, 20- and 25-metre Siberian larch stems (Hakkila & Winter 1973)

In the Finnish study by Hakkila & Winter (1973) the percentage of heartwood in Japanese larch appeared to be higher than in the other larch species (Hakkila & Winter, 1973), maybe due to the generally faster growth and bigger size of the Japanese larch. No significant difference was established between trees growing in the south and in the north of Finland.

5.7 Pathogens

Two properties are often mentioned in connection with larch: Its resistance to root rot and its resistance to larch canker. This study will not go further into these two properties, but a few comments should be added:

Root rot is mentioned in the literature both as an argument for planting larch and as the opposite. The reason is that larches in general are more resistant to root rot than spruce (Anonymous 1997), especially the hybrid *Larix x eurolepis*. Larch can therefore be an interesting alternative to spruce on the high productive sites where spruce is often a victim to root rot. However, the resistance varies between the larch species, and it seems that the European and the Japanese larch can be attacked to some extent. It is therefore

important to be aware of the different grades of resistance among the different species and provenances.

Larch canker (*Lachnelulla willkommii*) develops especially in a coastal climate with a long cool spring, mild summers and autumns and changeable winters. Especially young stands, age 20-30 years, are attacked (Børset 1957). To reduce canker, planting on lowland sites with stagnant air should be avoided. Sloping terrain is more suitable, and early and heavy thinning is also a weapon against canker. In particular European larch of Alpine origin falls victim to the disease, whereas the Japanese larch and its hybrids are largely resistant. Thus, the choice of species and provenance is important, but this topic will not be discussed further in the present study.

6. Wood properties

The larches are, at least at a young age, fast growing species, and the formation of heartwood begins early, making it feasible to produce a fair amount of heartwood even in short rotations. Furthermore larch wood is heavier than comparable wood of Scots pine and Norway spruce, making it harder and more durable.

Differences in properties between European and Japanese larch have often been a matter of controversy, although when comparable and tested under the same conditions no significant differences between the durability, strength properties and appearance have been found. It is believed that the differences in practice have occurred because most of the Japanese larch on the European market has been fast-grown wood from young trees, while the mature timber in general has been European larch. The differences therefore seem to be more due to age and growth conditions than to the differences between the two species (FPRL 1969). Anatomically as well as technically there are only small or no differences between European and Japanese larch (Sachsse 1979).

6.1. Physical properties

6.1.1. *The look/anatomy:*

The wood of larch looks much like the wood of pine, especially in dry condition (Børset 1957). The resinous heartwood is pale reddish-brown to brick-red in colour, sharply differentiated from the narrow light-coloured sapwood. From experience (Bergstedt 2002; Wimmer 2002) Japanese larch is generally darker and with a more reddish heartwood than the European larch. Also the natural-grown Siberian larch often has a dark reddish hue, partly due to its slow growth and high proportion of latewood. The heartwood of western larch is yellowish brown and the sapwood yellowish white, while the heartwood of tamarack is yellowish brown to russet brown and the sapwood whitish (Anonymous 1987).

The lines of the annual ring are very sharp and are clearly seen by the difference in colour between the light earlywood and dark latewood (Grosser & Teetz 1985; BRE 1986). Within the annual ring the change from earlywood to latewood is also very clear (Sachsse 1987). The amount of latewood is very sensitive to changing temperatures and precipitation, but the average latewood proportion in larch is around 35% for an annual ring width of 2.5 mm, which is more than in both Norway spruce and Scots pine (Mayer-Wegelin 1955). The wood contains resin ducts and often resin pockets (Grammel 1989).

Larch and pine are very alike when it comes to fibre dimensions, but in average larch has shorter fibres. Larch also has a lower share of tracheids compared to both pine and spruce, which is compensated by a larger amount of rays (Edlund 1966).

6.1.2 Density:

Density is an important property which has a large effect on the mechanical behaviour of wood. Higher density leads to higher strength, although knots and other defects also have a strong influence upon the strength. Besides strength, durability and combustion energy are positively connected to density. This is also the case for larch, and Russian researches of larch show a 30 % higher value of these three properties compared to pine (Martinsson 1999).

Having the highest density in earlywood as well as latewood, larch wood is the heaviest among conifer species in Northern Europe, except for yew (Grosser & Teetz 1985), heavier than both Norway spruce and Scots pine (Table 6.1). With equal ring width Edlund (1966) found that Siberian larch has a basic density which is 30 % higher than pine and 50 % higher than spruce. Timber of old growth larch averages about 590 kg/m³ at 12 per cent moisture content, while younger trees are somewhat lighter at about 510-540 kg/m³ (Harding 1988).

Table 6.1 Density of European larch, Norway spruce and Scots pine (low-middle-high) (Kollmann, 1951)

	European larch	Norway spruce	Scots pine
Density r^0 (kg/m ³)	400- 550 -820	300- 430 -640	300- 490 -860
Density r^{15} (kg/m ³)	440- 590 -850	330- 470 -680	330- 520 -890

Table 6.2 Densities of different larch species from literature sources.

	Density r^0 (kg/m ³)	Density r^{12} (kg/m ³)
Larch ¹		470- 600 -650
European larch ²		590
European larch ³		540
European larch ⁴	520-600	550-640
European larch ⁵	550	610 ^{r=15%}
Japanese larch ³		510
Siberian larch		
Western larch, USA ⁶	480	520
Western larch, Canada ⁶	550	
Tamarack, USA ⁶	490	530
Tamarack, Canada ⁶	480	

1. En 350-2 (Dansk Standard 1995), 2. BRE (1986), 3. Harding (1988), 4. Boutelje & Rydell (1986), 5. Norsk Treteknisk Institut, in Lutdal (1997), 6. Anonymous (1987)

Kollmann (1951) is often referred to in the literature when properties are described, probably due to lack of other sources describing the features of larch. Still, other figures and experiences appear here and there in the literature. Table 6.2 shows the density of different larch species found in other sources than Kollmann. All figures are within the range set by Kollmann (1951), but there is a tendency that other sources find a lower density, probably because the original material of Kollman represented old growth larch of Alpine origin. As with most other conifers there is a negative correlation between annual ring width and density; hence young fast growing trees will produce lighter wood

than the old and slow-growing trees of the natural forest. The fast growth of the Japanese larch is reflected in a lower density figure; according to Building Research Establishment (BRE 1986) 530 kg/m³ versus 590 kg/m³ for European larch, both quoted at 12 percent moisture content.

Siberian larch does not enter table 6.2 but Finnish research showed an average basic density of Siberian larch of 492 kg/m³, which was considerably higher than that of other softwoods (*Pinus silvestris*, plantation-grown: 395 kg/m³ and *Picea abies*, plantation-grown: 352 kg/m³). The density of Dahurian larch was higher and the density of Japanese larch was distinctly less than that of other larches (Hakkila & Winter 1973). Also Swedish results (Edlund 1966) indicate that the wood density of Siberian larch is higher than that of European, Japanese and Western larch.

Hakkila & Winter (1973) showed that the density of Siberian larch decreases from the south northwards and similarly with increasing altitude, when comparing wood with equal ring width. In reality, deceleration of growth moving either north or to a higher altitude seems to compensate for this tendency so that density is in fact the same at a certain age in spite of the geographical location of the stand, even though the annual ring width is different between the two (Hakkila & Winter 1973).

Another interesting feature is the variation of basic density within the stem. Finnish results show that the basic density decreases relatively sharply from the butt of the stem towards the top compared to most other species (15 % in defect-free wood), even though the wood density of Scots pine decreases much more than in larch (Hakkila & Winter 1973).

6.1.3. Shrinkage and drying properties:

Drying of larch wood proceeds slowly compared to most other conifers, and may take 2-3 times longer than for Scots pine (Terziev 2002a). By artificial means (kiln drying) larch can be dried rather quickly, but due to the low permeability of the heartwood steep moisture gradients can be induced, and it takes a careful drying to avoid checking. According to FPRL (1969) two-inch (app. 5 cm.) material can be dried from green condition to about 12 per cent moisture content in slightly less than three weeks. The corresponding figure for Norway spruce would be 8-10 days, for comparison. If not dried long enough there is a higher risk of resin exudation, especially if the wood is exposed to high temperature (Grosser & Teetz 1985).

The shrinkage in larch is higher than that of either spruce or pine (Edlund 1966), in accordance with the higher density of larch (Lutdal 1997). The rather disadvantageous relation between the tangential and the radial shrinkage (approximately 2.4, compared to 2.2 for Norway spruce and 1.9 for Scots pine, see Table 6.3) contributes to the tendency of larch to twist and warp during drying.

Table 6.3 Shrinkage in larch, Norway spruce and Scots pine when dried from green to oven-dry condition. (Kollmann, 1951)

	Larch	Norway spruce	Scots pine
Shrinkage % β^L	0,3	0,3	0,4
β^R	3,3	3,6	4,0
β^T	7,8	7,8	7,7
β^V	11,4	11,9	12,1

Table 6.4 Shrinkage in different larch species when dried from green to 12 % moisture content

	Shrinkage % β^L	Shrinkage % β^R	Shrinkage % β^T	Shrinkage % β^V
Larch ¹		2,8	4,0	
European larch ²		3	4,5	
European larch ³		2,3-3,3	4,0-6,0	
European larch ⁴		3	4,5	
Japanese larch ⁴		2	3	
Western larch, USA ⁵		2,7	5,5	8,4
Tamarack, USA ⁵		2,2	4,4	8,2

1. FPRL (1969), 2. BRE (1986), 3. Boutelje & Rydell (1986), 4. Harding (1988), 5. Anonymous (1987)

When larch is straight-grained and the wood contains regular annual rings the form stability when dried is satisfactory. Normally, however, larch is characterised by spiral grain, which affects the form stability negatively in the drying process (Grosser & Teetz, 1985). Both theoretically and in practice it can be shown that twist arises from a combination of spiral growth and a large difference between tangential and radial shrinkage (Stevens 1961). As both of these phenomena apply to larch, the drying distortions experienced with sawn wood of larch are not surprising.

Problems caused by twisting are mentioned relatively often in the literature. A Danish study by Harvald (1988) showed that sawn wood of larch was more prone to twisting than most other conifers. The twisting was closely correlated to the occurrence of spiral grain. Although the tendency of spiral grain is a bit higher in Japanese larch, British tests show that Japanese larch seasons with slightly less distortion than the European larch (FPRL 1969).

To find use as sawn wood early and consistent thinning of the larch stands is recommended. Are the thinning neglected over a period of time, large variations in the width of the annual rings will appear, and small rings will be followed by wide rings leading to tensions in the wood and as a result of that shakes and twisting during drying. The same will happen if the juvenile diameter growth is too fast (Anonymous 1997). Also, varying amounts of latewood caused by climatic differences during the growth season causes variations in density, and hereby differences in shrinkage and swelling between the annual rings, leading to some warping and checking (Sachsse 1979).

6.1.4. Stability of larch wood:

The dimensional stability of larch sawn wood under changing moisture conditions is a matter of dispute. Sachsse (1987) considers the stability of the wood satisfactory, once it is dry, and Harding (1988) claims that the wood will work less under changing humidity than Norway spruce and Scots pine. On the contrary, Moltesen (1952) describes the stability as being not satisfactory, referring to some rather unfortunate English experiences with telegraph poles.

Among craftsmen the general opinion is that larch is prone to twisting when dried, and that it “works” a lot because of the shrinkage and swelling. However, opinions vary and people working with larch normally have a positive attitude towards it. One probably has to learn how to handle and use larch, especially during sawing and drying. Anyway, the applicability is strongly affected by where it was grown and how the stand was treated (Anonymous 1997).

In practical use larch wood is often chosen for applications subject to changing moisture and risk of frequent wetting. One reason is that larch wood because of its low permeability can cope with varying levels of humidity without absorbing much water, and thus without severe shrinkage and swelling. This low permeability applies to the heartwood only, whereas the sapwood will absorb water much more quickly (Hansen & Venås 2002).

In traditional shipbuilding larch wood was extensively used for lifeboats and dinghies because it would stand the harsh conditions of alternating sunshine and sea spray without checking, and still remain watertight.

6.2. Mechanical properties

Larch is generally regarded as one of the strongest if not the strongest softwood in common use, although the results of laboratory tests show that Douglas fir is superior in certain strength properties, like modulus of elasticity. In general terms mature larch is considerably harder than Scots pine and with higher bending strength and toughness (FPRL 1969). The good strength properties in larch have been appreciated for many years. Collinder & Borgstrand (1929) stated that larch in Central and southern Europe had the position it deserved in respect of its properties, and quoted Lang, who in his book “Das Holz als Baustoff” says that European larch is superior to the other European softwoods because of its strength, resin content, beauty and durability. Collinder (1929) also wrote that since the strength properties only decrease slowly with increasing annual ring width it should be possible to use fast grown larch without compromising on the strength properties. Unfortunately, Collinder & Borgstrand’s view on this matter seems to be too optimistic, although no particular study regarding the relationship between speed of growth and wood quality of larch has been identified in the literature.

The mechanical properties are mainly depending on the basic density, the size and number of knots and the direction of the grain. The values shown in table 6.5 and 6.6 are measured on small clear samples. Due to the large number of knots - if not artificially

pruned – the figures for commercial larch timber will be much lower. Harvald (1988) found for structural size boards cut from young vigorous trees of European larch a bending strength (MOR) = 45 N/mm², and Modulus of Elasticity = 9.6 GPa. Because of large variations in the amount and size of knots in the stem as well as variations in annual ring-width, even within the same tree, the overall variation is rather large (Harvald 1988, Dansk Skovforening 1997).

Table 6.5 Strength properties for European larch, Norway spruce and Scots pine

	European Larch ¹	European larch ²	Norway spruce ¹	Norway spruce ²	Scots pine ¹	Scots pine ²
Tensile strength $\sigma^{ZB} \parallel$ (N/mm ²) (u = 12%)	105	97	88	116	102	95
Tensile strength $\sigma^{ZB} \perp$ (N/mm ²) (u = 12%)	2		3		3	
Compression strength $\sigma^{DB} \parallel$ (N/mm ²) (u = 12%)	54	50	49	39	54	50
Modulus of elasticity (GPa)	13,8	12,5	11	10	12	10,9
Shear parallel to grain (N/mm ²)	9	8,2		6,8		9,1
Bending strength (N/mm ²)	96-99	90	78	87	100	91
Impact strength (kJ/m ²)	60	55		40		36

1. Kollmann (1951), 2. Norsk Treteknisk Institut, in Lutdal (1997)

Table 6.6 Strength properties for different larch species

	Larch ¹	European larch ²	European larch ³	Western larch, USA ⁴	Western larch, Canada ⁴	Tamarack, USA ⁴	Tamarack, Canada ⁴
Tensile strength $\sigma^{ZB} \parallel$ (N/mm ²) (u = 12%)	105	105		111,7			
Tensile strength $\sigma^{ZB} \perp$ (N/mm ²) (u = 12%)		2,3		3		2,8	
Compression strength $\sigma^{DB} \parallel$ (N/mm ²) (u = 12%)	48	47-54	54	52,5	61	49,4	44,9
Modulus of elasticity (GPa)	12	9,9-13,5	13,5	12,9	14,3	11,3	9,4
Shear parallel to grain (N/mm ²)	9	9-12		9,4	9,2		9
Bending strength (N/mm ²)	93	92-94	88				
Impact strength (kJ/m ²)	60-70	70	59				

1. DIN 68364, in Grosser (1985), 2. Boutelje & Rydell (1986), 3. Sachsse (1984), 4. Anonymous (1987)

In Table 6.5 the strength properties of larch are compared to Norway spruce and Scots pine. Figures from Kollmann and Norsk Treteknisk Institut are presented to show the difference in results, not only in larch, but also in Norway spruce and Scots pine. Some variation between different larch species is present (Table 6.6), especially between the north American species, but the figures are all within the range of values presented by Kollmann in 1951 for European larch.

Due to the faster growth of Japanese larch the seasoned timber is about 20 % less stiff, less resistant to radial splitting and 30 % softer than European larch, while the differences in other mechanical properties are negligible (BRE 1986).

6.3. Working properties:

Compared to Norway spruce, larch must be seen as rather difficult to work with, because of:

- Bad stem form
- Spiral grain
- Higher density
- Larger amount of latewood
- Harder latewood
- Larger contrast between earlywood and latewood
- The dry knots
- Thicker bark

Still, larch can without serious problems be worked on with all manual and mechanical tools (Sachsse 1979; Boutelje & Rydell, 1986), although the knots, which are often hard and loose, tend to spoil the cutting edges of tools (Harding 1988; Boutelje & Rydell 1986; FPRL 1969). Dry wood is relatively easy to work with, and gives a nice and clean finish if the wood is not characterised by strong spiral grain, severe knots and wide annual rings. Growth stresses and compression wood can cause some problems, just as the large taper and the sometimes severe curvature can lead to lower yield (Grosser & Teetz, 1985). With severe basal sweep it can be necessary to discard the butt end of the stem.

Because of a tendency to spring on leaving the saw (due to internal stresses), larch is more difficult to convert than most species of softwood; losses in conversion tend to be rather high on account of the irregular shape of some logs. Besides from that, the timber saws and machines fairly readily and finishes cleanly in most operations. There is generally a fair amount of wastage however, in truing up seasoned, slash-sawn material. The difference between European and Japanese larch is practically of no importance. Although Japanese larch is softer than European larch, and although the soft springwood zones are liable to tear or crumble, a clean finish is obtained in most operations if sharp cutting edges are used. But also in Japanese larch the knots are troublesome (FPRL 1969). Because of their hardness, dry knots can destroy the surrounding fibres, especially in fast grown wood because of the severe density contrast between the knot and the surrounding wood (Sachsse 1987).

Because of the higher density and the hard knots a more laborious tool maintenance as well as a lower performance in the working process compared to Norway spruce must be expected.

Problems can occur in the sawing process because of the high amount of resin, especially in fresh wood (Terziev 2002b, Boutelje & Rydell 1986). The problem can be solved by lubricating the saw blade with water or light oil, or by sawing the wood in frozen

condition (Martinsson 1999, Grosser & Teetz 1985). Seasoned wood is normally easy to work (Moltesen 1952).

When larch is straight grown and the wood contains regular annual rings and no knots, veneer can be cut of it without problems (Grosser & Teetz 1985). However, the veneer can have a tendency to crack at the annual ring borders, and it is furthermore not suitable for bending (Boutelje & Rydell 1986).

Larch can have a tendency to split in nailing, and pre-boring is therefore recommended (Grosser & Teetz 1985, Boutelje & Rydell 1986). On the other hand, when nails and screws are in place the properties are good. Iron nails and screws corrode only weakly in heartwood of larch, because of little acid in the heartwood, but in humid wood a blue-grey colouring of the surrounding wood can appear.

Larch is easily glued (Grosser & Teetz 1985, Sachsse 1987), except when a high content of resin is present (Boutelje & Rydell 1986). Concerning surface treatment larch has the same properties as Scots pine (Harding 1988), which means that wood with large contents of resins can cause some problems. It is therefore recommended to pre-treat the wood with a resin-dissolving product, especially if it is exposed to high temperatures.

6.4 Resin and heartwood extractives:

6.4.1. Resin:

The amount of resin in European larch is by Kollmann (1951) estimated to be approximately 4.2 % (2.5 % in the sapwood and 4.6 % in the heartwood), compared to Scots pine with 4.8 % and Norway spruce with 1.7 %. Martinsson (1999) quotes higher figures for Siberian larch, stating that the resin content normally is between 6 and 16 % in (in *L. gmelinii* 23% has been measured), compared to approximately 5 % in pine. Because of the large content of resin, larch has a strong aromatic odour, decreasing as the wood dries (Moltesen 1988).

Pitch pockets are often present in larch wood, and some craftsmen claim that pitch pockets are more numerous in larch than in Scots pine or Norway spruce. The presence of a pitch pocket renders the affected piece useless for joinery purposes, as resin oozing out from the pitch pocket will mar the surface, in particular if the wood is subject to direct sunlight or high temperatures.

Also shakes caused by stress/tension in the lower part of the stem are common with fast grown larch trees. In addition to reducing the strength of the sawn wood, they will be filled with resin, hereby lowering the value of the wood because of higher risk of resin exudation (Sachsse 1987).

6.4.2 Heartwood extractives:

In general, heartwood consists of inactive cells that do not function in either water conduction or food storage. The transition from sapwood to heartwood is accompanied

by an increase in extractive content. Frequently, these extractives darken the heartwood and give species their characteristic colour. In some species, such as black locust, western red cedar and redwood, heartwood extractives make the wood resistant to fungi or insect attack. However, not all dark-coloured heartwood is resistant to decay, and some nearly colourless heartwood is decay resistant, as in northern white-cedar (*Thuja occidentalis*).

Heartwood extractives may also affect wood by:

- (a) reducing permeability, making the heartwood slower to dry and more difficult to impregnate with chemical preservatives,
- (b) increasing stability in changing moisture conditions, and
- (c) increasing weight (slightly).

However, as sapwood changes to heartwood, no cells are added or taken away, nor do any cells change shape. The basic strength of the wood is essentially not affected by the transition from sapwood cells to heartwood cells (Anonymous 1987), but hardness and wearing qualities can be affected positively.

A characteristic feature of larch heartwood is the presence of large amounts of arabinogalactans. Arabinogalactans are polysaccharides possessing numerous branches, and they are the only major polysaccharides that can be extracted in high yield from untreated wood with water (Lewin & Goldstein 1991). In Russian studies (Terziev 2002b) the wood of *Larix dahurica* showed a lower content of celluloses compared to the controls of Scots pine and Norway spruce (which showed an average of 49 %), but a higher content of water soluble extractives, especially arabinogalactan. In extreme cases the content of arabinogalactan of larch wood can be as high as 30-35 % (Terziev 2002b, Lewin & Goldstein 1991), but the average amount is generally in the range 10-15 %. In a study from University of British Columbia of Western larch (*L. occidentalis*) the proportion of water soluble extractives was found to be 11.9 %, of which 11.1 % or more than 93 % of the water soluble extractives was arabinogalactan. Giwa & Swan (1975) found in Finland the amount of water soluble extractives in larch to be 9.3 %, which is still considerably more than in any other Finnish grown tree species. The longitudinal variation in the amount of hot water extractives follows the changes in the percentage of heartwood and diminishes (parallel to other extractives) from the butt towards the top (Hakkila & Winter 1973).

Other extractives, mainly of phenolic constitution, can be extracted with organic solvents like acetone, ether or ethanol-benzene. The phenolic compounds are present in much smaller amounts than arabinogalactan: In Dahurian larch the ether-soluble extractives amount to 0.7-1.8 % and the ethanol-benzene-soluble extractives to 1.8-6.3 % (Terziev 2002b). Research has shown that the amount of phenolic extractives in the heartwood of larch is increasing from the pith and outwards, and furthermore that there is a negative correlation between the annual ring-width and the content of phenolic extractives and arabinogalactan. As the annual ring width is getting smaller and smaller after a certain age, this may help explain the higher amount of extractives in the outer part of the heartwood. Together with the general tendency of a darker heartwood colour and a higher amount of extractives in older trees, this may explain the same feature as for Scots pine, namely that the durability of larch grows as the tree ages (Lutdal 1997). However, the

chemical composition of larch varies a lot, and Russian research found only weak relations between the age of the tree and its chemical composition (Terziev 2002b).

The amount of extractives is to some extent genetically controlled (Lutdal 1997) and to a certain limit it is possible to affect the amount of heartwood extractives in the course of a breeding programme.

6.5 Permeability

According to results referred by Borsholt (1997) larch heartwood absorbs water more slowly than both Norway spruce and Scots pine heartwood. However, this applies to the capillary axial water absorption (when the ends of wood samples are soaked in water). A recent small study on the transversal water uptake (Hansen & Venås 2001) failed to confirm the above results. In the latter study larch heartwood was comparable to Norway spruce, whereas water absorption was significantly less with Douglas fir heartwood. The study indicated that differences exist between the larch species and provenances regarding water absorption, but the material was too limited to reveal statistically significant differences between the larch species, and further tests are necessary to clarify this matter. Slow grown wood with narrow annual rings absorbed water faster (measured in $\text{g/m}^2/\text{h}$) than wood containing wide annual rings, and tangential faces absorbed more water than the radial faces of the samples.

7. Durability

By means of chemical wood preservation it may be possible to obtain a longer life from a relatively non-durable but easily treated species than might be possible with a more durable timber that is difficult to treat. Together with relative costs and availability, this should be considered when selecting a species. However, with the ban on use of several chemical substances used for impregnation, this situation has changed in northern Europe where the natural durability of wood is once again coming into focus.

This is reflected by the situation for research on larch in Scandinavia, which has for many years been mainly on silvicultural matters. During the last decade increasing attention has been paid to the durability of larch wood.

The natural durability of wood depends on several properties: sap-/heartwood, annual ring width, the amount of resin, the age of the tree (the maturity of the heartwood) and the location within the tree (corewood/outer wood, height above the ground). Sapwood does not contain any conserving chemical components and is therefore not as durable as heartwood. The content of extractives increases together with density and make a more durable wood, just as a more intensive formation of heartwood makes a more durable tree. The best strength properties and the best durability are found where the growth has been slow, meaning that wider annual rings give lower durability because of a lower basic density. Heartwood from the lower part of the stem will in general be more durable than from higher up in the stem, just as the durability increases from the pith and outwards (Lutdal 1997).

The durability of larch wood depends strongly on the origin of the material (and methods of measurement). For instance, young fast growing larch with lots of juvenile wood often present in Scandinavia is hardly comparable with the old larch from natural forests in Siberia (Martinsson 1999).

Besides the properties of the wood, also the conditions of use (especially moisture and temperature) are decisive for the durability. As one of the few, Kollmann dared to present values for different wood species subject to varying conditions (Table 7.1).

Table 7.1 Expected service life of larch, Scots pine and Norway spruce (Kollmann 1951)

Species	In ground contact	Unprotected (min–mean–max)	Sheltered (min–mean–max)	Always dry
Larch	9-10	40-65-90	90-120-150	< 1800
Scots pine	7-8	40-60-85	90-100-120	120-1000
Norway spruce	4-5	40-55-70	50-60-75	120-900

Table 7.1 shows that durability of the species above ground is many times that of the durability in ground contact, but the same ranking applies. On behalf of this, larch is considered to be “very durable” above ground, Scots pine and Norway spruce to be “durable” (Kollmann 1951).

Björkman (1944) tested the hardness of larch-wood against rot. His results showed that wood with narrower annual rings, and thus a greater percentage of latewood, and wood with greater specific gravity, usually is more resistant to rot than that of the same kind with broader annual rings and lower specific gravity. This shall not be seen as a greater inherent resistance to rot, but rather be explained by the greater difficulty experienced by the fungi in penetrating into denser wood. The heartwood of larch proved to be considerably more resistant towards rot than that of spruce and birch, though scarcely more than that of pine.

According to Björkman (1944) no noteworthy difference, with regard to hardness against rot, has been established between the woods of European larch, Siberian larch and Japanese larch. German tests showed that the durability of European larch is better than that of Japanese larch, which was explained by the wider annual rings in Japanese larch (Mayer-Wegelin 1955). More recent studies indicate that Japanese larch may be more durable than the European larch, but that a very large variation is present even within the same species (Jacques 2002).

Most studies agree that the durability of larch heartwood in ground contact is within the same range as that of Scots pine heartwood.

7.1 Heartwood / sapwood

The natural durability is to a wide extent dependent on the extractives present in the heartwood. Variation in the natural durability reflects the type, quality and distribution of these extractives (BRE 1985). The phenolic compounds of the larch heartwood have a toxic effect on certain fungi, whereas other fungi seem to attack heartwood as eagerly as sapwood.

Because of their fungicidal properties, the concentration of phenolics might be the best indicator of the durability. Some of these substances are distinctly coloured, and it may be possible to assess the durability of a piece of timber by means of color measurements. Within the recently finished EU research project “Towards a European Larch Wood Chain” (Contract No. FAIR-CT98-3354) it was found that reddishness is an indicator of durability (Wimmer 2002). Using wavelengths outside the visible range may enhance the possibilities even further. In connection to the above project a more general method was developed to rapidly determine heartwood extractives in *Larix* sp. by means of Fourier transform near infrared (FT-NIR) spectroscopy. NIR spectroscopy proved to be an easy, reliable, accurate and fast method for non-destructive wood extractive determination. Due to the strong link between certain wood extractives and bio-deterioration a NIR-based classification for durability classes was found feasible (Gierlinger et al. 2002).

A certain level of moisture content is a prerequisite for fungal attack. Pit aspiration, as well as the inclusion of heartwood substances, leads to reduced permeability in the heartwood compared to the sapwood. This physical barrier to water absorption resulting from physiological changes during heartwood formation is another important source of wood durability (Lutdal 1997).

7.2. Larch in ground contact:

The durability of wood in ground contact is a property that has been extensively studied. Most trials have been established to document the effect of chemical treatment, but still the natural durability of untreated wood is included in several studies.

Extensive field tests on round timber fence posts were established in Scotland, England and Wales by the Forestry Commission in 1957-58 (Clarke & Bosswell 1976, referred by Borsholt 1997). The results showed that the mean durability was more than 15 years for European larch, 9 years for Japanese larch, 3 years for Scots pine and 8 years for Sitka spruce (Norway spruce was not included in the test). The superior results for larch compared to Scots pine reflects the fact that heartwood formation starts much later in Scots pine than in larch. Thus, the pine poles probably contained no heartwood at all whereas some heartwood was present in the larch poles. The test showed that the poles would last longer in peat soil than in clay soil, and that they lasted longer in areas with high precipitation.

The results agree fairly well with results from a Danish fence pole trial initiated in 1937 (Borsholt 1997). The average natural durability for larch (Japanese) was in the range between 6.5 and 14.5 years depending on diameter. Even though a great variation both between and within sites was present, the tests showed that larch was more durable than Douglas fir (7 – 10 years) and Scots pine (5.2 – 8.5 years), which again seemed to be a bit more durable than Norway spruce. This trial also showed that the durability of Norway spruce could be improved by debarking and storing the poles under roof for one year prior to use.

Since the fence-poles are expected to contain only a little amount of heartwood (if any at all), the results are very sensitive to the inherent sapwood width of the particular species, and the above tests are not comparable to testing sawn material of pure heartwood. One of the most relevant sets of data concerning the natural durability of sawn wood in ground contact has been produced by the Building Research Establishment in England (Smith & Orsler 1996). The study comprised two field trials established in 1932 with 50 x 50 mm sawn wood specimens. Among the many species tested, the durability of larch heartwood grown in UK and New Zealand was in average 12 years. For Norway spruce and Sitka spruce (UK grown) it was 5.2 years, whereas Norway spruce grown in Finland lasted on the average 7.4 years. Scots pine heartwood varied between 7.4 years (UK grown) and 9.4 years (Baltic grown) compared to 5.8 years for sapwood from UK Scots pine. The results also showed that the heartwood of larch can vary greatly in durability, from 2 to 30 years (Borsholt 1997). One of the reasons for the large variance is that the outer heartwood is more resistant to decay than the central core of juvenile wood (FPRL 1969).

The different test results on larch described above harmonise quite well with the European Standard EN 350-2. According to this the durability of larch can be summarized as below:

- Natural durability to wood-destroying fungi is 3-4 (moderately-slightly durable) on a scale from 1 to 5, where 1 is the best.

- Sapwood is classified as susceptible to *Hylotrupes bajulus* (Longhorn beetles) and *Anobium punctatum* (Powderpost beetles). The heartwood as durable.
- Heartwood is classified as susceptible to termites.
- The width of the sapwood is small (2-5 cm).

These properties go for European larch, Japanese larch, Dunkeld larch and Western larch. The same figures apply to European grown Douglas fir.

EN 350-2 only classifies the durability in relative terms and presents no figures for the expected service life of wooden structures. A more operational approach is taken by Building Research Establishment Digest 296 (BRE 1985), summarizing the natural durability and resistance to preservative treatment for several wood species. The durability grades relate to the heartwood only and describe the ability of a timber species to withstand fungal attack in ground contact. The grades are approximations, since durability varies within as well as between species and even between pieces cut from the same tree. Larch (European, Japanese, Tamarack and Western) is categorised as being moderately durable (10-15 years) and resistant to preservative treatment (BRE 1985). Although just classified as moderately durable, it is expected to last longer than Scots pine, but not as long as oak (FPRL 1969). A Finnish study (Viitanen et al. 1993) of different species' resistance towards rot confirmed that larch heartwood is more resistant than pine heartwood, but much less resistant than impregnated pine and heartwood of oak. Still, in EN 350-2 larch is classified together with heartwood of pine. According to Swedish experience (Anonymous 1997) a service life around 15 years can be expected for larch in ground contact.

7.3 Larch above ground

As shown above, focus has often been on the durability in ground contact. However, much of the timber used externally will be subject to less hazardous conditions. Generally timber is at risk for attack by wood-rotting fungi if its moisture content remains above 20 per cent for any length of time. The actual conditions of use must therefore be considered when selecting a timber for use where durability is important. Larch is believed to be suitable for external use above ground, but very little information is available on the durability of larch for such purposes.

During the last decades a number of buildings with exterior cladding made from larch have been erected in the Nordic countries. In general these houses are still too new to reveal the durability of larch wood, but in the future valuable experience will be gained. Much of the larch wood used for this purpose is imported from Siberia, and most likely differences will be evident when comparing the fast grown local wood with the imported old-grown material from the natural forests of Siberia.

7.4 Larch in contact with water

Wood is more affected by deteriorating fungi when in ground contact than above, but wood either in water-saturated soil or in water is in a condition where it can not be attacked by ordinary wood-destroying fungi.

Larch is according to Grosser & Teetz (1985) excellent for constructions in contact with water and for this purpose comparable with oak. Also, the traditional use of larch for boatbuilding reflects the opinion among craftsmen that the wood will stand frequent wetting and re-drying without deteriorating.

However, Norman (1976) tested the ability of different species of Swedish timbers to withstand attacks by marine wood-boring molluscs. The conclusion was that none of the tested species, among these larch, Scots pine, spruce and oak, had a natural durability in salty seawater which made them useable in harbour constructions without impregnation.

No information is available regarding the durability of larch wood in fresh water, but there is reason to believe that larch will be somewhat more durable than most other conifers, due to its higher wood density.

7.5 Preservative treatment

Although larch is often grown for the reason of its naturally durable heartwood the durability is sometimes improved and extended to the sapwood by means of chemical treatment.

Heartwood in European larch is almost totally resistant to pressure impregnation, while the sapwood is moderately resistant or satisfactory, but the variation within the species is large (Moltesen 1988). Japanese larch is considered a little easier to impregnate than European larch. The same description is found in the European standard EN 350-2:1995: The heartwood is categorised as extremely difficult to treat (4 on a scale from 1 to 4), whereas the sapwood is categorised as moderately easy to treat (2 on a scale from 1 to 4), but with a high level of variability. Both Japanese larch and European larch are approved for pressure impregnation by the Nordic Wood Preservation Council.

The heartwood of Western larch is characterised as difficult to treat (3 on a scale from 1 to 4, according to EN 350-1), whereas Tamarack is characterised as very difficult to penetrate (Anonymous 1987).

For use as harbour timbers or utility poles the sapwood of freshly felled stems may be impregnated by sap displacement. Larch is approved for this method by the Nordic Wood Preservation Council.

7.6 Concluding remarks

Comparing wood of equal density, heartwoods of Scots pine and larch have approximately the same durability. However, larch has normally a higher density, and hereby also a higher durability. Larch also has higher toxic effect towards certain types of fungi and it is a little better when it comes to water absorption. Still, based on the literature available, there is no reason to believe that heartwood of larch necessarily is more durable than that of Scots pine or Douglas fir in ground contact. The durability of larch in ground contact seems to be well documented and it can therefore be concluded, that larch, with an average durability in ground contact around 10-15 years, is only suited for temporary structures in ground contact.

Moving from the ground to above-ground structures the same ranking will apply but the service life will be longer. Larch is here considered to be very durable, even unsheltered, however protection from the rain prolongs the service life considerably.

Larch is often mentioned as a suitable species to be used in water, or under conditions where it is saturated with water. But because of attacks by marine wood-boring molluscs caution has to be taken if used in sea water for a longer period of time.

8. Discussion

Focus is directed more and more towards naturally durable wood in the search of an environmentally compatible product, which can replace chemically treated wood. Larch is interesting in this context because of its high proportion of heartwood and a high durability above ground. In this study information based on the available literature is presented. However, the amount of information presented here leads to a discussion of the information and of larch as a future wood product in the north European countries.

The experiences with larch in the north European countries are concentrated to a few of the larch species. Furthermore, information is scattered and shows large variations. Especially experiences from the north European countries concerning Siberian larch and Dahurian larch are few, though large amounts of information are available in Russia (in Russian). Some of the latter are gathered in a review by Terziev (2002b), attached as appendix to this literature review. However, these results are from Russian grown larch and the planting of these species in the Nordic countries may show other results. Also very little information about the North American larch species planted in Europe is available. This is also an area which could be interesting to focus on, to see if some of these species could find more use in Europe.

The growth and volume production of larch is often compared with Scots pine and Norway spruce. Yield tables have been consulted and concerning volume production larch can have difficulties competing with Norway spruce in long rotations, but in short rotations Japanese larch, Hybrid larch, and probably also Dahurian larch and Siberian larch are capable of a volume production comparable to Norway spruce, especially in the North. It is not clear whether the volume production of larch is higher or lower than that of Scots pine, although figures showing a faster growth of larch in the North have been presented.

In general, more experience and more test-results are necessary in order to know the real potential of growing larch in the Nordic and the Baltic countries. A fair amount of information exists regarding the height-growth, volume production and resistance to pathogens, at least in European and Japanese larch, while more research on stem form and wood quality is needed. Additionally, the possibility of obtaining better provenances of Siberian and Dahurian larch has vastly improved during the last decade, with the opening of Russia to common trade. New provenance trials with Siberian larch are now being established in the Nordic countries. It is expected that the results from these experiments will lead to better provenance recommendations and provide material for the future selection and breeding of larch.

8.1 Wood properties

Very limited information is available on the physical and mechanical properties of larch wood. Kollmann (1951) obviously is the main source on this matter and is still often referred to. Other test results are scattered in the literature and some of them differ

considerably from the figures presented by Kollmann, especially concerning shrinkage. Still, Kollmann's figures are considered to be some of the best available. Although Kollmann's results probably are quite representative for central Europe, other growth conditions, species and provenances apply to the Nordic and Baltic countries and further investigation on the matter of physical and mechanical properties of larch is needed.

The working properties seem to cause some problems. Spiral grain, internal stresses and drying deformations (twist) are the main obstacles. Furthermore the drying process proceeds more slowly and with more difficulties than with the commonly used Norway spruce. On the other hand, it seems like the saw mills expect that larch can be sawn under the same conditions as Norway spruce, and when this is not possible larch is denoted as difficult to work with. Larch has, of course, properties different from those of Norway spruce, and some of them can cause problems during the working process if identical methods are employed for both species. However, with the correct processing methods, larch is not necessarily difficult to work with.

Foresters as well as customers are sometimes left with the choice between larch and comparable conifer species with durable heartwood, notably Scots pine and Douglas fir. The wood of all three species is within the same range of density and heartwood durability, but some particular differences must be considered:

- 1) Larch has very narrow sapwood (in general 10-15 annual rings) compared to Scots pine (30-50 rings) with Douglas fir coming in between (15-20 rings). Accordingly, the heartwood proportion of larch is much higher than for Scots pine.
- 2) Larch is the heaviest of the three species, closely followed by Douglas fir and Scots pine. As with most other conifers, the density depends strongly upon the growing conditions, and this ranking only applies to wood grown under similar conditions of soil and climate.
- 3) Larch shows a strong tendency of spiral grain, leading to twisting of the sawn wood during drying. Twisting is probably one of the greatest problems facing the use of larch wood, and caution should be taken if using larch of long lengths and heavy dimensions in structural work. Douglas fir is better suited for those applications, due to the very limited occurrence of spiral grain in this species. Larch should primarily be used in shorter lengths or thin dimensions (boards, cladding) that will be held firmly in place by nails or screws during service. For Scots pine the spiral growth is mainly a juvenile feature, and structural timber from old trees will normally dry without excessive twisting.
- 4) The ratio between tangential and radial shrinkage during drying is somewhat unfavourable with larch, leading to more drying deformations than with Douglas fir. Scots pine is intermediate. The outer wood with narrow growth rings behaves more favourably than the fast grown juvenile core.
- 4) With all three species the heartwood is impermeable to water. Concerning the sapwood Scots pine is very permeable, and pine sapwood should never be used unprotected outside for any length of time. The other two species are by far less permeable, but due to the absence of protecting heartwood substances, sapwood boards should normally be

confined to interior use. Douglas fir sapwood is normally the least permable among the three species.

8.2 Durability

Examples of larch wood which has been in the ground for hundreds of years without deteriorating are mentioned here and there in the literature. For instance, Martinsson (1999) describes an examination he made of timber houses in Siberia the poles placed directly on, and even in, the soil. One was 40 years old, another 150 years old - both still containing mainly fresh wood. He has also examined 10, 32-year-old, larch poles put in the field on sandy moraine in Västergötland, and they were still only insignificantly attacked by rot. Another example is a 30-year-old plank, also in Västergötland, placed on the ground and used as a footbridge. Also this was insignificantly attacked by rot; though, near the pith the attack was more severe implying that juvenile wood has a lower durability. According to Martinsson (1999) the high durability of Siberian larch may be caused by the high amount of resin, since high amounts especially in *L. gmelinii* have been found.

The figures mentioned above are quite impressing and may give an indication of the durability of larch imported from Russia, just as they make it even more interesting to grow larch species like Siberian larch and Dahurian larch in the Nordic and Baltic countries. However, the figures seem extreme compared with the results from tests made in northern Europe, and similar examples can be found for Scots pine (Lutdal 1997). Only because the proportion of heartwood is much higher in larch than in pine, larch is believed to be a better alternative than Scots pine for unprotected outdoor use. The often heard statement that “all houses in Siberia are built of larch” may reflect availability more than durability. Over large areas Siberian larch was the only species available, so the use of it does not necessarily document the durability of larch wood. Second, the ground remains frozen almost year-round in many places, protecting the wood from being destroyed by fungi.

The extreme cases of durability cannot be confirmed under laboratory conditions, where a moderate durability is always found for both species. However, the durability is subject to a very large variation, even in controlled experiments. In ”graveyard tests” also the microenvironment at the place, especially the humidity and the amount of nutrients can have an effect on the durability of larch in ground contact.

EN 350 places larch as well as Scots pine heartwood in durability class 3-4 (moderately-slightly durable). Heartwood of larch is often described as being a little more durable than heartwood of Scots pine. This is to some extent true, but the difference is small and seems mostly to be attributable to the generally higher density of larch wood.

A frequently asked question is whether or not larch is an alternative to pressure-impregnated wood. This question cannot be answered in simple terms. Placed in ground contact the performance of larch heartwood will not at all match the durability of CCA-impregnated wood. However, wood is very often used for more or less temporary structures (fence poles, playing grounds, sheds and shelters) where the natural durability

of larch (in the range of 15 years) is quite sufficient. Attention should be paid to the expected service life, the cost and possibilities of replacement, and to the consequences of a sudden breakdown. If the structures are meant to be in service for a prolonged period of time, wood in ground contact should generally be avoided. But if this rule is not obeyed and severe damage may result from a sudden breakdown (bridges, roof supports) chemically treated wood will normally be the better alternative. For more temporary and less demanding structures, however, larch heartwood is certainly an alternative to pressure impregnated wood.

For many uses above ground (claddings etc.) the durability of larch heartwood may very well exceed the expected service life of the building. In this case there is no need to further enhance the durability by chemical treatment, and untreated or surface coated larch heartwood can very well be applied without compromising functionality. In some cases structures can be designed in a way that allows easy replacement of the most exposed parts. In this case the use of untreated wood can be extended even to problematic parts as close-to-the-ground wall cladding, and roof details.

8.3 The present and future use of larch

Larch has earlier found many different uses, which make the future use of larch look promising, but until recently larch has mostly been used for special products. Knowing the large variations in the properties of larch wood, it is tempting to look at this specialised use, not as a coincidence, but as a result of a deeper knowledge and understanding of the different properties of larch wood. This is said with the purpose of directing focus on to the possibilities that might be in the use of larch, if this is graded the right way. However, the use of larch in both northern and central Europe seems to have been a victim of a too low supply. In order to make larch a desired species for other than very specific uses, a constant and sufficient supply must be established. At the moment this is primarily done via an increasing import from Russia. It is important to keep in mind though, that the imported larch is often old growth larch with narrow annual rings. It can therefore not be expected that the quality of this and the quality of larch grown in northern Europe are alike.

Larch as a product in the pulp and paper production is briefly mentioned in the study. The average approach to this topic is that because of the high amount of resin and heartwood substances in larches, these are not suitable for paper production. Since the technical properties of larch wood differ from other softwoods in many respects, larch wood behaves slightly differently from the conventional raw material used in the production of pulp and paper. Water-soluble extractives cause difficulties especially in the sulphite process. The bisulphite or the two-stage processes give the best result, but even then the pulp yield is lower than for pine and spruce. Therefore, if used in pulp production, larch wood is above all a raw material of sulphate pulp. Characteristics of larch compared with pine and spruce are high consumption of alkali, lower yield, lower brightness, poorer tensile and burst strength, but distinctly superior tear strength.

However, in the USA they have great expectations to larch, especially in the pulping industries. European and Japanese larch can be readily pulped by the kraft process, and the bisulfate and the two-stage Stora processes have also been used. To avoid high

amounts of heartwood and hot-water extractives only young larch are being used, 18-23 years old. These larches can produce higher kraft yields than 50-60 year old jack pine (*Pinus banksiana* Lamb.) and with pulp strength properties similar to those of jack pine (Einspahr et al. 1984). This proves that although some difficulties appear, young larch trees may be suitable for pulping. Still, no large amounts of larch can be expected to be used within the north European pulp industry, which enjoys abundant supplies of Norway spruce and Scots pine.

Larch timber should be promoted on behalf of qualities like durability, hardness/wearing qualities and aesthetics (Dansk Skovforening 1997). Because of its tendency to twist and the problems with many knots, it is advised only to use larch for floors in cases where the demand first of all is toughness, and where the demands for quality and tolerance are moderate. For internal wooden panelling larch should be sold on its exclusive looks. Still, for this use only the best qualities can find use, and twisting during the drying process will still be a problem. For windows and doors the twisting is considered to cause too many problems. For structural purposes larch can be used, but the working properties are inferior to those of Norway spruce and it is therefore recommended only to use larch when special demands to strength are given or when the construction is visible and the exclusive look of larch is preferred. Bridges could be an example that combines both properties. For outdoor use the demand on the quality of the wood can mostly be lowered. As long as ground contact is avoided no surface treatment is needed, unless a certain look is wanted, and larch is then a serious alternative to chemically treated wood. Small dimensions containing little heartwood can be difficult to find use for, if they can not be used as poles or stakes.

Although larch may be an alternative to Norway spruce and Scots pine, the amount of knots and branches are worth considering when growing larch. The natural pruning in larch is rather bad, which means that artificial pruning is required in order to get a high quality stem. Also, the very fast juvenile growth of larch may lead to wood of poor quality, if the increment of the individual tree is not restricted by competition. This is demonstrated e.g. in larch planted at wide spacing for shelterwood purposes. When choosing silvicultural system it might be worthwhile to put more effort into quality production and not entirely on volume production, as pointed out by Alriksson (1992). More focus on quality rather than focus on dimension, is desirable.

Since the variation in quality is very big in larch, both between different stands and within the same stand, it is a task for the forestry sector to narrow down this variation by growing larch of a better and more homogeneous quality. Planting material has not been discussed in detail within this literature review. Larch has lent itself to much breeding and hybridization work, and selected material from seed orchards is available in European and Japanese larch as well as their hybrid. As new provenances become available from e.g. Russia and China also other larch species are likely to be included in the European breeding work. Selection and breeding has hitherto been mostly focused on stem straightness, resistance to larch canker and branching habit. With new methods for determining heartwood extractive content (e.g. NIR spectroscopy) also wood durability might become a breeding goal within the near future.

Literature

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2:

Siberian Larch as raw material

A summary translated from:

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Translation: John Derome

1. PROCUREMENT, PRE-STORAGE AND SAWING THE LARCH LOGS

The objective of the sub-project carried out at the Joensuu Research Centre, the Finnish Forest Research Institute (Metla), was to collect empirical stand, stem, log, saw timber and wood sample material, as well as to investigate how the pre-storage and sawing methods affect the drying of saw timber and the gluing of boards.

The main material consisted of 23 stems of 101-year-old Siberian larch (*Larix sibirica*), collected from Metla's research area in Punkaharju. 13 green stem logs were sawn in April and May 1998, and 10 were stored for sawing in spring 1999. Two 3 m-long butt logs, as well as two 3 m-long middle logs with a minimum upper diameter of 30 cm, were cut from the stems. The sawn wood from five of the freshly sawn logs were delivered to the companies involved in the project. The study also included 5 larch stems from Puhos, Kitee, during 1996-97. Six-metre butt logs with a diameter exceeding 40 cm were cut from these stems, which had been stored for 2-3 years by Lehtikuusela Ky. In addition, 15 stems with a diameter of 15-30 cm were obtained from a Siberian larch cloning trial in central Finland. The trial is owned by the Finnish Forest and Park Service and the stems were cut when the trial was in the thinning stage. Only the 3 m butt logs from these stems were sawn into 50 mm sawn goods. However, these sawn goods were not investigated in detail because the results obtained from small-dimensioned logs were considered to be of little practical use compared to those obtained from large logs. As a result, more determinations were made on the larger logs than had originally been planned. In other respects the study was carried out as planned as regards both quantity and quality.

The normal external quality characteristics were measured on the stems and logs, and they were pre-stored with bark outdoors at the Pietiläinen sawmill in Eno. In addition, larch sawn timber (50*125 mm) imported from Russia was obtained from Puukekus Oy for studies on the drying and gluing of larch sawn timber, and larch sawn timber (50*150 mm) from the Krasnojarsk area in Russia was acquired from Lehtikuusela Ky for studying the drying of larch. The origin of this material varied, the wood arrived in Finland already sawn and dried. Previously felled and dried aspen and pine timber were used as reference materials.

The large-dimensioned logs from Punkaharju and Kitee were round cut mainly into 50 mm sawn timber, although 32 mm sawn goods were taken from the edge of the logs in order to maintain the sawing yield at a reasonable level. Taper sawing was also tested on the butt logs, but this led to defects in the shape of the central yield (wedge shaped sawn goods). The use of special sawing techniques proved to be problematic with the circular saw used in the study (measurement precision, sawn wood yield, quality). After sawing the sawn goods were graded for quality, and the occurrence of defects noted (knottedness, slope of grain, form and growth defects, resin pockets). The sawn goods were then sent to the Technical Research Centre of Finland (VTT), the University of Joensuu and to the companies involved in the project for studies on the drying of larch timber. The small-diameter logs were sawn at the Utra Sawmill of the North Karelian Vocational High School. Samples were taken from the ends of all the sawn logs for the determination of moisture content, density, annual ring widths and extractive contents separately on the sapwood and heartwood. The annual rings of the material were very compact compared to typical Finnish larch: 1 mm in the sapwood and 2 mm in the heartwood. However, the density of the wood was relatively normal: green density 750-800 kg/m³.

The moisture content in different parts of the sawn goods during outdoor drying was monitored using a resistance-based, Protimber Timberlogger probe moisture gauge. The drying rate of larch during outdoor drying, as well as the final result, followed the same pattern as for pine and spruce. In December 1998 the moisture content was 19-21%, which corresponds to that of shipping-dry sawn goods. Because of the warm summer in 1999, however, the moisture content in July 1999 was only 15-16%. The moisture content of the sawn goods prepared from butt logs was lower at both measuring times than in those from middle or top logs, especially in the sapwood. The moisture content in the surface layer of the heartwood was somewhat lower than that in the inner layer of the sapwood and heartwood. The decline in moisture content was slightly faster in the sapwood than in the heartwood. No exceptional splitting or twisting was detected in the sawn goods during the measurements. However, some narrow splits that made handling difficult were found on the surface during the first measurement, and the splits increased in size between the two measuring times. Some bluing and mould was found in some of the sawn goods, mainly in the sapwood and especially in the surface layer of the sapwood.

2. DRYING OF LARCH

The work carried out at the Faculty of Forestry, University of Joensuu, was primarily concerned with studying the drying of larch in hot-air (kiln drying) and vacuum drying. The effect of outdoor storage of larch logs and sawn goods on the drying result was also studied. The empirical drying data produced during the research was used as reference material when VTT's quality kiln-drying simulator was calibrated for larch. The moisture content, splitting, form and colour defects in the sawn goods were compared in eight different drying batches. There were three lots each of normal hot-air and vacuum drying. Two special hot-air drying lots were also included; one of the lots had been stored as green sawn goods outdoors for one year before drying, and the other had been stored as logs before sawing and drying. Both the quantity and quality objectives of this sub-project were attained as planned.

The study material consisted of Siberian larch (*Larix sibirica*) cut during winter 1997-1998 in Metla's Puhos Research Area. The stems were crosscut into sawlogs; some of the logs were stored outdoors at the sawmill with the bark still attached, and some were sawn immediately after cutting. A 50 mm-thick piece of timber was round cut from every log. After sawing the sawn goods were piled and wrapped in plastic to prevent drying. Prior to drying the piles were stored in a cold room at a temperature of +5-7°C and a relative humidity of 70-80%. Storage of all the logs and sawn goods stored for one year took place outdoors. The final moisture contents achieved with the different drying treatments varied considerably. The moisture content of all of the vacuum-dried lots was not even close to the target level. The basic density in the lots also varied considerably. According to the moisture content gradients, the most evenly dried lots were those consisting of wood that had been stored outdoors for more than one year. The internal moisture content of one of the vacuum-dried lots remained considerably high. The differences in moisture content between samples taken from the inner and outer parts of the stems were significant for all the drying treatments. However, not all the drying lots showed differences.

The lot that had been stored as logs for one year had the lowest incidence of surface splits. The second vacuum-dried lot had the best quality as regards splitting, and this lot also proved to be the best as regards form changes. However, it should be remembered that checking of the face side of heartwood is mainly caused by anisotropism, and not the drying conditions.

The sawn goods that had been stored outdoors had developed surface checks before they were dried. The drying conditions during outdoor drying cannot be controlled and, despite the rainy summer, a lot of checking occurred. There were only slight differences concerning checking between the mechanically dried lots. The sawn goods from certain trees developed splits irrespective of the drying technique used. The colour of the sawn goods from one of the vacuum-dried lots remained the brightest. However, the differences in colour were relatively small.

The aims of the research carried out at VTT Building and Transport was to model the drying of Siberian larch (*Larix sibirica*) by means of their Quality Kiln simulator program, and to draw up drying programme recommendations for the larch species studied. Two test dryings were made with 50*150 mm sawn goods in order to obtain suitable parameters for the Quality Kiln simulator program. In these tests the mean moisture content and moisture gradient in the sawn goods were determined at 4 different times. The first lot was dried at a temperature of 50°C and the second at 70°C. Drying programmes were chosen that resulted in minimum checking. The drying programme was developed on the basis of the available literature and the Quality Kiln simulator program, in which pine parameters and the measured initial moisture content and density of larch were used as the starting values.

New parameters were set for the Quality Kiln simulation model on the basis of measurement results. The aim was to obtain a model that would as realistically as possible resemble the drying operations. The model has a total of 6 optimising parameters that depict the movement of moisture inside the wood and the evaporation of water from the surface of the wood. A separate calculation programme was made to determine the optimum values. This program finds the combination of parameters that makes the calculation made by the simulator model on the development of moisture content during drying as similar as possible to the actual drying procedures.

When the original moisture content and density values are known, it is possible to predict, to a reasonably accurate degree, the drying of larch on the basis of the new parameters. However, many more test drying runs will have to be made before the simulation program can calculate the model for larch as accurately as it does for pine and spruce.

3. GLUING OF LARCH

The aim of the sub-project carried out by VTT Building and Transport was to perform a comprehensive investigation on the gluing of larch. Successful, durable gluing is one of the main prerequisites for the wider use of wood materials. The gluing of common Finnish tree species such as pine, spruce and birch is usually successful, and the glued joint is durable as long as the correct glue has been used in the right place and the gluing process has been controlled throughout the process. Larch differs considerably from the common Finnish tree species: the density of larch wood is higher, the composition of the extractives is different, the wood is more permeable, and changes in the shape of the wood caused by moisture are greater.

In this sub-project three different types of glue were used in the gluing test on pieces of larch that had been dried using different procedures. Although most of the tests were made by gluing two pieces of larch together, a few tests were also made in which a piece of larch was glued to a piece of European aspen (*Populus tremula*). The effects of moisture changes on the mechanical strength and changes in the shape of a gluelamelled

board were studied by comparing a D3-glued larch board and a corresponding gluelamelled pine board.

The joint made with PVAc (Poly-Vinyl-Acetate) and RF (Resorcinol-Formaldehyde) glues had good mechanical strength. The drying procedure of the larch wood had no effect on the quality of the glued joint. The pieces were glued together such that the grain in the two pieces was at an angle of about 45 degrees. One series of gluing tests was also performed in which tangential and radial surfaces were glued together. The direction of the grain had no effect on the quality of the glued joint since the results were the same as those obtained when the direction of the grain was the same. As fractures occurred often in the wood of all the glued joints, it is clear that the glued joint is stronger than the actual wood.

In the larch gluing tests made with RF glue the delamination percentage was relatively low, usually less than 5%. Very good mechanical strength and fracture values were achieved in the glued joint in the test in which larch was glued onto aspen. No delamination occurred in the glued joint.

Microscopic examination indicated that the glue penetrates relatively easily into larch wood even though the composition of larch extractives is considerably different from that of the traditional domestic tree species, and therefore a longer pressing time may be needed to achieve a good gluing result.

Larch undergoes considerable deformation when the humidity of the surrounding air changes. Because the magnitude of deformation varies in different directions in the wood, considerable attention should be paid to the direction of the grain when gluing pieces of larch together.

4. SURFACE FINISHING OF LARCH

The aim of the sub-project carried out by VTT Building and Transport was to determine the weatherproofness and moisture penetration properties of larch wood. The weatherproofness of the finished wood depends on the properties of the coating and of the wood. The coverage, density and flexibility of the coating, as well as the moisture properties of the wood, affect the changes caused by sunlight, temperature and changes in humidity. As the density and chemical properties of the wood affect the degree of moisture induced deformation, it is important to use a water-repelling surface paint when using finishing materials that are readily permeable to moisture. The heartwood of finished pine wood checks more easily than the sapwood as a result of weathering.

Three products, which are also used on garden furniture and fences, were chosen as finishing materials. The weatherproofing of the finished pieces of larch was tested in accordance with the prEN 927-3 standard outdoor test, and the water and moisture permeability in accordance with the prEN 927-4 and -5 tests. The weatherproof test used during the project was of relatively short duration, but the test is still running. The coated larch and pine boards were subject to weathering starting in spring 1999. The 6-month test period was characterized by abnormally low rainfall.

The greater the permeability of the finishing material used, the more the properties of the wood affected the water absorption. A dense coating stopped water from

penetrating the larch and pine boards but, in the case of test pieces that were finished with permeable materials or with no coating at all, the tree species clearly became important: less water was absorbed by larch than by pine. Wood oil only slightly reduced the permeability of wood subject to water vapour in the case of pine, even though pine wood absorbed much more oil than larch.

The weatherproofness of the pieces was affected the most by the type of coating used. The water permeability of the coating partly explained the occurrence of checking in the weathering test, i.e. the denser the coating, the more effectively it protected the boards from checking. The tree species had no effect on the incidence of surface checking, although in the tests pine absorbed much more water than larch. When the coating was permeable the direction of sawing had a great influence on the degree of splitting. The pieces that were sawn tangentially developed more checks than those that were sawn radially. Although the boards used in the test should have been sawn radially, tangentially sawn ones also had to be used owing to the restricted amount of test material available.

When choosing a coating, the requirements set by the type of use and the ease of maintenance must be taken into consideration. If the wood is used e.g. in garden, then a finishing material that forms a skin cannot be recommended unless the furniture is sheltered to some extent from the weather. This recommendation is based on the extensive garden chair test performed by the Lahontorjuntayhdistys ry (LTY), in which skin-forming paints flaked off, especially from the seat part. Maintenance painting of chairs of this kind is difficult because all the flaking paint surface must first be removed. The best finish is achieved with a penetrable water-repelling material and it must be repeated every year. Finishing materials that form a skin are best suited for fences, as long as water cannot penetrate into the wood, e.g. through the ends of the timber. Water evaporating through the painted surface can cause blistering, flaking and even splitting in the wood.

5. VOLATILE ORGANIC COMPOUNDS (VOCs) IN LARCH WOOD

The aim of the sub-project carried out by VTT Building and Transport was to study the volatile organic compounds in larch and their effect on the use of larch wood. The indoor use of wood material is affected by the amount and composition of the volatile organic compounds in the wood. At the present time, surface materials exposed to indoor air have been categorized in the indoor air classification into 3 different classes: M1, M2 and M3. The best class (M1) includes emission-tested materials and materials such as brick, natural stone, glass, metals as well as sawn and planed wood (domestic tree species). According to the indoor air classification, the use of materials that produce considerable emissions should be minimised in order to achieve the best result. In the past it was normal to use low-emission woods (aspen, birch) in kitchen utensils. There is little information available about larch in this respect.

The decision was made in this sub-project to study the possible amount and quality of volatile compounds in larch, and the effect of the drying process on the emission of such compounds. The aim was not to gain approval of larch in the indoor air classification, but to study the volatile compounds and their effect on the possible uses of larch.

Samples were taken from green pine and spruce, and from larch that had been dried using different techniques. As the samples were taken at the same time from the different drying lots, the time between the drying instant and sampling varied. The wood material was milled at VTT Building and Transport, and then sent to VTT Chemical Technology. The samples were analysed by gas chromatography using the thermal desorption sample injection technique. The analysis temperatures were 50, 100, 150 and 200°C. The gas chromatograph was equipped with a flame-ionization detector (FID) and a mass selective detector (MSD). The limit of quantification of the method for individual VOCs is 1 µg/m³. The total amount of volatile organic compounds (TVOC) was calculated as the total surface area of the FID chromatogramme using toluene as response factor.

The amount and composition of VOCs from green larch wood differed significantly from the corresponding data for pine and spruce. Larch wood contained relatively little VOCs compared to pine. The amount of terpenes especially was smaller in larch, but acetic acid was emitted from larch wood but not from pine or spruce wood. Acetic acid emissions may increase the possibilities of metal corrosion or the rusting of nails. However, there may be differences between larch materials depending e.g. on the origin, individual tree, location along the stem, tree age, analysis time and manufacturing process. However, this variation was not studied in more detail in this study.

Only very small amounts of VOCs were emitted from the wood at the lowest temperature (50°C). This temperature is higher than normal indoor temperature. Corresponding values only occur in timber kilns or at surfaces exposed to direct sunlight. Because the method used in this study for the determination of VOCs is different, the results obtained at the test temperature cannot be compared to practical situations or to the results used as a basis for the indoor air classification.

The drying method had some effect on the amount and type of compounds emitted from the wood after drying. The influence was not very significant on the extractive composition. On the average more volatile organic compounds were emitted from fresh wood than from dried.

6. THE EXPERIENCES OF LARCH USERS

The sub-project carried out by the Joensuu Research Centre, Metla, consisted of a survey of the experiences gained by members of Puuseppämestari Ry and the Finnish Prison Service in the use of larch as a material during the course of the study, and the special features and problems that occurred during individual stages in the manufacturing process of larch-based products.

The members of Puuseppämestari Ry carried out a wide range of tests on larch: roofing shingles (thick veneers), furniture, doors, window frames, frames for currant bushes, flooring boards in wet environments, small panels, tools and utensils. The main emphasis was on the workability of larch: how suitable is larch compared with pine. A large number of factors affected the comparison: the direction in which the blank was sawn, the working technique and the blade angles used during working, the moisture content of the wood and changes in it, variation in the cellular structure and hardness of the wood, splintering and splits in the wood, deformation caused by changes in the moisture content, knottedness and the effect of knots on the workability, the resin content of the wood etc.

One common observation was that the dryer the wood, the harder it was to work with it. Current information cannot be used to define a critical moisture level for larch workability. Thin, 25 mm-thick larch timber is easier to work with than thicker 50 mm timber, probably because of the internal moisture gradient.

The main factors underlying workability and use were drying defects, checking being the worst. It limited the uses of larch wood, and produced a lot of waste material. At the beginning of the study especially there were so many checks in the 50 mm and thicker air-dried sawn goods, particularly around the pith, at the ends of the planks and on the upper face side, that the timber was almost useless in joinery. The situation in the case of thinner sawn goods (26-34 mm) was not so serious. The drying method (vacuum or hot-air drying) did not seem to have any significant effect on the occurrence of checking and other drying defects. On the other hand, the direction of the cutting surface of the timber did have a considerable effect on the number of checks. A lot of checking occurred on the tangential cutting surface and, as a result, the proportion of waste material in further processing was as high as 60-70%. The surfaces of timber cut in a radial direction were almost completely fault-free, and the waste proportion was only 5%. Attention was also drawn to heartwood cracks in a radial direction which do not pass through the pith and run from point to point in a radial direction. Splits in the timber caused a considerable amount of width wastage in joinery work, on the average 34% (5-70%).

Uneven final moisture content proved to be a difficult problem. Although the timber should have been dry enough for joinery work, the pieces that had been worked into blanks developed so much twisting and bending that, after the first working stage, they had to be left to stabilise for a considerable period of time before working could be continued. This was thought to be due to the drying of relatively moist parts in the wood after the initial working. The tensions that developed during drying of the timber had their own effect on twisting and crookedness. There was considerable cupping (convex/concave faces) in the planks. This was thought to be because of the unusually large differences between contraction in the radial and tangential directions. The users did not think that cupping was a major problem because they were able to obtain two almost straight pieces by splitting the plank in half down the centre.

Part of the larch material was relatively knot free and it was easy to prepare small knot free parts for small wood products. On the other hand, the material did include large, occluded vertical knots inside the stems that made it difficult to produce long sections. The knot sections were usually so large that they could not be left on the finished product and had to be removed by cutting the timber at the site of the branch. There were no intact sound knots in the dried timber because even the sound knots had split during drying. Stems had also usually crooks in the direction of the stem where the branch whorls were situated.

Larch contains so much resin that this must be taken into account when working the wood. In the worst cases resin oozes from all the cut surfaces in small droplets, and it also occurs in large resin pockets. There seems to be considerable difference between stems and different parts of the stem in this respect.

The splinters, especially in the surface of artificially dried sawn goods, are so sharp that it is virtually impossible to work the wood without getting some splinters in your fingers. This is such a problem that gloves have to be worn by the worker. On the other hand,

the use of gloves often makes it more difficult to work the wood because it reduces the “feel” or “touch” for the wood that you get when working with bare hands. The same problem with splinters occurs on planed and sanded surfaces when the fibres of the wood become loose and they stand up. Splintering is only the first stage of a much more serious phenomenon where the annual rings become detached from each other. Sometimes during working the annual rings in the heartwood close to the pith become so loose that – as one user stated – you can almost take the wood along the annual rings.

The bark of larch is very tough and compact. It is also so strongly attached to the wood that it does not peel off during drying. The bark can be worked by itself or left in the final product next to the wood. This quality could be utilized in designing and manufacturing small items.

There are considerable differences in the hardness of earlywood and latewood and, furthermore, the knots are markedly harder than the other parts of the wood. This sets special demands on the workability that cannot be solved with ordinary tools, blades and blade materials. The users indicated that differences in hardness can be overcome by, for example, changing the angle of the blades.

If the structure of fibres is a problem during working, it is also a special quality that gives a larch product some character. A strong grain pattern can also be used to advantage in product design. The clarity of the grain pattern can be even more accentuated by suitable finishing.

When a band saw is used to saw larch wood along the grain, the blade tends to follow the grain and it is hard to follow the desired sawing line. This is especially the case when a narrow, slightly blunt blade is used. When a circular saw is used, cross-sawing is the same as when sawing pine. With cross-cut sawing, the back support must be in extremely good condition to prevent ripping of the cutting surface.

Larch rips easily close to knots, especially when planing against the grain. Dead and also sound knots are especially problematic. When planing with blunt blades, the rings become loose in the tangential cutting surface and form splinters. In a radial cutting surface, planing larch is similar to planing pine. When moulding larch along the grain, the rings may come loose and be pulled off in front of the cutter as long splinters. A low input speed reduces splintering but, at the same time, it increases the risk of burn marks being formed. When milling across the grain the difference in the hardness of spring and summer wood can be a problem. This results in a relatively rough finish and smaller forms in the wood tend to break off along the line of the annual rings.

The sanding of larch is extremely difficult because of its high resin content. The sanding band becomes clogged before it has worn out. If you try to sand larch against a supported sanding band, then you have to use much more pressure. As a result, the softer springwood is sanded deeper than the summerwood, giving an uneven surface. A worn out sanding band causes burn marks, especially at the ends of the timber.

Drilling small holes into the cut end of larch timber is especially difficult because the direction of the drill tends to follow the orientation of the soft earlywood within the annual rings. If the drill does not have sharp cutting edges along its side, the edges of a hole drilled into the cut end will stand up without being cut.

Larch requires extremely sharp chisels. Even so, the fibres tend to bunch much more than with pine. Reducing the angle of the chisel to 22-25 degrees improves the final result, but this can also damage the edge of the blade and thus slow down the working and make it more laborious.

Larch has been turned with a lot of different kinds of chisel, in different grain directions, at different turning speeds, and different shapes etc. Investigating the true turning qualities of larch therefore requires the development of a special assignment and working method. A lot of the carpenters involved in this study tried turning and made observations that were similar to those that occurred in other working methods. In the turning work each carpenter had the opportunity to try out his own techniques. Some of them solved the problems, but others did not. How they solved the turning problems could provide some solutions for the workability problems of larch.

The suitability of larch as a decorative wood and for carving in general was tested by one of the top professional carvers. The workability qualities of larch mentioned earlier become much more evident when carving the wood. The hard summerwood and hard knots can damage the very sharp edges of the chisels, and the difference in the hardness of spring- and summerwood can cause the wood to flake off etc. The drier the wood, the harder and more difficult it is to carve. The optimum moisture content for carving is about 15- 17%. However, the finished carved product may split as the wood continues to dry. The strong grain pattern can be used to advantage on large surfaces especially.

When inserting nails and screws it was found worthwhile to drill holes for them. Also the use of untreated and galvanised nails and screws caused the wood to darken near to point of insertion, especially in outdoor conditions. It is assumed that the acetic acid in larch causes this corrosion effect. Joining wood with PVAc glues was similar for both larch and pine. However, a slightly longer compression time was needed for larch than for pine. Finishing with natural oils seemed to be very successful. An extra layer of varnish was needed to achieve a smooth surface because the spring- and summerwood absorb varnish to a different extent.

The test results reported by the Finnish Prison Service (Vaho) were similar to those obtained in the carpenters' tests. Both the Sukeva Central Prison and the Juuka Open Prison, which participated in the project, have been manufacturing garden furniture for years. The furniture has been made from domestic raw material and it has been pressure impregnated to withstand the weather and other moist conditions associated with the ground. It has so far been shown, without any tests but merely on the basis of expert opinion, that larch has a natural ability to withstand weather stresses in very demanding sites of the joinery industry, such as outdoor constructions and other sites exposed to moisture. The aim of this part of the study was to validate these qualities on the basis of tests and, at the same time, to obtain the latest information on the use of larch in the joinery practiced in prisons: the drying programmes for hot-air, condensation and vacuum drying techniques for larch, the workability and gluing of larch material, as well as the finishing methods.

The air-dried 50 * 150 mm Siberian larch timber used in Sukeva was supplied by Puukeskus Oy, and it had been stored outside for 3 months. The moisture content of the sawn goods was determined before and after drying, and the dry dimensions and drying faults were recorded. The larch timber looked very good when it was stored in piles prior to

drying. After drying the planks started to check severely. About half of the material had surface checks, and the checks ran diagonally across the planks. The depth of the checks was 5-15 mm and most of them were 300-500 mm long. The knots, except the pin knots, were loose. Larch is a much more problematic working material than pine or spruce. The working of larch requires very sharp blades and they have to be changed relatively frequently. However, the working was very successful with the CNC working centre. The finishing with wood oil makes the pieces very slippery, and the piles readily collapse during transportation. Wood oil dries very slowly. When large amounts of timber are produced, both drying and finishing become a problem. Knot free larch has a very beautiful grain pattern. In order to achieve a faultless final result, the raw material would have to be knot free and the drying have to be very successful. Stricter quality control will have to be applied compared to that employed with the lot in question. Otherwise the quality of the product will deteriorate as a result of knottedness and surface checking, and there will be a lot of customer complaints.

The timber used in Juuka, which was supplied by a private timber agent operating from the Niirala border post, was air-dried Siberian larch imported from Russia. Before use, the timber was dried to the final moisture content using a so-called long program, in which the starting temperature was maintained at 25°C for several days. When the moisture content fell to about 30%, rapid drying of the surface produced a lot of small, deep cracks in the 50 mm-thick timber. There were no problems in drying the 25 mm-thick timber. The drying time was very long for larch, almost 3 weeks. The larch timber was left to stabilize in the splinting trolley in the normal temperature part of the warehouse in order to ensure that all the water pockets had evaporated. During this time the moisture content levelled off to 6-8%. Larch wood is very hard and the working tools become blunt much faster than when working with pine or birch timber. On the basis of 3 years experience, screws and PVAc glue joints are used in producing the garden furniture. Holes have to be made for the screws in order to prevent splitting, especially when the screws are inserted close to the edges of the wood. The strips of wood used for the seat parts of garden furniture are glued as well as screwed in order to obtain a stronger joint. Rustic tables for indoor use have been made from glue lamelled larch boards, with positive results as regards working, gluing, external appearance and customer feedback. The first finishing treatment consisted of Tikkurila's wood oil, and it was applied by hand. This caused the furniture to turn grey after a few years of use outdoors. As a result of this and instructions from the manufacturer, it was then primed with Valtti primer and finished with hardwood oil. This has extended the weather resistance and preserved the original colour of the wood.

According to Lehtikuusela Oy, the price of green larch timber from Russia is 2000 mk/m³, and this includes all kinds of wood. Puukeskus Oy has stopped importing larch from Russia due to the lack of demand, but there are still a few small importers left. The conclusion is that it is economically viable to import larch in logs because the price is 500 mk/m³. The logs have about 24% bark (compared to 10% for spruce, 12% for pine) and the conversion ratio in sawing is 3.0. The cheapest way to acquire larch is to buy 25 mm lumber from Russia, as this has few checks.

7. UTILIZATION OF THE RESULTS AND THE NEED FOR FURTHER STUDIES

The existing and upcoming industries and companies that manufacture joinery products (outdoor furniture, outdoor and playground structures, surface structures for wet indoor areas, windows and doors, small articles and a range of kitchen utensils) are the main

beneficiaries of this research. These industries and companies were considered to be potential users of larch in the planning stage of the project. At the start of the project, the problem areas in the processing of larch were known to be drying, as well as to some extent finishing and volatile organic compounds. The results regarding drying especially can be utilized immediately in manufacturing companies and in optimising VTT's Quality Kiln simulator program.

Larch is a special raw material that is ideally suitable for small- and medium-volume production. However, the availability of large-dimensioned domestic larch is very limited, 1 000-2 000 m³/year. The establishment of regular imports from Russia would open up new possibilities for its wider use in manufacturing. In order to maintain the quality of the timber, however, it would be best to import it in the form of logs, although the price would be cheaper if it was imported as relatively knotfree boards or planks. The supply of larch thinnings from the larch stands that were planted in the 1960 will increase in the future. However, we still do not know its usability in the wood-working industry.

Of all the companies involved in the project, *Lehtikuusela Ky* has the longest tradition in the manufacture of a wide range of larch products; they have been using larch since 1968. Their manufactured products have included: 1) structures and furniture for outdoor use, 2) building windows and doors, 3) sauna interiors, platforms and floors, 4) floorboards and interiors for rooms, 5) table frames and furniture, 6) kitchen utensils, 7) pallets for the food industry, 8) roofing boards, 9) eave boards, 10) ridge beams, 11) roof ladders. In December 1999 the company had 14 different approved uses for larch. The company is benefiting especially from the results of the drying, gluing and VOC tests.

During the project the members of *Puuseppämestarit Ry* were able to test the use of larch for a range of products and, as a result, they received first-hand information and experiences with this material that are relatively new to most carpenters. A survey was performed among the members that provided new information to fill in the gaps in our knowledge about larch, especially in the production process.

The *Finnish Prison Service* concentrates on the manufacture of larch furniture for garden and outdoor use, as well as of rustic indoor tables. The service is benefiting especially from the results of the drying, gluing and finishing tests.

At the beginning of the project *Puukeskus Oy* was importing larch timber from Russia, but imports have subsequently ceased owing to the lack of demand. The company was included in the project on the assumption that there would be an increasing demand for larch, greater emphasis on green environmental values, better availability of Russian larch, and the need to be a pioneer in the industry. These justifications still exist, and also apply to other larch importers.

There are about 10 companies in Finland that use larch and they are all relatively small. Two medium-sized, wood-working companies that manufacture larch products have been established during the course of the project. Both *Timberwise Oy* in Loimaa and *Pariwood Oy* in Parikkala manufacture floor materials in the form of glue lamelled boards made from larch. Both of the companies are planning to use several thousand m³ of larch per year. These and other companies that are likely to be founded in the future are all potential users of the results of this and future research. The assumption that

new companies will be set up is based on the growing demand for larch in the domestic processing industry and in the exporting markets.

In the future it is essential to determine what kind of tools that are best suited for working larch. In carpentry every tree species should have its own tools. The working forces clearly increase after each working round, i.e. larch is not worth working with blunt blades; the fibres in the wood also clearly guide the tool. One topic that clearly requires further study is the blade materials and working angles required by the furniture and other processing industries in the manufacture of larch products. It would also be interesting to find out how the strongly attached bark of larch could be employed in decorative items.

Another important topic for future study is the finishing of larch. One option is to coat soft tree species with harder ones such as larch. There is also interest in studying the effects of finishing on the resistance of larch at points exposed to weather stress. A weathering test was started in this project, but the results cannot yet be utilized. There is also interest in studying the effect of the structure and chemical composition of the wood on its technical properties.

Other possible research topics include the design and mechanical strength of supporting structures made from larch, the manufacturing and product requirements of windows, and floor structures.

The production costs and economic viability of larch products were not included in this project. They are essential research and development topics for any larch-processing company that intends to expand either in quantity or by investing in new products. The most promising product groups when planning new research are: 1) outdoor furniture, 2) joinery products (windows, doors), and 3) small objects.

The utilization of small-sized larch thinnings has hardly been studied at all, not even in those countries with larch-dominated forests. This is at the forefront of research topics on larch if the industrial use of domestic larch, and especially the cultivation of large-dimensioned larch to meet future demand, are to be promoted.

Tekes and the regional funding organizations of the timber industry will undoubtedly provide funds for future research on larch in accordance with the interest shown by companies active in the field. Projects on larch are not excluded if the companies are themselves willing to invest in this subject. Other sources of funds include the EU, Craft, INTERREG, TACIS and the Academy of Finland.

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3:

Properties and Processing of Larch Timber -

a Review Based on the Soviet and Russian Literature

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Preface

The Nordic countries are famous with their concern about the environment. Recently, the public faces more than ever a variety of environmental problems, which must be solved. Regarding the above-mentioned issues, new and environmentally friendly wood products become of great interest to the industry and public. Sophisticated, well-informed customers insist on low-impact, sustainable wood products, thus making new rules and pushing ahead the development of the forest industry.

Society's striving for new wood products concerns directly the wood preservation, which is subjected to great metamorphosis. Historically, the Nordic countries have been the cradle of wood impregnation but recently they have to reconsider a lot of the preservatives used and to find new alternatives to protect the wood products. With respect to that, natural durability of new, particular wood products and well-known but yet "new" species become of urgent interest to the research community and industry. Such a "new" species is larch.

The present literature review is based only on the data found in the Soviet and Russian literature and comprises chemistry, physical and mechanical properties as well as processing of larch timber. The Institution of Forestry at the Russian Academy of Sciences has been established during the thirties of the last century and has been relocated to Krasnoyarsk in 1959. For more than seventy years the larch timber has been an object of studies at the above-mentioned institute and enormous numbers of scientific papers and reports on all aspect regarding its properties and utilisation are available. Other relevant data sources, published in Russian, are also included in the review.

The author of this review has had the humble ambition to summarise some of the most important papers on the chemistry, physical, mechanical properties and utilisation of larch timber; it has been virtually impossible to study all the immense number of papers. Part of the information is presented in tables; the reader can observe and compare the original results. The review could be of use during the coming joint Nordic project "The potential of Larch wood for exterior use compared to Scots pine and Norway spruce" but also for the sawmill and woodworking industries. The author kindly thanks Dr. Galina F. Antonova, a leading researcher at the Institution of Forestry, the Russian Academy of Sciences, Krasnoyarsk, for the help when forming the review.

Siberian forests

Siberia is the largest forest region in Eurasia. The forests cover an area of 471.7 millions ha and have a growing stock of more than 40 billion m³ what makes about 11 % of the world stock resources. 49 % of Siberian forests are in permafrost zone, 32.1 % of the stands have low productivity. High classes of yield (I-II) are characteristic only for 7.6 % of the stands. The annual average volume increment is about 1.31 m³ per ha, the average growing stock consists of 150 m³ per ha in mature stands. The actual capacity of cutting comprises 80-100 m³ per ha because of ecological, economical and technological restrictions.

Top priority ecological importance of the forests

The Siberian forests are a complicated natural system that provides ecological stability of various natural complexes. Water protective, water regulating, soil protective and climatic roles of the Siberian forests are the most important. The diversity of forest ecosystems in various natural zones and altitudinal complexes determines their quantitative and qualitative characteristics. Mountain forests form a specific category. Their role is distinctively seen in forming the flow of the largest Siberian rivers.

Rather high wind activity in mountains promotes the spreading of forests gaseous substances and chemical compounds being contained in transpiration vapour moisture. Biosphere forest functions are weakened in the northern regions because of short vegetation period. However, there the local ecological importance of forests increases. It is revealed in soil protection, water regulation, avalanche prevention and other forest functions as well as in forming of a more favourable environment.

Northern forests as a habitat of aboriginals

Siberian northern forests stretch from the West to East along the tundra line for more than 7000 kilometres. Low productivity, peculiarity of tree forms, small dimensions, prevalence of small shrubs, mosses and lichens, increased natural fire danger, little floristic diversity are part of their characteristics. Sub-arctic forests are of great significance for the inhabitation of about 20 ethnic groups of aboriginals.

The culture of these people is a sample of a man adaptation to extreme conditions of high latitudes as well as of wise utilisation of Nature. The industrial exploitation of the North resulted in decrease of nature utilisation and in large worsening of the ecological situation. The stable development of the northern area can be provided only on the base of revision of approaches to economical activity based on regional ecological demands.

Biological diversity of woody plants

36 tree species and 104 shrub species grow in the forests of Siberia. The main species forming the forests are Siberian larch (*Larix sibirica* Ledeb.), Gmelin larch (*Larix gmelinii* (Rupt.) Rupt.), Cayander larch (*Larix cajanderi* Mayr), Scots pine (*Pinus sylvestris* L.), Siberian pine (*Pinus sibirica* Du Tour), Siberian spruce (*Picea obovata* Ledeb.), Siberian fir (*Abies sibirica* Ledeb.), birch (*Betula pendula* Roth.), and aspen (*Populus tremula* L.).

Soils of Siberian boreal forests

Siberian forests soils are formed under conditions of the cold and temperate-cold climate under various conditions regarding genesis and composition. There are two macroformations: frozen soils where the soil remains frozen for many years (permafrost) and closes down with a seasonal-frozen layer, and cold soils where permafrost is absent or it does not close down with the seasonal-frozen layer. The heat and water are the limiting factors of forest productivity in Siberia. Frozen soils are characterised by an unfavourable hydrothermic regime that determines the slow biogeochemical substance turnover, accumulation of dead plant residues as well as low assimilation of nutrients. The frozen soils permit growth of monodominant larch tree stands of low productivity. Forest site characteristics of cold soils are more variable, and the forests have higher productivity.

Maximum age of soils is determined, obviously, by the late pleistocene. The distribution of the areas of frozen and cold soils has changed over time because of repeated climate changes.

Resources of larch in Siberia

The larch forests in Siberia predominate when measured by area and stock (Table 1). Data are published by Sokolov (1997) and Sokolov *et al.* (1998).

Table 1. Geographical distribution of larch forests in Siberia.

Region	Area, thousand ha	Timber stock, mil. m ³	Volume of harvest, mil. m ³ (data from 1996)
Altay territory	70.8	12.7	-
Republic of Altay	624.9	116.4	-
Kemerovo	6.3	0.7	-
Novosibirsk	3.0	0.4	-
Omsk	2.1	3.0	-
Tomsk	9.5	1.4	-
Tyumen	0.3	0.04	-
Khanty-Mansiisk	858.7	72.9	0.1
Yamalo-Nenetsk	5151.2	417.4	0.3
Total West Siberia	6726.8	622.3	0.4
Krasnoyarsk	7915.8	1126.9	1.4
Taimyr	1474.6	71.3	0.1
Khakasia	413.6	59.9	0.3
Evenk distrikt	34761.5	2588.8	0.1
Irkutsk	17240.1	2576.5	2.3
Ust-Ordynskii Buryat district	191.1	34.9	0.1
Chita district	15240.3	1616.9	1.2
Aginskii Buryat district	247.0	39.7	0.1
Buryatia district	9845.0	987.9	0.9
Tyva district	3701.1	565.2	0.2
Total Eastern Siberia	89556.5	9596.7	6.8
Total Siberia	96283.3	10219.0	7.2

The larch stands take 8.5 % from the forest area in West and 41.4 % in East Siberia. The main massifs of larch forests are concentrated in East Siberia, predominating in northern and central regions.

The share of mature and over mature stands makes about 80 % from total area of larch forests, varying from 40 % in Altai and up to 90 % in Krasnoyarsk territory. The output of commercial timber changes from 70 % in north taiga and up to 76% in a south taiga and forest-steppe regions, being reduced to 74 % in mountains of southern Siberia. The ecology-economic accessibility of timber harvest from operating annual designed cuttings areas on an expert evaluation changes from 10 % in northern taiga to 70 % in Angara river basin (southern taiga). The average value for the whole Siberia can be evaluated to 40-50 %.

According to an expert evaluation the larch timber is used mainly as constructing logs (20 %), sawn timber (30 %), plywood (5 %), furniture (5 %), wood chips for the cellulose and paper industry (5 %), sleepers (15 %) and fire wood (20 %).

Taxonomy of larch

Eight naturally growing species of larch, i.e. *Larix sukaczewii* Dylis [=*L. russica* (Endl.) Sabine ex Trautv.], *Larix sibirica* Ledeb., *Larix gmelinii* (Rupr.) Rupr., *Larix cajanderi* Mayr, *Larix ochotensis* Kolesn., *Larix olgensis* A. Henry, *Larix kurilensis* Mayr, *Larix kamtschatica* (Rupr.) Carr. are distributed on the territory of Russia. The majority of these species are not universally recognised and are an object of discussion yet.

According to Milyutin (1998) the species *Larix decidua* Mill., *Larix polonica* Racib. and to less extent the Asiatic *Larix leptolepis* (Siebold et Zucc.) Gord. are also found in Russia. The North American species of *Larix* are spread on the territory of Russia to a very limited extent, mainly as experimental forests.

Intraspecific taxons are studied in details in *Larix sibirica*. This species has the following subspecies (ecotypes, geographic races): *obensis*, *altaica*, *sajanensis*, *jenisseensis*, *polaris*, *lenensis*,

baicalensis, *transbaicalensis*. Only morphological forms are described for the other species; the forms differs by colour of young female cones, by colour of antherouses, by type of bark and other features.

Comparative wood anatomy of some larch species

Only a few studies related to the wood anatomy of larch species, especially on the Siberian ones could be found in the literature. One of the most comprehensive studies is that of Benkova and Nekrasova (1998) who have studied comparatively the anatomical features of three Siberian larch species, i.e. *Larix gmelinii*, *Larix cajanderi* and *Larix sibirica*. The samples of *L. gmelinii* and *L. cajanderi* have been collected from the northern timberline and those of *L. sibirica* are from Shira steppe. Brief description of larch anatomy on comparative basis is presented below.

Transversal section

Distinct growth ring boundaries. Sharp early/latewood transition. Extremely rare diffuse and terminal axial parenchyma. Resin canals are bordered by 8- 14 secretory cells. Average mean of the ring width in *L. cajanderi* and *L. sibirica* are not exactly distinct (0.417 mm and 0.414 mm respectively). On the other hand, ring width in *L. gmelinii* is approximately 1.6 times larger than that in the two other species. Average radial earlywood tracheid dimensions are statistically, different in all three species: 36.1 μ in *L. gmelinii*, 44.7 μ in *L. cajanderi* and 54.1 μ in *L. sibirica*.

Radial section

Rays are heterocellular. Transversal tracheids are present in rays. Piceoid and taxodioid pits occur in the crossfields of the earlywood. Thick-walled parenchyma ray cells; nodular tangential walls are also present. Ray tracheid walls are smooth and wavy. Bordered pits in radial walls of the tracheids are mainly uniseriate in *L. gmelinii*, biseriate in *L. sibirica* and *L. cajanderi*; pits are of the same diameter in *L. gmelinii* and *L. sibirica*. Pit diameter in *L. cajanderi* is 1.2 times larger then that in the above-mentioned species. Pits in the crossfields of

the earlywood are statistically different in size in all studied species; in *L. gmelinii* they are 1.8 times larger than in *L. cajanderi* and 1.2 times larger than in *L. sibirica*.

Tangential section

One to three-seriate rays. Rays are composed of 2-30 cells in height in *L. cajanderi*, and up to 25 cells in *L. gmelinii* and *L. sibirica*. Radial resin canals in multiseriate rays are bordered by mostly 12 secretory cells in *L. cajanderi*, by 8 cells in *L. gmelinii* and up to 20 cells in *L. sibirica*. Resin canals are often eccentric in rays. Helical thickenings are present, but mainly in latewood tracheids. Tracheids in *L. sibirica* are 1.5 times shorter in average than those in *L. cajanderi*; among them earlywood tracheids are 1.8 times shorter and latewood tracheids are only 1.2 times shorter.

Since the tracheids are the main anatomical element, some morphological data are shown in Table 2.

Table 2. Morphology of tracheids for some coniferous wood species (Ugolev 1982).

Species	Diameter of tracheids, μm						Length of tracheids, mm
	In radial section		In tangential section		Wall thickness		
	Early wood	Late wood	Early wood	Late wood	Early wood	Late wood	
Larch ¹ spp.	52.4	21.8	32.0	27.4	3.3	6.6	2.6
Pine ² spp.	40.0	20.0			2.0	5.5	2.8
Pine ³ spp.	40.9	19.7	29.4	32.5	1.5	5.9	
Spruce ⁴ spp.	35.0	13.0			2.2	3.9	
Spruce ² spp.	45.0	22.0			3.0	5.0	

¹ data presented by Vikhrov (1949), ² Perelygin (1954), ³ Moskaleva (1957) and ⁴ Ugolev (1982).

The anatomical description of the three larches must be interpreted cautiously having in mind the diversity of climate, soils, forest operations, etc. in Siberia.

Chemistry of larch wood

The earliest studies on the chemical composition of larch wood, its extractives and utilisation of resins are dated 1930 (Shavrov). This is the most studied topic, the number of publications found exceeds those dedicated to the physical and mechanical properties.

The main chemical feature of larch wood is the presence of a high amount of arabinogalactans. The arabinogalactane content of larch wood is 10-15% (Aleksandrova *et al.* 1998) but, as it will be shown below, often could exceed 20 % of the total dry weight. Arabinogalactan is hydrolysed to 88.1 % galactose and 11.9 % arabinose (Tzvetaeva *et al.*, 1952). The polysaccharide arabinogalactane has a broad spectrum of uses, for example as a hardener and weak glue in the textile industry.

Tzvetaeva *et al.* (1952) have also studied the main structural compounds and extractives in the wood of *Larix dahurica* and tried to relate them to the age of tree. The summarised results are shown in Table 3 and 4.

Table 3. Chemical composition of the wood of *Larix dahurica* at various ages, % of the dry weight.

Age of tree, years	Cellulose (Kürschner)	Pentoses in the cellulose	Klason lignin	Uronic acids	Mannan	Amount of extractives			Arabinogalactane	Ash
						Ether	Eb ¹	H ₂ O		
149	46.7	1.7	27.8	3.0		1.2	2.4	11.9	9.8	0.2
151	45.4	2.8	26.7			1.1	2.2	15.0	13.9	0.3
168	39.1	3.1	24.7			1.2	4.3	24.6	22.3	0.1
216	39.5	3.3	25.3	2.9	6.1	1.4	6.3	22.6	16.4	0.3
250	38.0	2.8	27.4	2.9	8.7	1.7	3.6	17.8	12.5	0.5
250	30.5	0.7	23.1	3.0	5.2	1.8	3.8	33.3	29.7	0.6

¹ ethanol benzene

The wood of *Larix dahurica* has lower content of cellulose compared to the controls of Scots pine and Norway spruce (an average of 49 %) but higher content of water-soluble extractives.

Table 4. Amount of extractives in the wood of *Larix dahurica* at various ages.

Age of tree, years	Amount of extractives, %			Arabinogalactane, %
	Solved in ether	Solved in ethanol benzene	Solved in water	
26	0.7	2.5	12.2	10.1
82	0.9	2.8	13.6	9.6
113	0.8	2.1	9.8	6.8
114	1.2	3.5	13.2	8.1
120	0.7	1.8	11.6	9.7
121	1.0	1.9	8.0	6.6
121	1.1	2.6	13.3	12.1
149	1.2	2.4	11.9	9.8
151	1.1	2.2	15.0	13.9
168	1.2	4.3	24.6	22.3
183	0.7	1.8	5.6	4.5
216	1.4	6.3	22.6	16.4
250	1.7	3.6	17.8	12.5
250	1.8	3.8	33.3	29.7

The highest value for the amount of arabinogalactane is almost 30 %. The variations of the arabinogalactane amount could not be related to the age of tree (Table 3 and 4). No relationship between the arabinogalactane and other extractives solved in the organic liquids can be discovered.

As expected, the sapwood and heartwood of *Larix dahurica* differs significantly regarding the chemical composition (Tzvetaeva *et al.* 1952, Table 5). The heartwood has been found to contribute to 90 % of the cross cut area of the stem. The sapwood is rich in cellulose but has very low content of extractives (both solved in organic liquids or water). Heartwood has significantly less cellulose but very high amount of arabinogalactane. Resins (soluble in ethanol benzene) are mainly located in the heartwood (5.6 %) and somewhat less in the sapwood (3.0). Galactane in the wood *Larix dahurica* is found almost entirely as arabinogalactane.

Table 5. Chemical composition of the sap- and heartwood of *Larix dahurica*, % of the dry weight.

Compounds	Sapwood	Heartwood
Cellulose (Kürschner)	52.9	37.6
Pentoses in the cellulose	3.7	2.4
Klason lignin	25.6	21.6
Amount of extractives (H ₂ O)	2.0	19.9
Arabinogalactane	0.8	19.5
Galactane	1.0	15.8
Mannan	9.4	7.3
Uronic acids	2.8	2.7
Amount of extractives (ethanol benzene)	3.0	5.6
Ash	0.2	0.5

Antonova *et al.* (1980) has studied the organic soluble extractives from the heartwood of larch. The dominant flavonoids found are quercetin (11 % of the total amount flavonoids), dihydroquercetin (69 %) and dihydrokaempferol. Additionally the authors have measured the amount of fatty acids extracted from the heartwood (Table 6).

Table 6. Fatty acids in *Larix dahurica*.

Fatty acid	Amount related to the total of picks, %	
	Sapwood	Heartwood
Pelargonic acid	69/trace ¹	Trace
Palmitic acid	2/15	3/4
Oleic acid	3/38	12/19
16-methyloctodecanoic acid		8/0
Linoleic acid	Trace/24	22/trace
Octodecanoic acid	Trace/14	20/21
Linolenic acid		Trace/33

¹ the nominator shows free acids, the denominator is bounded acids

Almost all studies on the chemical composition of larch wood show a great variation in the amount of substances. Usually this is explained by the diversity of stands and climate. Data from the Siberian Technology University shows the variability of the main structural compounds and extractives in the sapwood of *Larix sibirica* regarding the time of year (Table 7).

Table 7. Annual fluctuations of main structural compounds and extractives in the sapwood of *Larix sibirica*.

Compounds	Amount, % of the dry weight				
	February	April	June	September	December
Cellulose (Kürschner)	33.0	40.5	38.7	41.5	38.2
Klason lignin	37.3	29.4	30.3	25.9	28.4
Penthoses	10.4	9.9	7.0	10.3	7.1
Proteins		3.0	3.6	4.1	3.1
Amount of extractives (H ₂ O)	9.8	6.9	12.9	4.8	9.2
Amount of extractives (ethanol benzene)	1.4	1.6	0.4	4.6	1.3
Ash	0.40	0.58	1.21	0.44	0.66

The chemical composition of larch is significantly different from that of Scots pine but even great variations exist among the various larch species. The water-soluble extractives show a wide variation between species and growing stands (Table 8).

Table 8. Comparative chemical composition of two larch species and 4 stands (areas), % of the dry weight.

Compounds	<i>Larix dahurica</i>		<i>Larix sibirica</i>	
	Far East	Sahalin	Central Siberia	Krasnoyarsk
Cellulose (Kürschner)	52.1	39.5	45.8	45.9
Klason lignin	26.6	25.3	29.5	29.5
Penthoses	11.6	8.8	9.3	9.4
Hemicellulose	20.4			
Mannan		6.1		
Galactane		14.4		
Uronic acids		2.9		
Amount of extractives (ethanol benzene)	1.3	1.4	1.8	2.2
Amount of extractives (H ₂ O)	2.2	22.6	5.1	12.2
Elementary composition				
Carbon				46.9
Hydrogen				7.24
Oxygen				45.27
Ash	0.21	0.3	1.0	0.59

Physical and mechanical properties of larch

The usage of larch timber in Russia has long traditions going back to the Medieval time when the material has been used for constructions, ship building, bridges, etc. There are a great number of wooden buildings and churches in Russia that are more than 300 years old. Some examples are the wooden towers in Jakutsk and Ilimsk built in 17th and 18th centuries, remains of Mangaseisk defence establishment from 1601, the dam on the Iset river in Ekaterinburg built 240 years ago and buildings in Perm, Solikamsk, Cherdyn, Verkhoturie and other places (Polubojarinov *et al.* 2000). The wide use of larch imposes knowledge and skills about the physical and mechanical properties of material.

The larch wood is characterised by a 30-60 % higher mechanical strength than Scots pine wood.

Despite the great growing stocks and excellent mechanical properties, logging of larch does not exceed 5 % of the total logging volume and industrial use of wood in Russia. The reasons for the limited industrial use of larch wood are the difficulties under the timber processing caused by some specific features in the structure and, probably, chemistry.

A comprehensive study on the properties and use of larch timber is presented by Chubinsky *et al.* (1998). According to that, the total volume of larch timber in Russia is more than 28 billion m³. However, the distribution of larch forest over the country is irregular (Table 9).

Table 9. Growing stock of larch in Russia.

Region	Forest area, (%)	Growing stock, (%)	Average growing stock (m ³ /ha)
Vologda, Arkhangelsk, Komi and Central part	0.16	0.2	106
Ural	0.04	0.05	159
West Siberia	1.9	2.15	131
East Siberia	78.5	77.0	102
Far East	19.4	20.6	110

Larch trees can reach 30-45 meters in height and up to 1 meter in diameter at breast height. For industrial use the average diameter of larch timber is 30-40 cm. More comparative data about wood species are shown in Table 10.

Table 10. Relative volume of tree parts, %.

Tree species	Trunk	Branches	Roots
Larch <i>spp.</i>	77 -82	6-8	12-15
Pine <i>spp.</i>	65- 77	8-10	15-25
Birch <i>spp.</i>	78-90	5-10	5-12
Beech <i>spp.</i>	55-70	5-10	20-25

The properties of larch wood are specific and differ from those of the other conifers. Larch has a thin layer of sapwood. The thickness is 8-20 mm of total diameter (Bokschanin 1982). In the natural forest the width of the annual ring is 0.4-2.2 mm (Vikhrov 1949, Terletskii 1932).

According to Bokschanin (1982) the annual ring width can vary between 1 to 3 mm depending on the growth conditions and age of tree. The late wood proportion can vary from 0.07 to 0.76 mm, or 20-30 % of the total annual ring width (Vikhrov 1949). The total late wood proportion of the larch stem can reach 39 % (Bokschanin 1982) compared to 31 % in silver fir (*Abies sibirica*) and 27 % in Scots pine. The high portion of late wood in larches establishes to the great extent their mechanical properties.

There are large chemical and morphological differences between the early- and late wood resulting in variation of their physical and mechanical properties (Table 11). Physical and mechanical properties of wood also depend on the age of tree. Density increases until the age reaches 70-80 years, and decreases after that. According to Terletskii (1932), the average density of *Larix dahurica* is 490 kg/m³ at age of 20 years and 736 kg/m³ at 80 years.

Table 11. Average values of some physical and mechanical properties of larch.

Properties	Early wood	Late wood
Oven dry density, kg/m ³	362 (383) ¹	863
Raw density, kg/m ³	1030	1090
Max moisture content, %	206	80
Shrinkage, %		
-volumetric	13.4	22.8
-tangential	7.9	13.9
-radial	6.1	7.1
Volume of pores, %	66 (73.5) ¹	21.0 (46.7) ¹
Tensile strength, MPa	44.2 ¹	151.0 ¹
Bending strength (MOR), MPa		
-at moisture content of 9 %	48.3 ¹	259.0 ¹
-at moisture content > 30 %	25.8 ¹	104.7 ¹

¹ data presented by Vikhrov (1949)

The mechanical properties of larch are 30-60 % higher compared to these of Scots pine timber (Table 12). The higher density of larch explains this.

Table 12. Mechanical properties of larch wood based on data from Bokshanin (1982) and Borovikov and Ugolev (1989).

Tree species	Density, kg/m ³	Compression strength, MPa	Tensile strength, MPa	Bending strength, MPa	Shear strength, MPa	Hardness, MPa	Modulus of elasticity (MOE), GPa
<i>Larix</i> (average)	640	56.7	119.5	98.5	8.7	24.9	13.8
<i>Larix dahurica</i>	650	57.3	-	106.2	7.7	-	13.0
<i>Larix sibirica</i> ¹	620	52.3	-	93.2	9.1	24.9	12.9
<i>Larix sibirica</i> ²	660	61.5	120.5	97.8	8.5	-	14.9

¹ timber from West Siberia, ² timber from East Siberia.

The influence on growing conditions on the properties of wood has been investigated by Terletskii (1932) and shown in Table 13. The larch from eastern Siberia shows the highest values.

Table 13. The influence from growing conditions on physical and mechanical properties of larch.

Region	Density, (kg/m ³)	Bending strength, MPa	Modulus of elasticity, GPa
Leningrad region	584	82.0	7.64
Komi Republic	563	104.5	10.79
East Siberia (Jakutia)	685	132.3	10.31

From 1990 to 1995 wood logging in Russia has been reduced from 380 million m³ to 150 million m³ per year. Only 7 million m³ of larch has been logged and exported mainly to Japan (Chubinsky *et al.* 1998). Some of the variations in the chemistry and physical properties have a negative influence on the processing of timber. The most important factors are listed below:

1. High density, large variations between the density of sapwood and heartwood, late and early wood;
2. Consequent variations in the physical and mechanical properties of sapwood and heartwood, early and late wood;
3. Variations in the content of arabinogalactane and resin;
4. Low vapour and gas permeability.

As a result of the above-mentioned factors, a number of problems must be solved when processing larch timber:

1. Rapid obstruction (gumming) of tools, i.e. during sawing the resin and gums fill in the gaps between the teeth, making sawing difficult;
2. Internal stress and deformation during drying and pressing, causing checks;
3. Low surface activity in finishing resulting in a lower durability of glue bond.

Sawing and drying of larch

As already mentioned there is a practical problem when sawing larch timber. Sprinkling water on the cutting tool under sawing can facilitate the process. The cutting blade must also be cleaned daily with some organic solution. Only the presence of resin cannot explain the sawing difficulty since the amount of it is not higher than that of Scots pine. One speculation is the much higher content of water-soluble extractives.

The drying schedules for larch timber dried in a batch kiln (Table 14) are recommended in the Russian standard (Rukovodjashtie tehniczeskie materialy po tehnologii kamernoj sushki pilomaterialov (1985). The schedules are valid for an air velocity in the kiln of 2.5 m/s.

Table 14. Drying schedules for larch timber and batch kilns with air velocity of 2.5 m/s.

Wood moisture content	Thickness of timber, mm							
	Parameters	< 22	22-25	25-32	32-40	40-50	50-60	60-75
<i>Normal schedules</i>								
> 35	$t, ^\circ\text{C}$	70	70	70	65	60	60	60
	$\Delta t, ^\circ\text{C}$	9	8	6	5	4	3	2
	$RH, \%$	64	68	76	78	81	86	90
35-25	$t, ^\circ\text{C}$	75	75	75	70	65	65	65
	$\Delta t, ^\circ\text{C}$	15	15	15	10	9	7	5
	$RH, \%$	49	49	49	61	63	71	78
< 25	$t, ^\circ\text{C}$	80	80	80	75	70	70	70
	$\Delta t, ^\circ\text{C}$	26	25	25	20	19	18	15
	$RH, \%$	28	29	30	38	37	39	47
<i>Intensified schedules</i>								
> 35	$t, ^\circ\text{C}$	90	90	82	75	75	72	70
	$\Delta t, ^\circ\text{C}$	9	7	4	4	3	2	2
	$RH, \%$	69	75	84	84	87	92	91
35-25	$t, ^\circ\text{C}$	98	96	87	80	80	78	76
	$\Delta t, ^\circ\text{C}$	12	11	8	8	6	5	4
	$RH, \%$	63	65	72	70	77	80	84
< 25	$t, ^\circ\text{C}$	112	110	108	100	100	95	90
	$\Delta t, ^\circ\text{C}$	32	30	29	28	26	20	18
	$RH, \%$	30	32	32	32	35	44	47

where t is the dry-bulb temperature, $^\circ\text{C}$,
 Δt is the wet-bulb depression, $^\circ\text{C}$,
 RH is the relative humidity, %.

The schedules used in the progressive kilns are shown in Table 15.

Table 15. Drying schedules for larch timber and progressive kilns.

Thickness of timber, mm	Parameters of the air at the dry end of kiln	
	$\Delta t, ^\circ\text{C}$	$RH, \%$
	<i>Mild schedules</i>	
	Dry-bulb t is constant and equal to $55 ^\circ\text{C}$	
< 22	15	40
22-25	14	44
25-32	12	50
32-40	11	53
40-50	10	57
50-60	9	60
60-70	8	64

Thickness of timber, mm	<i>Normal schedules</i>	
	Dry-bulb <i>t</i> is constant and equal to 85 °C	
< 22	23	35
22-25	20	41
25-32	17	47
32-40	15	52
40-50	13	57
50-60	11	63
60-70	9	69
<i>Intensified schedules</i>		
Dry-bulb <i>t</i> is constant and equal to 105 °C		
< 22	20	46
22-25	18	50
25-32	16	55
32-40	14	60
40-50	12	64
50-60	11	67
60-70	10	69

According to Bogdanov *et al.* (1990), larch timber dries significantly slower and shows more defects than the other softwood species, for example pine and spruce. The comparative Table 16 comprising the drying times (hours) for pine and larch timber dried in a batch kiln under the recommended normal schedules is presented below. It is obvious that the larch timber requires 2-3 times longer drying time than that for Scots pine timber.

Table 16. Comparison between drying times for Scots pine and larch timber, h.

Thickness, mm	Width of timber, mm											
	40-50		60-70		80-100		110-130		140-180		> 180	
	<i>P</i> ¹	<i>L</i> ¹	<i>P</i>	<i>L</i>								
< 16	23	58	25	63	26	64	27	67	27	68	27	68
19	29	68	31	72	32	74	33	77	33	77	33	77
22	34	75	37	80	39	83	39	86	39	87	39	87
25	45	83	50	88	53	91	54	92	55	93	55	94
32	59	94	63	99	68	104	72	108	73	110	73	113
40	71	113	79	129	84	144	86	157	88	166	88	175
50	-	-	93	182	99	224	100	256	104	279	105	304
60	-	-	103	235	114	304	122	361	125	400	130	443
70	-	-	-	-	147	431	161	521	178	585	194	635
75	-	-	-	-	156	466	177	574	197	650	218	737

¹ *P* is Scots pine and *L* is larch.

Other processing

Lumber production is described in detail (Bokschanin 1982) and procedures for plywood manufacture are given by Chubinsky and Chubov (1982). It is known that laminated veneer lumber (LVL) is one of the progressive ways for production of structural timber because gluing

gives the possibility to use material of any length, width and thickness. The strength of LVL is higher than the strength of the original timber (sawn beams and boards) due to even distribution of natural defects especially knots.

Experimental studies on the LVL have been carried out at the St. Petersburg Forest Technical Academy and Bratsk plywood factory. Laminated veneer lumber is fabricated from rotary-cut larch veneer of 2.5, 3.0, 4.0 and 5.0 mm thickness by using phenol-formaldehyde resins under various gluing schedules (Tables 17 and 18).

Table 17. Schedules for hot gluing of LVL.

Thickness of LVL, mm	Temperature, °C	Pressing time, min
19	115	20
	125	15
	135	13
22	115	22
	125	18
25	115	25
	125	20
32	115	32
	125	29
40	115	40
	125	38
50	115	50

Table 18. Quantity of glue (phenol-formaldehyde) for production of plywood.
Initial pressure 1.7 MPa.

Veneer thickness, mm	Quantity of glue, g/m ²
2.5	120-130
2.5-3.0	130-140
3.0-4.0	140-150
4.0-6.0	150-160

The special features of larch wood create some problems during the rotary cutting and production of veneer. It is necessary to adapt the wood pre-heating and rotary cutting regime. Tables 19 and 20 present some mechanical properties of larch and pine veneers of different thickness Table 19 shows that the tensile strength along the grain is 3-7 % higher in larch veneer than in the pine one.

Table 19. Properties of larch and pine veneer.

Property	Strength, MPa	
	Larch	Pine
Tensile strength along the grain		
Thickness of veneer, mm		
2.5	93.2	87.1
3.0	89.4	84.3
4.0	87.2	83.6
5.0	86.3	83.6
6.0	86.1	81.2
Tensile strength, perpendicular to grain		
Thickness of veneer, mm		
2.5	0.54	0.75
3.0	0.46	0.62
4.0	0.42	0.58
5.0	0.39	0.51
6.0	0.38	0.49

The tensile strength perpendicular to grain of pine veneer is 22-28 % higher than that of larch veneer. That is caused by the large difference in density of the larch's early- and late wood. The main mechanical properties of the laminated veneer lumber produced of larch veneer are shown in Table 20. It is easy to see that all properties of LVL from larch are higher than that those of pine veneer. Larch LVL has very good mechanical properties (1.2-1.6 times higher strength values than those of structural timber).

Table 20. Properties of laminated veneer lumber (Chubinsky 1992).

Property	Strength, MPa		
	Larch	Pine	Larch 40 %, pine 60 %
Tensile strength along the grain	80	65	69
Bending strength perpendicular to the sheets of veneer	80	58	76
Bending strength, parallel to the sheets of veneer	93	71	83
Compression strength, along the grain of outside sheets of veneer	78	48	68
Compression strength perpendicular to the sheets of veneer	13	8	10
Compression strength parallel to the sheets of veneer	8	5.7	6.4

Durability of larch timber

The durability of larch wood deserves special attention. In recent years larch has been presented in the Nordic countries as a very durable wood species, able to substitute the impregnated timber. Although the durability of larch in comparison to impregnated timber and even to Scots pine heartwood is a very debatable matter, a number of sawmills and other companies have started active import from Russia. The internal larch sources in the Nordic countries, e.g. small size round wood from thinning, are also considered and set on use. Apart from the durability aspects of larch, there are a lot of unanswered questions concerning the processing of larch timber, e.g. storage, sawing, drying and finishing. Since a wood species growing at various geographical regions can have a great variance in the physical and mechanical properties, it is worth comparing larch timber from Siberia to the one grown in the Nordic countries.

The Russian academician P. Pallas (1741-1811) has been among the first scientists to observe the high natural decay resistance of larch wood. After his long Siberian field tours he has come to the conclusion that "larch wood does not decay, that is why it is used for dams, bridges, piles, pipes for water moving, mills and barrels" (Petrov 1977).

Studies of larch wood decay resistance have been carried out during the sixties by scientists of the USSR Academy of Science, The Russian Institute of Forestry and Wood (Bazhenov and Kharuk 1967, Kharuk 1961) and the Siberian Technological Institute (Shaltyanene 1962). Telegraph poles have been used for the study and they have showed that the average durability of larch wood poles was 19-23 years in the Abakan region and 24 years in the Krasnojarsk region (Bazhenov and Kharuk 1967). The first sign of degradation appeared after 4 years of use. After 4-15 years of use, 10-20 % of the telegraph poles had been destroyed. However, after 25 years, almost 50 % of the poles have still been in use. As a result of these studies Shaltyanene (1962), has suggested that the larch is resistant to decay and can be used in ground contact without chemical protection.

Physical and mechanical properties of larch wood exposed in ground contact have been investigated by Isaeva and Bryukhanov (1969). Samples of wood taken from a 230-year-old building in Krasnoyarsk have been tested.

Comparative data on the resistance of spruce and larch wood poles are shown by Gorshin (1977). The data shows that spruce wood poles have an average durability of 7-8 years while the larch poles serve 14-24 years. The durability of the larch wood telegraph poles was 12-20 years according to Lomakin (1990). Chubinsky et al. (1998) explain the decay resistance of larch by its high density and natural resin content.

Data about the high decay resistance of larch wood has also been given by Varfolomeev (1995). Field trials to test the relative decay resistance of larch wood have been arranged by the Senezhskaja laboratory near Moscow in 1956 (Gorshin and Cherntzov 1966). Samples with dimensions of 15×15×220 mm along the grain have been exposed in soil. The durability has been assessed on a scale from 0 to 100; the last number characterises a sample with no decay. Complete destruction has been evaluated as 0.

The decay resistance of *Larix sibirica* wood expressed by the mass loss has been investigated in pure culture tests (Melnikov 1963, Petrenko 1964). Petrenko's results (1964) are shown in Table 21.

Table 21. Mass loss of *Larix sibirica* wood in a pure culture test with 4 fungi.

Fungus	Mass loss after 4 months of exposure, % of the dry weight
	Sapwood
<i>Coniophora cerebella</i>	32.15
<i>Merulius lacrimans</i>	14.2
<i>Lenzites sepiaria</i>	34.2
<i>Lentinus squamosus</i>	46.8
	Heartwood
<i>Coniophora cerebella</i>	23.3
<i>Merulius lacrimans</i>	6.0
<i>Lenzites sepiaria</i>	24.6
<i>Lentinus squamosus</i>	34.5
	Pine sapwood (<i>Pinus sylvestris</i> L.)
<i>Coniophora cerebella</i>	63.8
<i>Merulius lacrimans</i>	18.5
<i>Lenzites sepiaria</i>	54.6
<i>Lentinus squamosus</i>	62.8

A great number of studies concerning larch durability and properties have been done in USSR/Russia (Petrenko 1964, Polubojarinov *et al.* 2000). Reading the results of these studies, one could easily conclude that larch is a very durable species. Despite this, some drawbacks can hinder the interpretation of the results for usage of larch in Europe. The majority of studies are carried out on Siberian larch grown and tested there. The researchers cannot deny the durability of this species but most of the tests are done in Siberia, a place with rather cold and specific climate particularly in the winter, thus making the conclusions irrelevant for the same species exposed in another climate. The wide variation of decay resistance within the same wood species has also been observed (Viitanen *et al.* 1997). According to Viitanen *et al.* (1997), decay resistance depends on both genetical and environmental factors. In Sweden, a preliminary study (Terziev 1998) showed that the European larch (*Larix decidua* Mill.) has significantly higher susceptibility to fungal discoloration than Siberian larch (*Larix sibirica* Ledeb.) and Scots pine.

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