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Technical wood wool for composites

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Abstract

Due to its very good mechanical properties at low density, wood is a high potential and sustainable raw material for composite applications. Wood as small particles are commonly processed with polymers to Wood-Polymer-Composites (WPC). Thereby, the inherent strength of the wood is not used to its full potential. In order to transfer the strength properties of solid wood with good shaping properties to composite, wood wool properties were studied. Wood wool is a well-known raw material in the wood-processing industry and is mainly used for packaging, animal bedding and insulation boards [1, 2]. The use of wood wool as a flexible, formable reinforcement for polymer composites is not known so far. Therefore industrial wood wool and developed experimental wood wool are investigated and evaluated for their suitability as fibre reinforcement for composites. The mechanical properties, in particular the tensile strength, are the relevant factors.

1 Introduction

Wood wool is a wood-based material produced mechanically by wood wool machines from kiln-dried hardwoods and softwoods. The maximum length of a single wood wool fibre is equal to the length of timber being used and is usually 500 mm long. The biological, chemical and physical properties of the wood wool depend on the wood species used. Wood wool as a renewable raw and residual material has so far been used in lower quality applications, e.g. as a filling, stuffing, insulation and filter material as well as for the packaging and transport of sensitive products and foodstuffs (Fig. 1) [1]. However, the use of wood wool in significantly higher-value applications in polymer composites is not known yet.

Figure 1: Classic wood wool types: pine, spruce thick, spruce thin (left to right)

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Wood wool is produced with a special planing process (Fig. 2). In a first step, wood gets scored according to the required wood wool width. Secondly, the chip is planed off. This basic principle is implemented in different machine designs [3]. Wood wool can be divided into different classes depending on the thickness. According to DIN 4077 (1976) [4], the thickness of wood wool varies from 0.05 to 0.5 mm, the width from 1 mm to 5 mm [5]. Although DIN 4077 is no longer in existence, similar grades are still generally available [1, 6]. The field of application is selected according to this wood wool fineness. So the thinnest wool (0.15 mm) is used, for udder wool and the thicker wood wool (0.25 mm) for packaging and technical applications such as lightweight boards or wood wool as a material in cement-bonded chipboard [7].

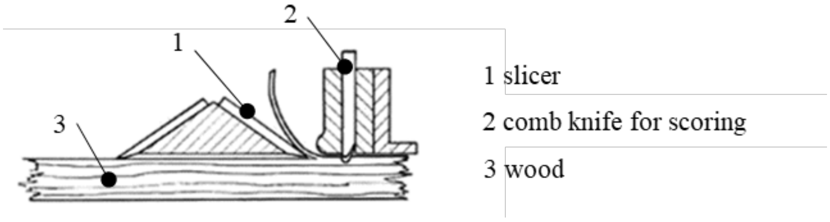

Figure 2: Basic principle of wood wool planing [3]

Besides the thickness, length and moisture content of the wood wool, the respective wood species influence its further use. Currently, the main wood species used for wood wool are spruce and pine. Hardwoods such as beech and poplar are also occasionally processed [1].

The use of wood as a reinforcing material for fibre-reinforced plastics is currently limited to the use of particles (so-called wood fibres, Fig. 3), i.e. largely as a filler [8]. In before mentioned wood-polymer-composites, these fibres are combined with thermoplastics in extruding processes [9]. However, wood application for WPC does not use the inherent material properties of wood. Wood itself is a natural fibre composite material and its structural anisotropy in composites is used for technological material developments [10].

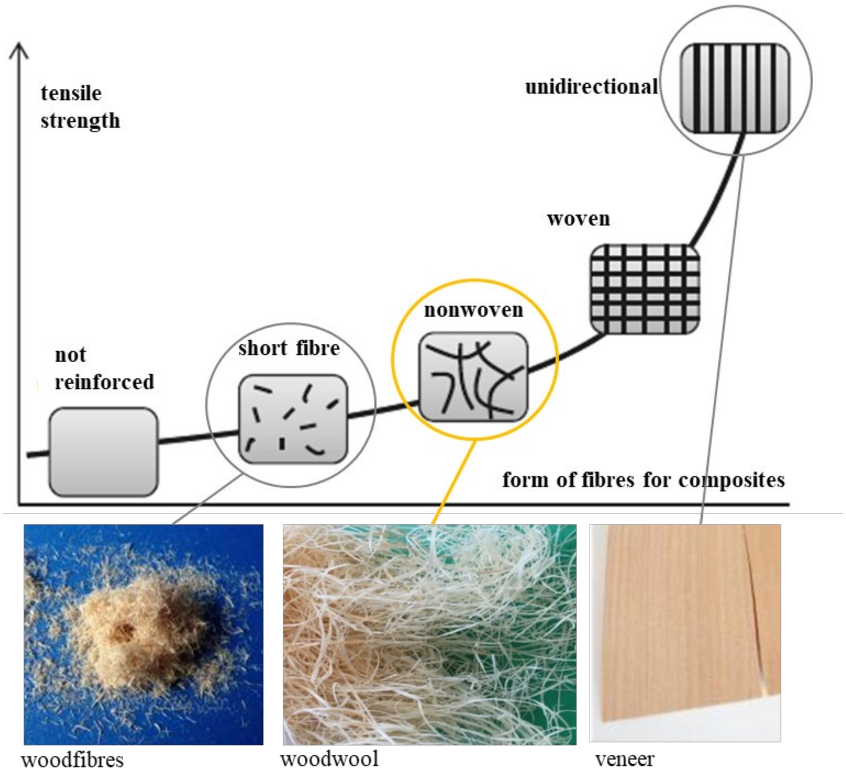

Figure 3: Increase in composite strength according to textile structure for wood [11]

Varying the textile form of the reinforcement material, the composite strength can be classified (Fig. 3). Thus, the lowest strength is present with wood particles and the highest with veneer. These strengths of the fibre reinforcement are accordingly in the strengths of the composite as well. The veneer strength corresponds to the solid wood strength. Wood wool can be classified in the middle strength range of composites (Fig. 3). The advantage of wood wool compared to veneer is the flexible formability and compared to wood fibres the higher strength. Wood wool has the potential to be an additional wood raw material for composites and to provide both, formability and high strength.

In order to determine the potential properties for composite applications, the possible maximum strengths of the wood wool were investigated. Based on the industrial wood wool processing, the production was analysed and modified to ensure gentle manufacturing. The anatomy of the used wood species had to be considered and suitable geometries were analysed respectively. The aim was to preserve the material-immanent solid wood properties (strength, density) inside the wood wool.

2 Materials and methods

2.1 Material

Besides spruce, which is the typical material for industrial wood wool, hardwood species were investigated. Regional woods were selected and their tensile strength and density were the selection criteria. The regional hardwoods beech and birch have higher tensile strengths than softwoods and are therefore more suitable for use in composites. Due to their structure, hardwoods consist of so-called vessel (Tab. 1, Fig. 4). These vessel sizes limit the possible thickness of the wood wool. Accordingly, it is assumed that birch with an average vessel diameter of 0.13 mm can only be produced in a thickness of more than 0.13 mm. Based on the known mechanical properties, the vessel properties and its distribution, the following wood species were selected: Hardwood species birch and beech and as softwood spruce and pine. According to the industrial main wood species spruce for wood wool, industrial spruce wood wool is the reference material of the investigations.

Table 1: Suitable wood species for wood wool in composite applications

Wood species	**Raw density (∅) (kg/m³)**	**Tensile strength II (∅) (MPa) in fibre direction**	**Vessel diameter (µm)**
Beech	720	135	to 85
Birch	650	140-…	90-130
Spruce	470	90	-
Pine	520	100	-

In addition to the favored thickness of 0.2 mm the thinnest and most flexible wood wool in this investigation is 0.1 mm thick. The width was set at 0.9 mm and the length of 300 mm remained constant. Thus, the limits and perspectives of wood wool with regard to wood type and wood wool thickness for application in composites were investigated.

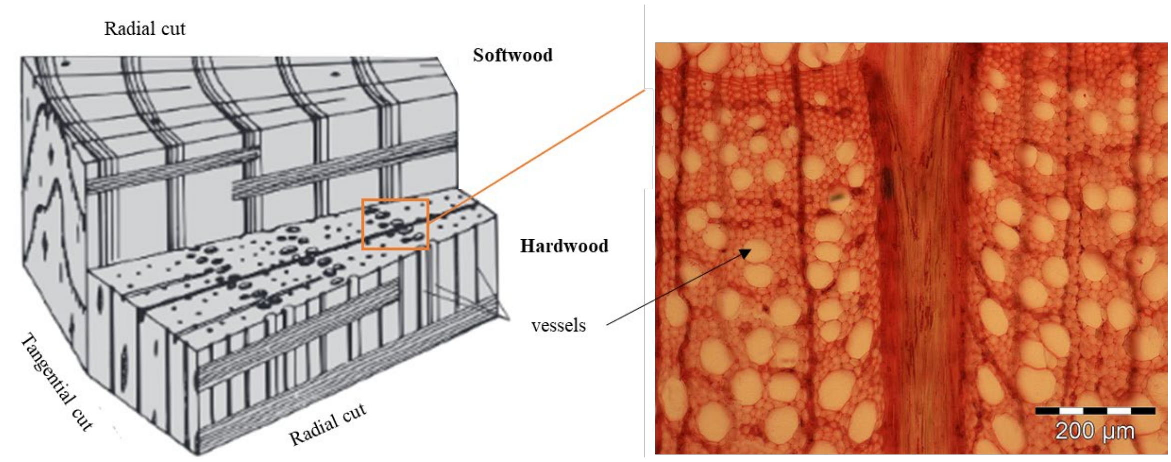

Figure 4: Cross-section of softwood and hardwood (left) [12] and cross-section of European beech (right) [14]

2.2 Methods

The aim is to produce undamaged wood wool, regarding the manufacturing process. To this end, two basic approaches were applied on a laboratory scale: Firstly, the processing of wood with higher wood moisture (above 65 % humidity), which offers better plastification and leads to gentle processing compared to the traditional procedure [13]. Secondly, the application of a diagonal cut in the planing process during wood wool production. To achieve this, the planing process is carried out with an industrial lengthwise veneer slicer. The inclination of the planing knife of approx. 75° in relation to the feed direction (Fig. 5) leads to gentle wood processing because low cutting forces allow the usage of a small rake angle [13]. Due to the inclination, even smaller effective rake angles are possible to manufacture. Wood shavings planed in this manner are gently deflected and do not fracture during planing, which is always the case in traditional wood wool manufacturing. To implement the scoring process, a separate so-called scoring device was developed (Fig. 6). It allows the scoring of wood blocks (W x L x H: 130 x 500 x 300 mm³) parallel to its fibres. The device consists of a manually operated carriage, which allows a previously clamped block of wood to be precisely guided along an assembly of scoring knives (spindle gear and linear guide). The layered structure of this assembly can be modified, so that different scoring geometries and in turn wood wool geometries can be produced. The separation of the two processes scoring and planing means that only low productivity is achieved, but this is accepted during research state. The scoring process takes approx. 1 min with a depth of 2 mm and 10 times planing also takes 1 min. Accordingly, 10 layers of wood wool are produced in 2 min.

The wood wool produced in this manner has the potential to transfer as much fibre reinforcement as possible into a component, as fibres remain undamaged. The wood wool variants produced in this way, are shown in Tab. 2, whereby the type of wood and the thickness vary.

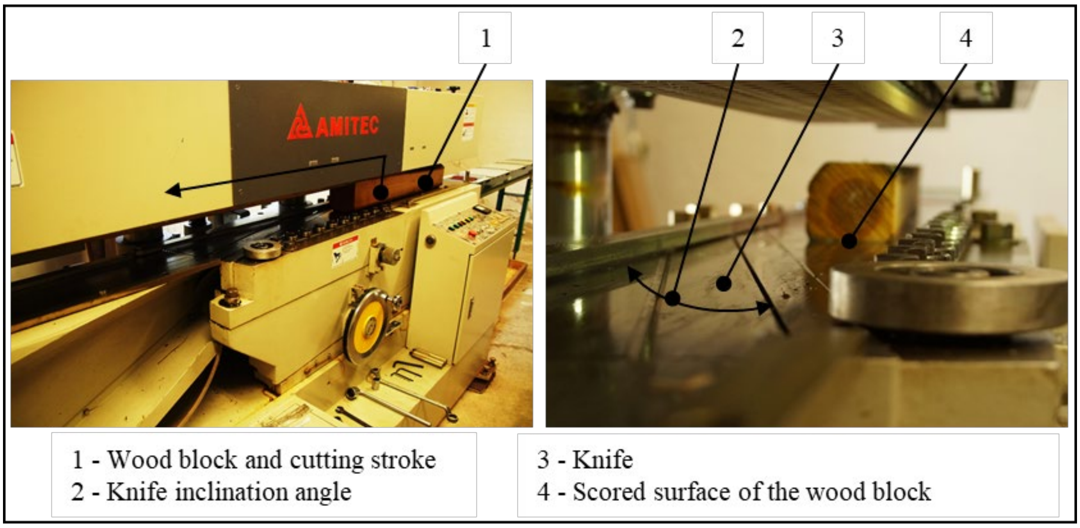

Figure 5: Veneer slicer used for planing wood wool out of a previously scored wood block

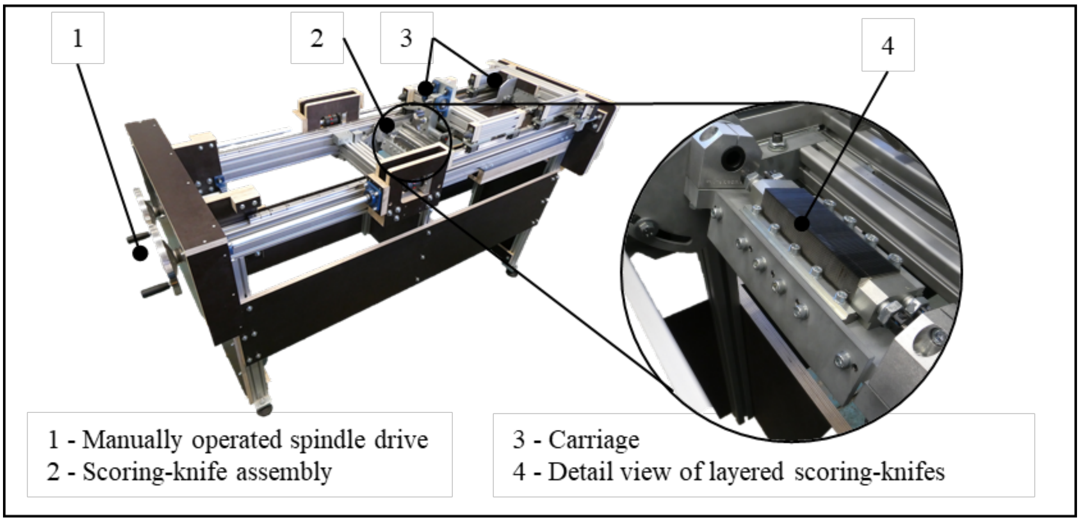

Figure 6: Scoring device on a laboratory scale

Table 2: Overview of all experimental types of wood wool

Name	Thickness [mm]	Width [mm]	Length [mm]
Spruce	0.1	0.9	300
	0.2		
Pine	0.1		
	0.2		
Beech	0.1		
	0.2		
Birch	0.1		
	0.2		

2.3 Test method

To identify the mechanical properties, the wood wool types were tested in a tensile test. The tests were conducted with a Hegewald & Peschke Inspekt 10 testing machine (Hegewald & Peschke, Nossen, Germany). The set-up is shown in the Fig. 7. The test parameters are as follows:

- 100 mm free length,
- Test speed = 100 mm/min,
- Load cell 500 N,
- Traverse path for strain (and modulus),
- Parallel clamping jaws (EN ISO 1924-2),
- 20 specimens,
- Standard climate (20 °C, 65 % relative humidity).

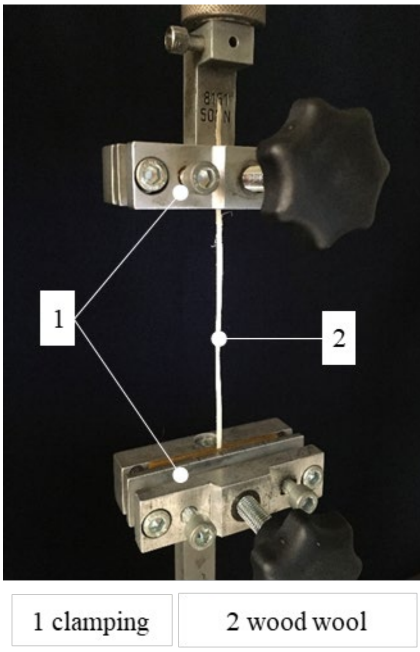

Figure 7: Setup of the tensile test

2.4 Microscopic analysis

To compare and evaluate the quality of the wood structure within the wood wool, the different types of wood wool were examined microscopically. The wood wool types were observed in longitudinal and cross-section with the OlympusBX51 light microscope. The sample preparation of the cross-sections was performed with a microtome Jung, Heidelberg. The microscopic examination of the wood wool surface was conducted with the Keyence VHX 7000.

3 Results and discussion

3.1 Experimental wood wool

The types of wood wool produced in the laboratory process are shown in Fig. 8. Beech, birch spruce and pine can be produced up to the low thickness of 0.1 mm. However, these experimental wood wool types cannot be produced in the requested minimum length of 100 mm at this low thickness. Due to the low thickness, the wood wool breaks in the cross-section, and only comparatively short lengths can be manufactured. This seems to confirm the correlation between vessel diameter and minimal wood wool thickness. In comparison, the industrial wood wool is shown in Fig. 1.

Only the spruce wood wool could be reproducibly produced in the desired length at 0.2 mm thickness. All other wood types of wool, the fibre length became shorter with decreasing thickness. This can be seen in Fig. 08 by the obvious tangling of the short fibres. Only the spruce laboratory wool has a directional structure. For the determination of the characteristic values in 3.2, only fibres of the desired length were manually taken.

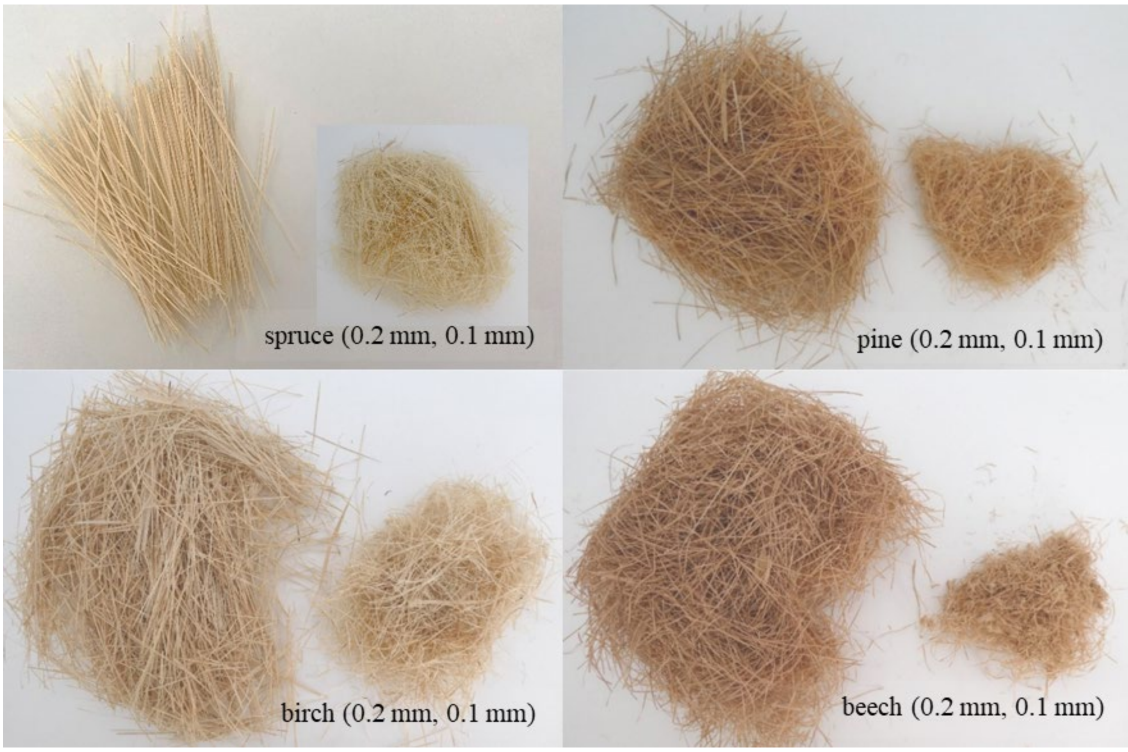

Figure 8: Experimental wood wool

3.2 Tensile strength

The tensile strength decreases with decreasing thickness of the experimental wood wool, for all wood types (compare Table 2). Obviously, the tensile strength of the experimental wood wool spruce 0.2 mm with 102 MPa, is in the range of solid wood, as well as the modulus of elasticity with 10 GPa. The same applies to birch. Accordingly, the experimental wood wool in 0.2 mm thickness is much more promising for structural applications than the thicker industrial wood wool with the strength of 35 MPa. Comparing the strength of the experimental wood wool of 0.1 mm with the industrial thin wood wool also shows the higher strength of the experimental wool variant with 65 MPa compared to 26 MPa. Thereby, the experimental production process leads to wood wool with less damages and thus to higher strengths. The tensile strength of the experimental wood wool made of birch with a thickness of 0.2 mm is comparatively the highest at 118.63 MPa. This is an alternative to the commonly used spruce. In general, 0.2 mm thickness exploits the inherent strength of the wood wool. With lower wood wool thicknesses, the strength of the wool decreases in advantage of a possibly higher flexibility.

Table 2: Properties of wood wool types of different thicknesses and wood species (Mean and standard deviation)

Name	**Tensile Modulus (MPa)**	**Tensile strength (MPa)**	**Width (mm)**	**Thickness (mm)**
Industrial thick (Spruce)	3215 (158)	35 (3,18)	2	0.25
Industrial thin (Spruce)	2845 (152)	26 (1,7)	1.5	0.15
Spruce	10669 (257)	102 (36,04)	0.9	0.2
Spruce 01	9860 (1989)	65,36 (19,24)	0.9	0.1
Pine	4309 (216)	36,25 (32,57)	0.9	0.2
Birch 01	10686 (1448)	62,95 (29,28)	0.9	0.1
Birch	10683 (386)	118,63 (21,88)	0.9	0.2
Beech	3994 (1090)	21,04 (6,71)	0.9	0.2
Spruce solid wood (DIN 68364:2003)	11000 (2167)	95 (13,3)	-	-
Birch solid wood (DIN 68364:2003)	14000 (840)	137 (8,22)		

3.3 Microscopic analysis

To determine the correlation between the tensile strength and the anatomy of the wood wool, a microscopic examination was conducted. For this purpose, industrial wood wool made of spruce (thickness 0.25 mm) was compared with laboratory wood wool (0.2 mm). Longitudinal cross sections of spruce wood wool as industrial and experimental variant were examined microscopically. The fibre direction of the thicker industrial wood wool is shown in Fig. 9. The fibre orientation lies along the longitudinal direction. The optimal fiber orientation can be seen in width- and thickness-related cross sections.

Also the microscopic characterization of the experimental wood wool shows the axial orientation of the fibres on both cross sections (Fig. 10). In theory, this would indicate a good tensile strength of the industrial and experimental wood wool.

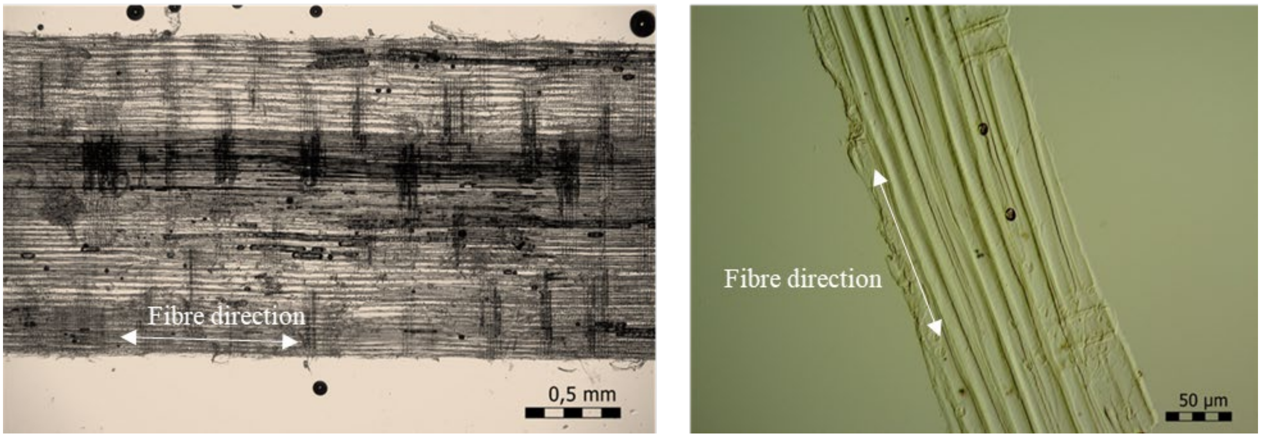

Figure 9: Cross section of the industrial wood wool width (left) and thickness (right) with load-orientated fibre direction; (OlympusBX 51)

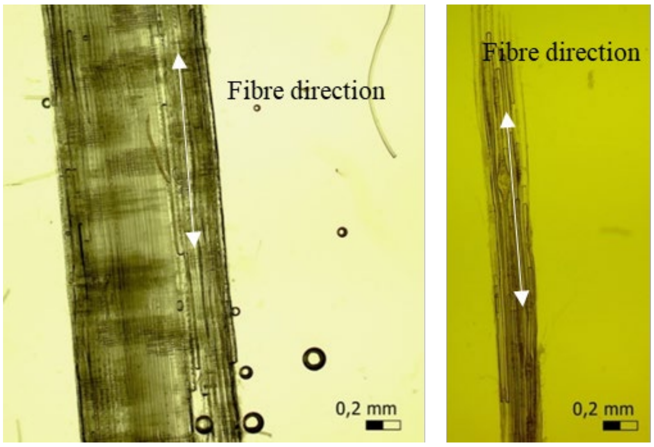

Figure 10:Cross section of the experimental wood wool; width (left) and thickness (right) with load-orientated fibre direction; (OlympusBX 51)

The surface microscopy was used to examine the surface damage of industrial wood wool and experimental wood wool (Fig. 11). The significant damage of the industrial wood wool is shown in Fig. 11 (orange). This may explain the lower strength of the industrial wood wool compared to the experimental wood wool. The experimental production showed lower damage in terms of rake angle.

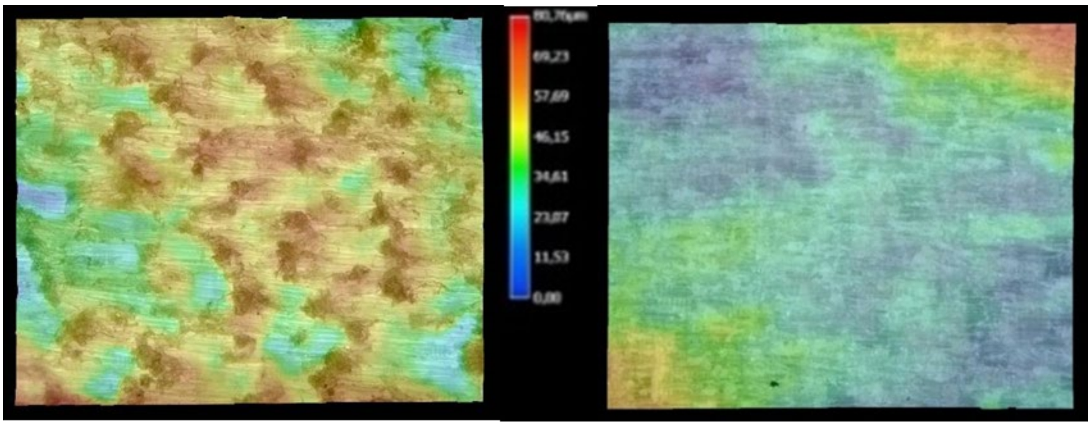

Figure 11:Difference in surface finish/damage of the wood wool (industrial wood wool left, experimental wood wool right), (KeyenceVHX7000)

4 Conclusion

The investigation shows:

- The tensile strength and the tensile modulus of the experimental wood wool (birch and spruce) of 0.2 mm thickness reaches the mechanical properties of solid wood.
- The thinner experimental wood wool has comparatively good mechanical properties, lower than solid wood and higher than the industrial wood wool.
- The modified cutting angle in the experimental process leads to less damaged wood wool structure, shown in the tensile strength of the wood wool.
- Due to its good mechanical properties, the use of wood wool as a reinforcing material for plastic composites is promising.
- In order to transfer the inherent wood strength into the wood wool structure/fiber, the minimum thickness should be 0.2 mm.
- Wood wool closes the structural material gap between short fibres and veneer as reinforcement for plastic composites (Fig. 3). With its flexible structure, wood wool has better forming properties than veneer and, due to the length of its fibres, higher strength than the raw material for WPC.
- Further investigations into the specific forming behaviour of wood wool for composites is recommended.

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