Wooden Roofing: Split Shingles versus Sawn Boards

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Abstract

Wooden shingles have been known in Europe and other regions worldwide for several thousands of years. They are usually split, and according to handicraft rules, as well as historical literature, a split surface has many advantages. It is more flexible, more elastic, stronger, and less exposed to cupping than a sawn surface because no fibers have been cut. It also follows wood rays; it is more durable than a sawn surface because cut fibers absorb more moisture, creating good conditions for fungal growth. However, because sawing is the main procedure for dividing logs into timber, sawn boards are currently used for roofing. The short life span of such roofing has often been discussed by craftsmen. In this study, a 37-year-old roofing was evaluated to determine the important parameters of high-durability sawn boards. Results showed that the presence of juvenile wood, fiber deviations, and knots reduced the durability of these boards. Therefore, sawn boards of the same wood quality as split shingles may have the same durability.
Keywords

wooden roofing – wood quality – durability – shingles – boards – handicraft rules

1 Introduction

Before hard roofing materials (e.g., stones and metals) were used, houses were roofed with straw and wood (Carstensen 1937). Wooden roofs, composed of long narrow boards, are called shingle roofs (Gayer & Mayr 1903; Carstensen 1937). This roofing type is extremely old; for example, fir (Abies alba) shingles found in Switzerland dated back to 3384–3370 BCE (radiocarbon dated; Arbon; Leuzinger 2000) and 980 BCE (dendrochronologically dated; Zürich; Eberschweiler 2004). Old shingles dating back to 425 BCE were also found in Hallstatt, Austria (Grabner et al. 2021). Wooden shingles have been described in Japan since the 4th–6th centuries (Coaldrake 2009).

1.1 Shingles: Wood Species and Types

Shingles are double or triple roofed, i.e., two or three shingles are placed on top of each other. “Good shingle roofs on a church roof must last 100 years” (Haid 1991). These shingles must be split by hand as rift shingles from approximately 100-year-old larch trees (Larix decidua). Duhamel du Monceau (1767) also described shingles as small boards split like barrel staves. Old barrel staves can also be used for this purpose. Shingles are pre-drilled with a nail bit to avoid splitting or tearing when nailed (Duhamel du Monceau 1767).

Krüinitz (1826) suggested that the best wood species for wooden shingles are oak (Quercus spp.), fir (Abies spp.), and spruce (Picea abies) from trees felled in autumn or winter. In Poland and the Baltic region (Europe), split shingles of aspen (Populus tremula) are used (Policinska-Serwa & Jakimowicz 2013). Western redcedar (Thuja plicata) has also been used for roof shingles and shakes in North America because its heartwood has a well-known reputation for durability and dimensional stability (De Groot & Nesenson 1995; Morell et al. 2017).

Several types of wooden shingles have been used in Austria, and some of them require a specific wood species. Originally, shingles were laid without nails (Moser 1985) and fixed to the roof with crosswise laying wooden poles and heavy stones. This requires longer and thicker shingles (80 cm long and 2–3 cm thick), and this type of shingle was made exclusively from larch wood (Phleps 1942; Milan 2000). They were called “Legschindel” (Fig. 1A), which already disappeared in Grossarl Valley, Austria, between 1900 and 1920 AD, and
was replaced by the well-known type named “Scharschindel” (see Fig. 1B; Fiala 1965). All other shingle types were fastened with nails (Moser 1985). Vancsa (1899) reported the repair work on castles in Laa/Thaya, Austria, where 10,000 shingles (presumably the type called “Nutschindel”; see Fig. 1D) and 15,000 shingle nails were ordered. This historical reference showed a high demand for iron nails, which were very expensive at the time. Phleps (1942) and King and Lohrum (2000) additionally mention that shingles were sometimes fastened with wooden nails.

Studies have described many regional types of wooden shingles, including those in Scandinavia, Poland, the Baltic States (Policinska-Serwa & Jakimowicz 2013), Japan (Piccinini 2003; Yamato 2006; Radzuan et al. 2014), and Bhutan (Lotay 2015). In Austria, the best-known type of wooden shingles is the “Scharschindel” (mostly 60 or 80 cm long, approximately 1 cm thick, and a few centimeters wide; laid vertically with a triple covering; see Fig. 1B and https://www.youtube.com/watch?v=rnc0346Dsgw), which are consistently made of larch wood (Milan 2000).
For other Austrian types, beside larch wood also spruce or fir wood can be used: The so-called “Schieferschindel” (see Fig. 1C and https://www.youtube.com/watch?v=fP-lIPr4UYAandt=28s), which is known from Styria, Austria (Moser 1985), is laid at a slight angle to the vertical – the angle changes in each row. Consequently, the covering has many cavities. Water drops have to “jump” as they run down because of the oblique orientation; thus, shingles do not get so wet. Simultaneously, a structure with cavities ensures fast drying.

The “Nutschindel” (60 cm long, approximately 1 cm thick, a few centimeters wide; with a groove on one long side and a tongue on the other; triple covered; Fig. 1D and https://www.youtube.com/watch?v=RuIGx4zsHKk) is pushed into the groove of the neighboring shingle on each side and laid tightly. With this arrangement, only the uppermost shingles of the triple cover are wetted with water. They can then dry quickly, which also allows the use of less-durable wood species (such as spruce and fir; Enigl 1987).

### 1.2 Manufacture of Shingles: Splitting

Shingles are primarily split (Phleps 1942). In splitting, wood is separated into more or less regular shapes along its fibers by using a wedge-shaped tool (Hartmann 1841; Gayer & Mayr 1903). It is easier and flatter along the radial plane of wood rays (i.e., radial) than in the plane of annual rings (i.e., tangential; Schwankl 1939). A log that can be split longitudinally into parallel planes, with fibers separating without much resistance, is easily cleavable (Krais 1910). Wood species, such as beech, oak, ash, alder, and fir (Hartmann 1841), have straight and coarser fibers, large and even wood rays, high elasticity, and low transverse tensile strength (Krais 1910). High elasticity promotes splitting, and sap-fresh wood splits more easily than dry wood (Moeller 1883; Krais 1910). Therefore, trees that felled in summer (in the sap) are better suited for splitting than those that felled in winter. Short fibers usually lead to poor surface quality (Moeller 1883). Splitting is also better in old trees than in young trees (Florinus 1721).

The demands on wood quality for splitting is relatively high. Splitting becomes increasingly difficult because of knottiness, spiral grain, and growth anomalies (Thon 1842; Printz 1884); in some cases, such as those with curl-like growth, splitting is impossible. The trunk should be straight, without knots, free of spiral or interlocked grain, and fine grained. These attributes, in combination with slowly grown wood, are suitable (Carstensen 1937; Enigl 1987). According to shingle makers, the lowest part of a log (approximately 1 m) is difficult to split (Nördlinger 1863) and is therefore not used. According to a traditional handicraft rule, straight-grained and slightly left-turned logs (counterclockwise) are usually easy to split, whereas right-turned logs are always difficult to split (Burger 1941).
Wood rays positively influence the splitting ability of woods, such as oak wood (a wood species with very large wood rays) that can be easily split. In Roman times, well structures were largely composed of radially split oaks (Grabner 2011). A similar construction of a well is known from the Czech Republic in 5196 BCE and Germany (Altscherbitz) in 5102 BCE (Elburg & Herold 2010; Rybníček et al. 2018).

Wood pieces are simply split to make firewood. However, in the production of shingles, vat and barrel staves, or furniture parts, splitting must be guided as precisely as possible (Schwankl 1939). Generally, wood is split from the top, that is, starting at the thin end of the trunk (Völker 1836). Shingles (of any kind) are split with a tool called shingle iron (Carstensen 1937). They must have the same thickness and the same length. Therefore, care must be taken such that the split does not deviate from the intended splitting direction. If the rift tends to move away from the craftsman, the craftsman must bend the part that is closer to him toward himself. In most cases, the thicker part is the one being bent. Through this process, the rift is split parallel to the work piece again. This technique can be applied to radially or tangentially split products. A film on shingle production shows how the splitting direction can be guided (https://www.youtube.com/watch?v=fP-lIPr4UYA).

Most shingles are split tangentially (“Legschindel” and “Scharschindel” made of larch wood; Eigl 1894; see Fig. 1A and B). Special forms, such as “Schieferschindel” or “Nutschindel,” made of spruce or fir wood, are split radially (see Fig. 1C and D).

1.3 Splitting versus Sawing
Splitting has the following advantages over sawing (Beckmann 1783; Völker 1836; Hartmann 1841; Möhl 1869): (1) It is faster and can be performed with simpler tools than sawing; (2) it hardly produces any waste; (3) split wood is more flexible, more elastic, and stronger than sawn wood because no fibers have been cut; (4) split wood is less exposed to cupping and warping than sawn wood because fibers are not cut and follow the wood rays; and (5) split wood is more durable than sawn wood because cut fibers absorb more moisture, creating good conditions for fungal growth.

Sawing is probably the most important method for timber processing. In wood processing, in contrast to splitting or hewing, sawing takes less account of the grown structure (Moser 1985). Sawn boards can also be used for roof covering (Milan 2000), but the quality of the surface of split wood is better than that of sawn wood because fibers are not cut; thus, water can penetrate less easily (Ast & Winner 2011).

This study was conducted to evaluate an already existing damaged old wooden roofing and determine the most relevant wood quality parameters.
for highly durable sawn boards. The aforementioned advantages of splitting over sawing on the durability of wooden roofing should be tested. There are no long-term experiments to compare split shingles with sawn boards used for roofing. In early times, craftsmen used split shingles which need the best log-quality. In modern times, they shifted to sawn boards as a cheaper alternative. This study was also conducted to assess which wood quality parameters are relevant for the durability of sawn boards and whether sawn boards could last as long as split shingles on the roof. These data would help to improve the durability of future wooden roofing made of sawn boards.

2 Materials and Methods

Sawn boards of the 37-year-old roofing of a single-story alpine hut installed in 1984 at Hopfgarten/Defereggental in Austria (46.91° N, 12.48° E, 1997 m a.s.l.; see Fig. 2) were examined in June 2021. It was a gable roof with an angle of 25°. The roof ridge is SW – NE oriented (one roof facing SE and the other facing NW).

Larch boards were sapwood-free and had a local origin. The trees (ring width) grew slowly and uniformly, and the ring width of the adult part of the tree was less than 1 mm. It was three-layered roofing with a board length of 60 cm, ending in an exposed area with a length of 20 cm and a varying board width for examination. Thus, only the uppermost part of the three exposed layers was examined. A total of 406 sawn boards were examined at the following areas: from the top of the roof, on a 1.5 m strip, in the middle of the roof ridge,

FIGURE 2 The alpine hut in Hopfgarten.
and to both sides of the roof (SE and NW); then, 20 of 26 rows of boards were investigated (see Fig. 3).

The following parameters were examined by visual determination:

(a) Condition (C) of the boards: intact, good, bad, or destroyed. The condition of the boards was defined as destroyed if their function had been lost, that is, water could leak due to existing holes (see Fig. 4–C4). They were characterized as intact if they were fully functional and could remain on a roof (see Fig. 4–C1). Their condition was good if their shingles remained functional but showed some signs of degradation.

(b) Orientation (O) of the tree rings within the board: rift board, half-rift board, flat board with the pith on the upper side, or flat board with the pith on the lower side. The orientation of the tree rings within the boards was evaluated at the visible cross-section. The cross-section had to be partially cleaned using a brush before evaluation. The orientations of the tree rings of the four categories are shown in Fig. 4–O1–O4.

(c) Juvenile wood (P): included or absent. Juvenile wood was defined as the innermost 5–6 cm (from the pith outward) of the previous

**Figure 3** The roof of the hut. The yellow dots at the SE facing roofing mark the 1.5 m wide strip from the roof ridge to the eave.
log. Additionally, the presence or absence of the pith was recorded (Fig. 4–P1, P2). If the pith was absent, 5–6 cm of juvenile wood was estimated due to the curvature of the existing innermost tree rings.

(d) Strong fiber (F) deviation: absent or present. Strong fiber deviation, which can be caused by large branches or rapid changes in diameter (tapering), was observed and categorized as absent or present (see Fig. 4–F1 and F2).

(e) Knots (K): absent, small, medium, large, or wing shaped. The different categories of knots on a board were mainly differentiated by the diameter of knots (Fig. 4–K1–K5).

(f) Cracks (CR): absent, small, medium, or large. The categories of visible crack sizes on the roof surface at the time of examination are shown in Fig. 4–CR1–CR4.

(g) Width of the boards measured in centimeters.

During the examination, the boards were not dismantled; therefore, only the exposed surface of the boards, particularly the uppermost layer of the three layers and the lowest 20 cm (as the upper 40 cm was covered by the fixed boards; see Fig. 4), could be evaluated. Because of these limitations, a simple evaluation, not complex evaluations, was performed as usually done in wood decay tests.

Data were collected and processed in Excel, and simple descriptive statistics (percentages) were used to describe the findings.

3 Results

Of the 406 evaluated boards, 20.0% were intact, 25.1% in good condition, 35.7% in bad condition and 19.2% were already destroyed (see Fig. 5). During the examination, two main reasons for the destruction became evident: the presence of fiber deviations and juvenile wood. Furthermore, 7.1% of the 406 boards (of all conditions) showed fiber deviations, and 31.5% had juvenile wood included. The share of these two parameters was much higher in the “destroyed” group than in the “intact” group (see Fig. 6).

The boards showing fiber deviations and juvenile wood were omitted to highlight the influence of knots and cracks; thus, 256 boards were further
Figure 4 The examples of the classifications. C, condition: C1, intact; C2, good; C3, bad; C4, destroyed. CR, cracks: CR1, cracks absent; CR2, small cracks; CR3, medium cracks; CR4, large cracks. F, fiber deviations: F1, absent (straight-grained); F2, strong fiber deviations. P, pith and juvenile wood included: P1, absent; P2, included. K, knot size: K1, knots absent; K2, small knots; K3, medium knots; K4, large knots; K5, wing-shaped knots. O, orientation of the tree rings/sawing strategy: O1, rift (quarter sawn); O2, half-rift; O3, flat sawn with the pith at the upper side; O4, flat sawn with the pith at the lower side.
FIGURE 5
The total share within the examination of the condition of all 406 boards.

FIGURE 6
The amount of juvenile wood and fiber deviations in all 406 examined boards was high, especially at the destroyed shingles and those in bad condition.

FIGURE 7
The results of the evaluation of the knot-size in boards without juvenile wood and fiber deviations. Total number = 256 boards.

FIGURE 8
The results of the evaluation of the crack-size in boards without juvenile wood and fiber deviations. Total number = 256 boards.

FIGURE 9
The evaluation of the sawing strategy.
analyzed. The knots were classified as follows (Fig. 7): a high number of large knots within the destroyed boards (29.4%) and a high number of absent and small knots within the intact boards (66.7% in total). The same pattern was observed in the cracks. Many large cracks were detected in the destroyed boards (82.4%), but small or no cracks were found in the intact boards (68.6% in total); Fig. 8).

Regarding the sawing strategy (grain orientation, i.e., the orientation of tree rings within a board), a large number of flat boards with the pith on the upper side can be seen (see Fig. 9). Flat boards (upper and lower sides) presented the highest and lowest shares in the groups of destroyed and intact boards, respectively. Conversely, rift and half-rift boards exhibited an opposite pattern; in particular, numerous flat boards were observed in intact boards. In conclusion, rift and half-rift boards appeared to be superior in terms of durability. Flat boards with the pith on the upper side (36.9% of all examined boards) were present in all groups, but their proportion in intact boards was lower than that in destroyed boards.

In summary, rift and half-rift sawn boards with few cracks and small knots, but without strong fiber deviation and juvenile wood, appeared to be efficiently preserved after 37 years.

4 Discussion

This study mainly aimed to evaluate whether sawn boards could last as long as split shingles on roofs. Some of the 37-year-old sawn boards were intact and some were completely destroyed. Therefore, the aforementioned wood quality parameters were determined by visually inspecting the exposed surface of the uppermost layer of the three-layered roofing.

4.1 Influence of Juvenile Wood

The presence of juvenile wood is one of the major factors that reduce durability. The most important factor influencing solid wood quality is grain orientation; ideally, fibers are aligned parallel to the long axis of a board. Spiral grain (Burger 1950; Harris 1988), as well as larger microfibrillar angles of the S2 layer of the cell wall of tracheids (Brazier 1985; Bao et al. 2001), can often exist in juvenile wood, cause low strength and stiffness, and tend to twist (Jozsa & Middleton 1994; Larson et al. 2001). The rapid growth rate and coarse grain formation, which is usually the case in juvenile wood, are the cause of reduced strength and stiffness and increased warping (Jozsa & Middleton 1994). Juvenile wood is less dimensionally stable (Bao et al. 2001) and can present unusual warping problems, which are related to compression wood that shrinks 10–20
times more than normal wood does (Harris 1988; Jozsa & Middleton 1994). In juvenile wood, the amount of (mild) compression wood is usually higher than that of mature wood (Larson et al. 2001; Cown et al. 1996). Furthermore, cracking occurs because stresses in boards with juvenile and compression wood may be so severe that they cause splitting (Larson et al. 2001).

Juvenile wood is formed during the early stages of tree growth (Larson 1969). The number of tree rings varies among wood species. Juvenile wood gradually undergoes transition to adult wood, and the number of rings in juvenile wood differs among various wood quality traits (Krempl 1970; Abdel-Gadir & Krahmer 1993; Yang et al. 1994). Ring width or wood density is often described to be equivalent to 10 years, in contrast to spiral grains with approximately 30 years.

Gierlinger and Wimmer (2004) found that the extractive and phenolic substance contents increase with increasing distance from the pith in larch heartwood. The higher the phenolic content, the higher the decay resistance in larch heartwood; as a result, the resistance of juvenile wood decreases. Juvenile wood has strong moisture absorption and diffusion capacity, resulting in enhanced wettability (Bao et al. 2001).

According to the handicraft rules on producing split shingles in the Austrian Open Air Museum in Stuebing (close to Graz, Austria), the innermost part, which is approximately 8–12 cm in diameter, must be omitted. This rule applies to all types of shingles; therefore, the juvenile part is not used for split shingles (see https://www.youtube.com/watch?v=rnc0346Dsgw).

In summary, juvenile wood has a higher tendency to warp and crack and is less durable than adult wood (see Fig. 6). Therefore, juvenile wood must be removed from sawn boards for roofing as in split shingles.

4.2 Influence of Knots and Fiber Deviations
Fiber deviations and large knots reduced the durability of the examined boards. Large fiber deviations could be observed, especially in the vicinity of the knots (Meierhofer 1976). Several studies have shown that even small fiber deviations result in significant reductions in strength and stiffness (Jozsa & Middleton 1994; Eberhardsteiner 2002). Therefore, in the case of sawn timber production, knots and the corresponding fiber deviations are the most common limiting factors influencing the strength and stiffness of wood. For roofing, the main problems are cracks in stem wood and knot wood. Knots are prone to undesirable cracks (Jozsa & Middleton, 1994). Knots have brittle and hard dark-colored wood that is difficult to work with (Knuchel 1947, 1954; Pereira et al. 2003). They are denser and shrink to a greater extent than stem wood; for this reason, knots produce cracks during drying (Götze et al. 1972). The presence of knots increases the longitudinal shrinkage up to almost 100%
because of fiber deviations (Perstorper et al. 2001). According to the rules of splitting shingles, as described in the introduction, logs must be free of fiber deviations and knots, which are usually checked at the bark.

In summary, fiber deviations and knots are responsible for warping and cracking; therefore, they cause the reduced durability (see Figs 6–8).

4.3 Influence of Sawing Strategy and Cracks
The number of rift sawn boards was much higher in the group of intact boards than that in the other groups, and the number of flat-sawn boards was higher in the group of destroyed boards than in the group of intact board (see Fig. 9).

Because of the different degrees of shrinkage between the radial and tangential directions, flat sawn boards cup or warp (Knuchel 1954). Radially oriented boards (rift sawn) do not cup; instead, they have reduced thickness and are less vulnerable to splitting and decay. For furniture and coopered vessels, rift and half-rift split and sawn boards are preferred because their dimensional stability is better than that of flat sawn boards (Klein et al. 2014).

Figure 8 shows the impact of cracks on the durability of sawn boards. Large cracks are found in the destroyed boards, but they are absent or only small cracks are detected in intact boards. Weathering is a combination of damage from sunlight, rain, and wind (Berdahl et al. 2008; Morell et al. 2020). Repeated wetting and drying can induce stress in wood, eventually leading to cracks. Because of these cracks, water can easily penetrate sawn boards and soak deeper into the wood body. Most defects in wooden roofing are moisture related. For example, if the moisture content is higher than 20%, fungal infection is the main problem (Berdahl et al. 2008). Wooden roofing maintains its function only if shingles dry out regularly (Kain et al. 2020). Decay fungi are typically found under shingle overlap, where moisture conditions favor their steady growth (Morell et al. 2020).

In summary, cracks that can be found more often on flat sawn boards than on rift and half-rift sawn boards reduce durability.

4.4 Comparison of the Life Span
Observations in the Austrian Open Air Museum in Stuebing have revealed the life span of different shingle types. In the last centuries, they were renewed after 35–50 years. Currently, the life span of sawn boards in the museum is 30–45 years.

Phleps (1942) described split shingles with an age of up to 100 and 70–80 years for oak and larch, respectively. For Sawara cypress (Chamaecyparis pisifera), a species native to Japan, split shingles have an age of 25 years (Murakami et al. 2016). The durability of redwood (Sequoia spp.) shingles is at least 25–33 years (Stirling 2010). Other species, such as western hemlock
Tsuga heterophylla), sugar pine (Pinus lambertiana), and western larch (Larix occidentalis), degrade after 32 years (Morrell et al. 2017). The untreated shingles of western hemlock and sugar pine decay after 10 years (Miller 1991). Species such as western hemlock, Pacific silver fir (Abies amabilis), and western white pine (Pinus monticola) should be used only after preservative treatments (De Groot et al. 1992, 1994, 1996).

The durability of shingles and boards varies remarkably. Therefore, whether the age of the examined roofing is high or low compared to split shingles cannot be easily specified. After 37 years of use, 20% of the boards were still intact and 19% were destroyed (Fig. 5). This finding indicated that 20% of the boards could stay another 10 or 15 years on the roof before they degraded. The durability of sawn boards was likely comparable with that of split shingles (for larch wood in both cases).

4.5 Splitting versus Sawing

Flawless wood is required to split shingles. Its stem must be free of knots, spiral grain, and other fiber deviations (see the Introduction; Thon 1840; Nördlinger 1860; Printz 1884; Carstensen 1937; Burger 1941; Enigl 1987). Additionally, the innermost part of the stem, approximately 12 cm in diameter, was removed to avoid spiral grain, indicating that the juvenile part of the stem was not used.

Our results with sawn boards showed that the presence of juvenile wood, fiber deviations, knots, and cracks reduced durability. We hypothesized that the same durability could be obtained if the same log quality, which is necessary for split shingles, was used to saw boards for roofing.

Previous studies described the advantages of splitting against sawn surfaces; for instance, fibers are not separated; therefore, shingles have enhanced water repellency and durability (Beckmann 1783; Völker 1836; Hartmann 1841; Möhl 1869; Phleps 1942). In the examination of the top layer at the upper end covered with the upper raw part of boards, wear of approximately 2–3 mm occurs because of photolytic degradation and mechanical abrasion by rain, snow, and wind (Fengel & Wegener 1989). This finding means that the aforementioned advantage of a split surface is lost after a few years, as soon as the uppermost surface is eroded by UV light and rainfall. This observation supports the hypothesis that sawn boards with the same wood quality can last as long as split shingles on roofs.

5 Conclusions

Wooden roofing made from split shingles has been known in Europe and other regions worldwide for several thousands of years. According to handicraft...
rules, split wood is more durable than sawn boards because cut fibers in sawn boards absorb more moisture, thereby creating favorable conditions for fungal growth. Splitting shingles requires good wood quality, that is, wood must not have spiral grain, tapered logs, and knots; juvenile wood must also be avoided. Therefore, sawn boards for roofing can last as long as split shingles if the same strict rules of wood selection are applied.

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