FIRENWOOD

Improved fire design of engineered wood systems in buildings

Sub report D3.4
Test series 2

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1 Introduction

Test series 2 exposes test specimens with glued-in rods to the Standard Fire Curve for 60 minutes. No mechanical load is applied. The aim is to generate thermal parameters for numerical simulations and to investigate the influence of different setups and thermal protection measures on the temperature development within the glued joint.

Within test series 2, a distinction is made between three different test setups. The test specimens of test series 2.1 and 2.2 are exposed to fire on only one side, while the test specimens of test series 2.3 are exposed to fire on four sides.

2 Materials and Test Methods

2.1 Materials

As there was no mechanical load and due to the small glue line thickness, it was assumed that the influence of the adhesive type on the heat transfer plays a minor role. Therefore, the same adhesive was used for bonding all test specimens. Adhesive 1 was chosen because it had shown lower thermal resistance in the previous tests of test series 1. It is assumed its results are therefore on the safe side.

The bonding dates of the individual test series are each shown in the appendices B.1, C.1, and D.1.

Metric rods of strength class 8.8 with diameters of 12 mm and 20 mm were glued into the test specimens.

Glued laminated timber of strength class G24 h was used. The beams were checked beforehand for defects and cracks before being cut to the required lengths. It was aimed to obtain test specimens that were as free of defects as possible especially for the lamella in which the rod was bonded. The timber was stored at room temperature for at least 28 days to achieve the equilibrium moisture content. The density was determined from the test specimens according to EN 408. [1] The following average densities were determined for the three test series:

- V2.1: 435 kg/m³ τ = 2,7 %
- V2.2: 431 kg/m³ τ = 3,9 %
- V2.3: 446 kg/m³ τ = 5,1 %

2.2 Manufacturing

2.2.1 Test series 2.1

Within test series 2.1, five test specimens were planned and exposed to the Standard Fire Curve on one side. The test specimens differed according to the rod diameter and the glue line thickness. They were named using three digits. The first digit stands for the test series (1: test series 2.1), the second for the borehole diameter (1: 14 mm, 2: 18 mm, 3: 22 mm, 4 26 mm) and the third for the test specimen number within the series (1 → only one specimen per series):

- SP101 Reference specimen without rod
- SP111 Threaded rod M12 & glue line thickness 1 mm
- SP121 Threaded rod M12 & glue line thickness 3 mm
- SP131 Threaded rod M20 & glue line thickness 1 mm
- SP141 Threaded rod M20 & glue line thickness 3 mm

The test specimens each had a cross-section of 100 mm x 100 mm. A test specimen was assembled from two sections, each with a length of 300 mm, resulting in a total length of 600 mm. The rods were glued in parallel to the grain direction (see Figure 1). The rods with a glue line thickness of 1 mm had an embedment length of 150 mm per side with a total length of 300 mm. With a glue line thickness of 3 mm, spacers in the form of plastic caps were installed at both ends of the rod to ensure a central position in the borehole. For these, the bonded length of the rod was increased by the height of one cap each. This results in total lengths of 324 mm and 328 mm for the rods of test specimens 121 and 141.

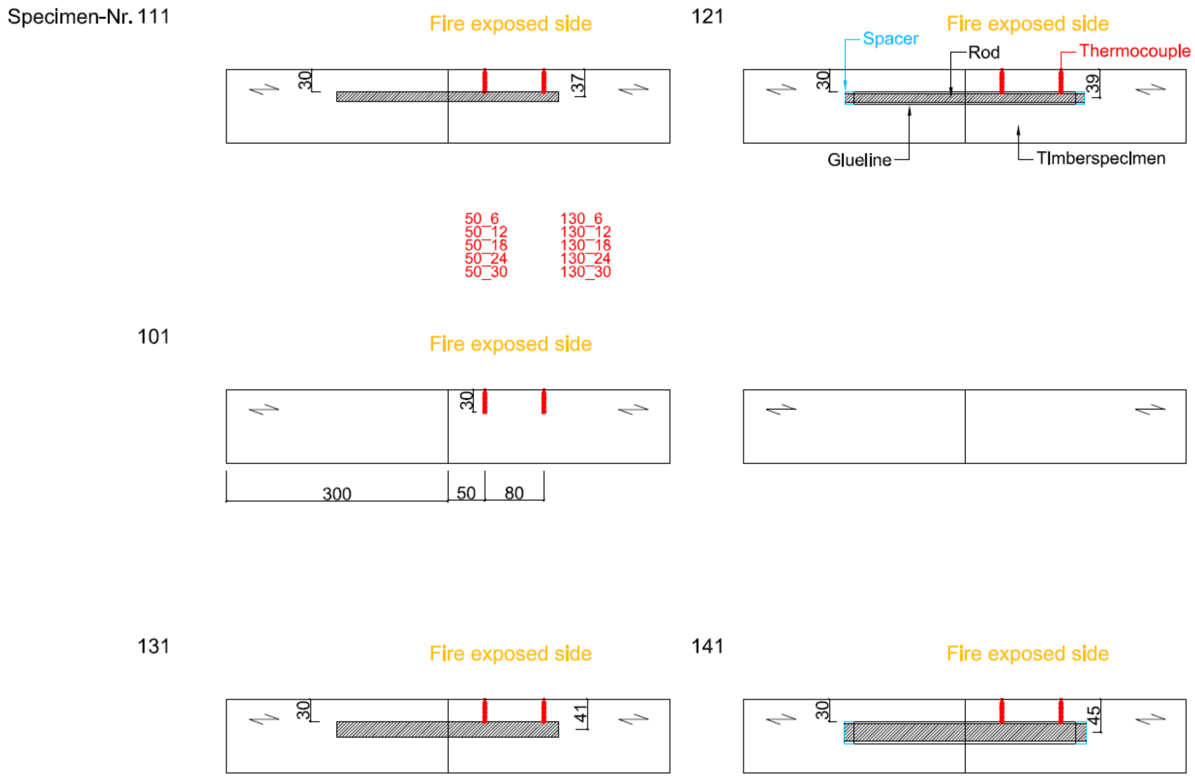

Figure 1: Sketch Specimens in test series 2.1 (red: thermocouples, blue: spacer)

In order to measure the temperature development in the specimens, type K thermocouples were installed. These were embedded in the test specimens on the left and right sides at intervals of 6 mm each. The boreholes were planned so that the edge of the borehole was at a depth of 30 mm from the surface exposed to fire. It was aimed to investigate whether the diameter of the rod or the thickness of the adhesive joint had an influence on the heating behavior. The two locations of the thermocouples were located at a distance of 50 mm and 130 mm from the joint of the two halves of the test specimen.

After sorting the wood, the beams were cut to 300 mm accordingly. For the half in which thermocouples were installed, the length had to be increased by 4 mm, as these were subsequently cut open again at the height of 50 mm and 130 mm (saw blade width 2 mm). Before the additional cuts, the boreholes were drilled with the corresponding thicknesses using a drill stand and a drilling machine. Due to the extensive drilling length, straight drilling could not be guaranteed. The drill can run out of line due to the grain flow in the wood or any knots present. Therefore, sometimes deviating distances of the borehole edge from the side exposed to the fire were achieved instead of the planned 30 mm (see Figure 2).

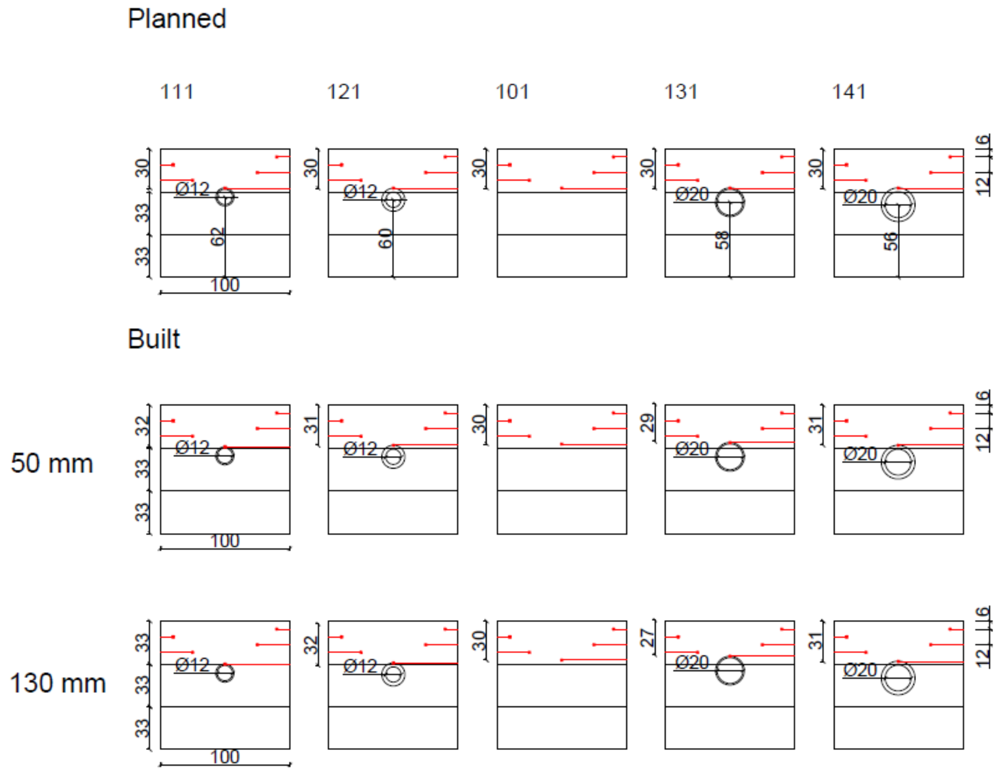

Figure 2: Planned and built location of the thermocouples in test series 2.1

After the drilling, the separation into three parts took place at a height of 50 mm and 130 mm on one specimen half. The channels for the thermocouples were milled into the two lower sections. These are located 6 mm, 12 mm, 18 mm, 24 mm from the surface exposed to fire and at the edge of the borehole. The length of the groove was increased by 2 cm the deeper the milled channel was located, starting with a depth of 2 cm (see Figure 2 and Figure 3). The measuring point is where the two stripped wires touch first. Since the twisted tips of the thermocouples each had a length of 1 cm, the first measuring point was at a depth of 1 cm. In the case of test specimen 131, at a distance of 130 mm from the joint, the milling channel was set incorrectly, not at a depth of 30 mm but at a depth of 24 mm, so there was no measuring point at the edge of the borehole. The same error occurs with test specimen 101 at a distance of 50 mm from the joint. The measured values were assigned to the depths of 24 mm accordingly. The grooves were made perpendicular to the lamella direction of the glulam. Since the adhesive joints of the lamellas are aligned at right angles to the fire exposed side, individual layers should be prevented from falling off.

Additional channels for the thermocouples were also inserted laterally to guide them to the side unexposed to the fire (see Figure 3).

Figure 3: left: View of the specimens after milling, right: Channels on the side of the specimen

After the milling process, the thermocouples were inserted into the milling channels and fixed with staples. The three individual parts were then glued together again with adhesive and screw clamps. Excess glue was removed from the edges (see Figure 4).

To glue the rods, two matching test specimen halves were pressed against each other using screw clamps after the holes had been cleaned of dust using compressed air. The joint was wrapped with adhesive tape so no adhesive could run off. Side holes with a diameter of 8 mm were drilled 1 cm above each of the two borehole ends. On one side, the adhesive was filled into the borehole using a compressed air cartridge gun. The other hole served as a vent. As soon as the adhesive leaked out of the ventilation hole, the two holes were closed with wooden dowels. The test specimens were removed from the screw clamps after seven days of drying at normal temperature conditions (20 °C, 65 % r. h.).

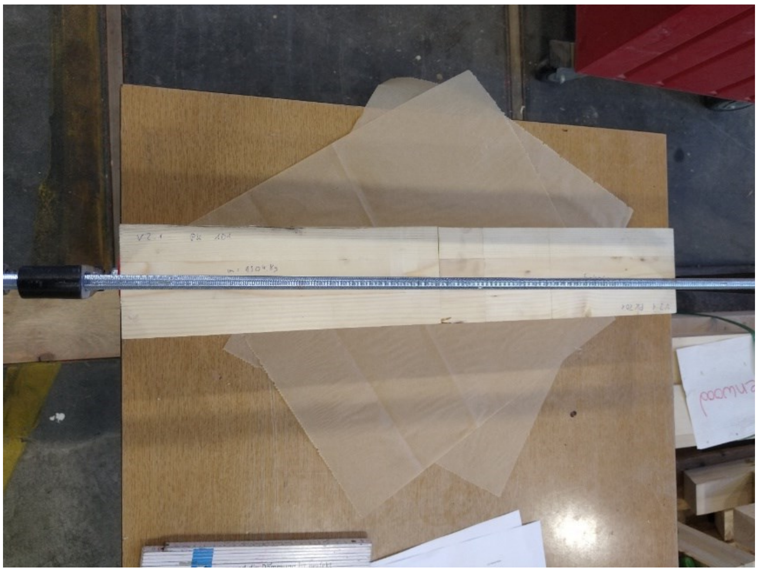

Figure 4: Gluing process for specimen 121

2.2.2 Test series 2.2

In test series 2.2, a total of eight test specimens were tested. The rods were inserted perpendicular to the grain direction of the wood. Four rods were glued into each test specimen. The lateral distance between the rods was 140 mm and 150 mm, respectively, to avoid mutual heat influence. Thus, the total length of a test specimen was 600 mm with a width of 140 mm. Two metric rods with a diameter of 20 mm and two with a diameter of 12 mm were inserted per test specimen. The glue line thickness was varied between 1 mm and 3 mm. The height of a test specimen differed depending on the structure and the length of the coverage:

- SP1 Embedment length 150 mm - rod leveled on the fire exposed surface
- SP2 Embedment length 150 mm - 10 mm wooden plug on the fire exposed surface
- SP3 Embedment length 150 mm - 30 mm wooden plug on the fire exposed surface fire
- SP4 Embedment length 450 mm - 20 mm projecting rod with flat washer and nut on the fire exposed surface
- SP5 Embedment length 450 mm - 10 mm wooden plug on the fire exposed surface
- SP6 Embedment length 450 mm - 30 mm wooden plug on the fire exposed surface
- SP7 Embedment length 450 mm - 12.5 mm GKF plate on the fire exposed surface
- SP8 Embedment length 450 mm - rod leveled on the fire exposed surface

For the test specimens with plugs, the total height of the specimen is the embedment length plus the height of the plug (see Figure 5).

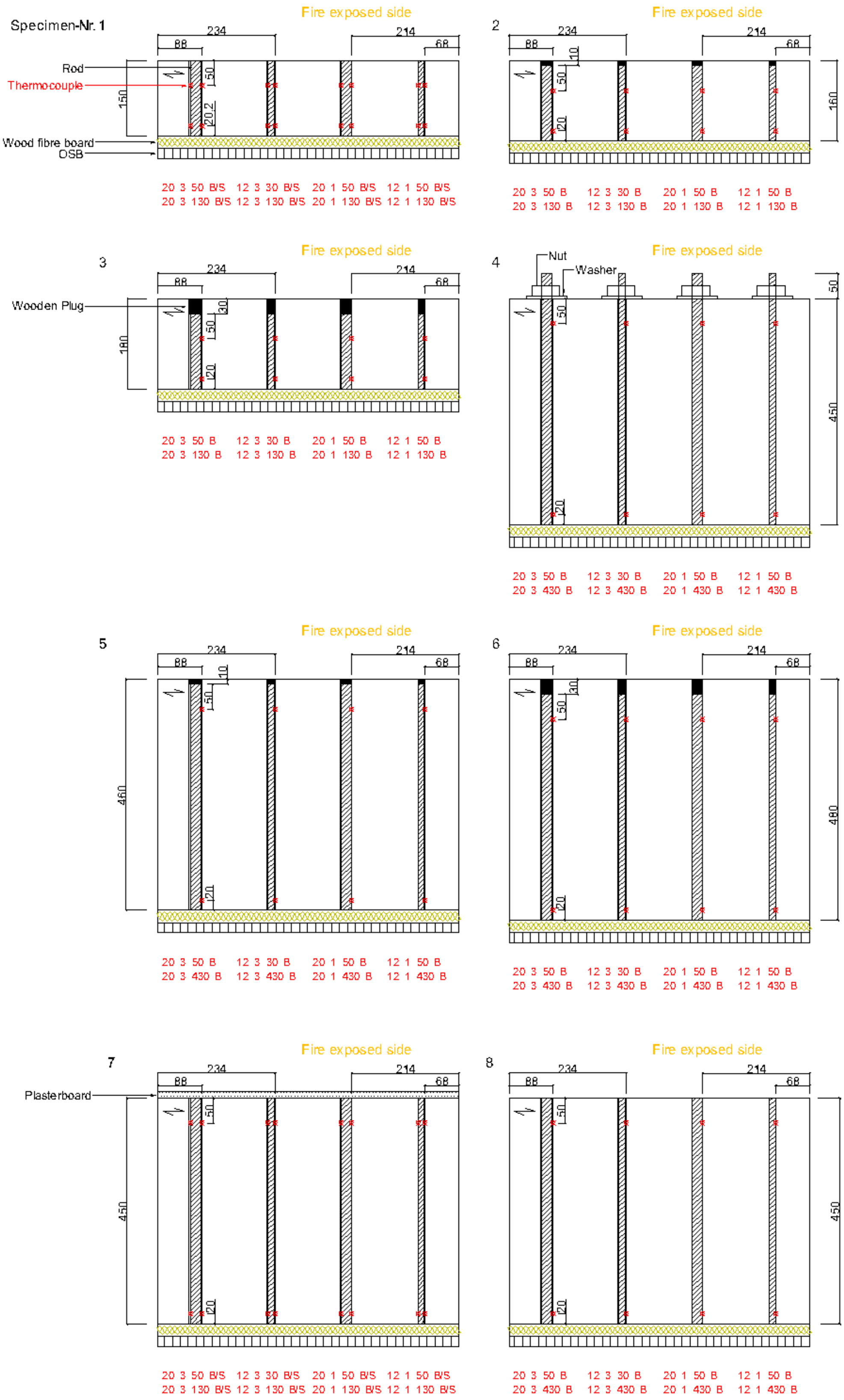

Figure 5: Sections of the eight specimens of test series 2.2 (red: thermocouples; Naming: 1. Digit: rod diameter, 2. Digit: glue line thickness, 3. Digit: measurement depth, 4. Digit: measurement position B → Borehole, S → Steel)

Type K thermocouples were inserted to measure the temperature in the glue line. These were located at a depth of 50 mm from the side exposed to the fire behind the protective layer and 20 mm from the fire unexposed side. The measuring point for all test specimens was the edge of the borehole. Only for test specimens 1 and 7 were additional measuring points placed in the contact area of the rod to investigate the influence of the glue line thickness on the heat distribution.

After cutting and weighing the test specimens, the boreholes for the rods were drilled in the appropriate diameters (14 mm, 18 mm, 22 mm, 26 mm) with the help of a drill stand and Auger bits. For the test specimens with lengths of more than 450 mm, drilling had to be done from both sides for the 18 mm and 26 mm diameters because of the maximum available Auger bit length of 350 mm. The prepared specimens are shown in Figure 6.

Figure 6: Drilled specimens 1 -3 on the left and 4 – 8 on the right

To insert the thermocouples, holes with a diameter of 2 mm were drilled on the sides of the specimens. In the beginning, a standing drill with a drilling length of 35 mm was used to pre-boreholes that were as straight as possible. The holes were then extended to a depth of 80 mm.

The wooden plugs required for the test specimens 2, 3 ,5 and 6 consisted of prefabricated spruce wood plates with a height of 10 mm and a diameter of 25 mm or 35 mm each. The smaller diameter was used for the M12 rods. After drilling the holes for the rods, Forstner bits were used to enlarge the existing hole on the side exposed to the fire to 25 mm or 35 mm in diameter and the necessary depth of 10 mm and 30 mm. Afterwards, the small plates were glued into the grouts. For the 30 mm long wooden plugs, three plates each were glued together before inserting them (see Figure 7).

Figure 7: Specimens with inserted wooden plugs

The twisted wire ends of a thermocouple had a length of 1 cm. Afterwards, the thermocouples were checked for functionality by connecting them to a measuring device. If measurement errors occurred, the corresponding elements were replaced. The thermocouple wires were marked by color at a length of 8 cm and inserted into the pre-drilled holes up to this mark, ensuring that the measuring point was centered in the test specimen.

The boreholes and rods were cleaned with compressed air afterwards. The boreholes were then filled with the amount of adhesive calculated in advance and the rods were pressed into the borehole while slightly twisting them. The greater likelihood of bubbles forming in the adhesive with this insertion method was accepted, as there was no mechanical load. Therefore, a weakening of the glue line did not influence the final result. To obtain a smooth surface of the fire exposed side of the test specimens 1 and 8 with leveled termination of the rods, the test specimens were covered with a layer of baking paper before the gluing process and then screwed to an oriented strand board. The combination ensured a clean surface after filling the adhesive in the borehole. The different joints on the bottom part were wrapped with tape to prevent adhesive leakage (see Figure 8). In the case of test specimen 7, the same procedure had to be carried out on the unexposed surface due to the sticking out rods. The adhesive that leaked out of the borehole was removed before it could dry.

Figure 8: Specimens before (left side) and during (right side) the gluing process

For the rods with glue line thicknesses of 3 mm, plastic caps were used as spacers at the upper and lower edges of the borehole to guarantee a straight insertion of the rods into the borehole. In order to avoid falsifying the results on the side exposed to the fire, the cover of the plastic cap was cut off so that only the ring was pushed over the rod and the rod surface was directly exposed to the temperature load without being covered. For this reason, red caps are only visible on the unexposed side (see Figure 9). The drying time before removing the oriented strand board and the adhesive tape was seven days.

Figure 9: Surfaces of the specimens after gluing and removal of the oriented strand board

The thermocouples were then guided in channels along the test specimen to the unexposed side and fastened with staples (Figure 10).

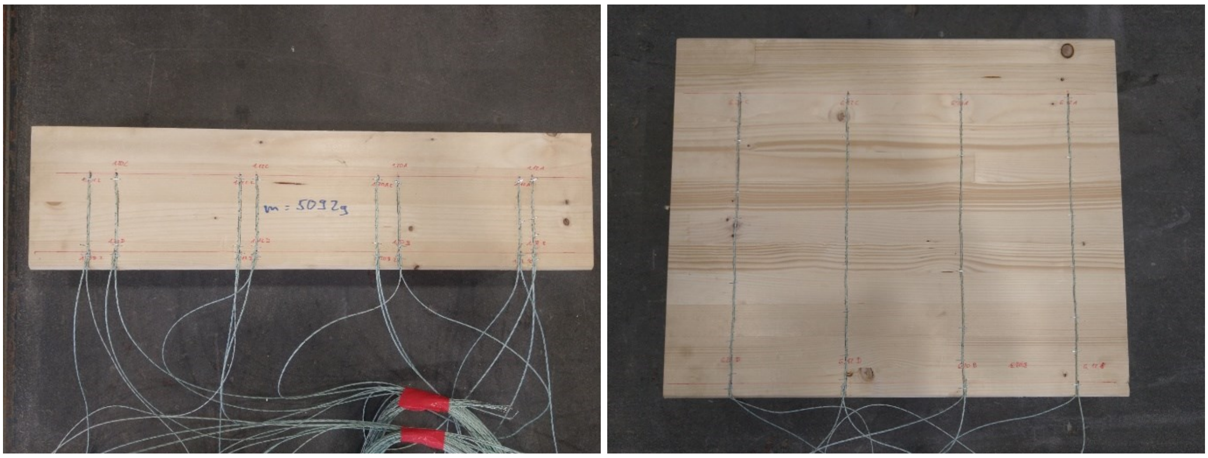

Figure 10: Routing of thermocouples on the edges of the specimens

A wood fiber board and an oriented strand board were finally attached to the unexposed side to prevent a possible fire or smoke leakage through the boreholes during the test. The oriented strand boards and the gypsum plasterboard in test specimen 7 were screwed with ten screws at a distance of 140 mm. The edge distance was 20 mm each (see Figure 11).


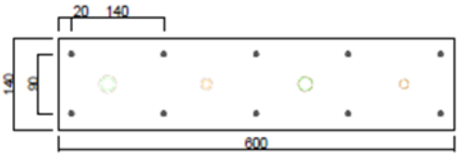

Figure 11: left: Finished Specimen, right: Screw spacing for the plasterboard and the oriented strand boards

2.2.3 Test series 2.3

Test series 2.3 consisted of three test specimens with fire exposure on all sides. The test specimens were each made of two halves of equal length and had a total length of 100 cm. The rods were located in the wood's center and glued parallel to the grain direction. The diameter of the rods varied between 12 mm and 20 mm and the cross-section of the test specimens between 60 mm x 60 mm and 100 mm x 100 mm (see Figure 12). The cross-section corresponds to the required minimum coverage according to EN 1995-1-1 of 2.5 * d_{rod}. [2] The test specimens with the smaller cross-section were made of beams with original cross-sections of 80 mm x 80 mm, of which 5 mm were cut off at each side. The middle lamella had a height of 40 mm to prevent a borehole in the glue line of the lamellas. The embedment length was 150 mm per test specimen half with a glue line thickness of 1 mm each.

The naming was done using the same method as for test series 2.1.

In one of the test specimen halves, two thermocouples were attached inside the glue line between the rod and borehole edge with contact to the rod to measure the temperature. These measuring points were located 50 mm and 120 mm away from the joint area of the two specimen halves.

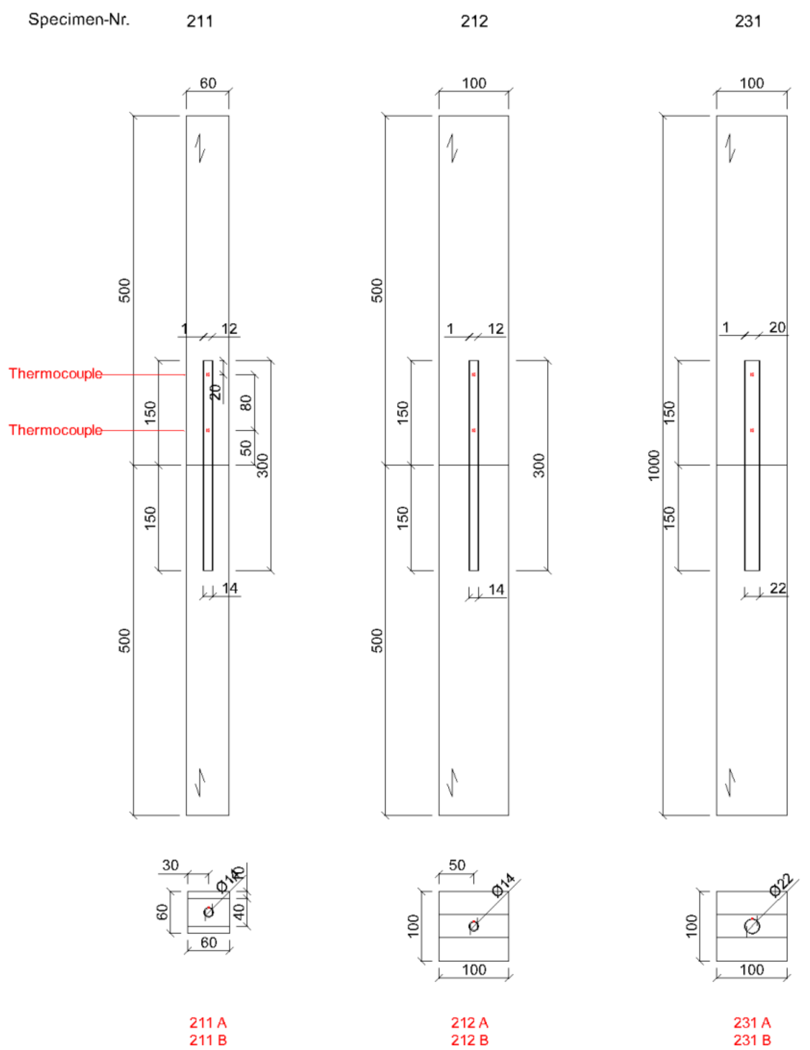

Figure 12: Dimensions of the specimens in test series 2.3 (red: thermocouples)

The timber beams were cut to a length of 500 mm at first. Afterwards they were cut in half in the longitudinal direction. The cut reduces the side length by the thickness of the saw blade by 2 mm, resulting in a cross-section of 60 mm x 58 mm and 100 mm x 98 mm.

The two halves were screwed together again to drill the holes for the rods with a diameter of 14 mm and 22 mm centrally into the wood with the help of an Auger bit and a drill stand. Afterwards, the screws were removed again. The thermocouples were fixed with staples in the borehole on one side of the specimen halves. Reducing the side length on one side reduced the wood cover in this area by 1 mm. The thermocouples were guided outwards along the grain direction via a milling channel in the center of the test specimen (see Figure 13).

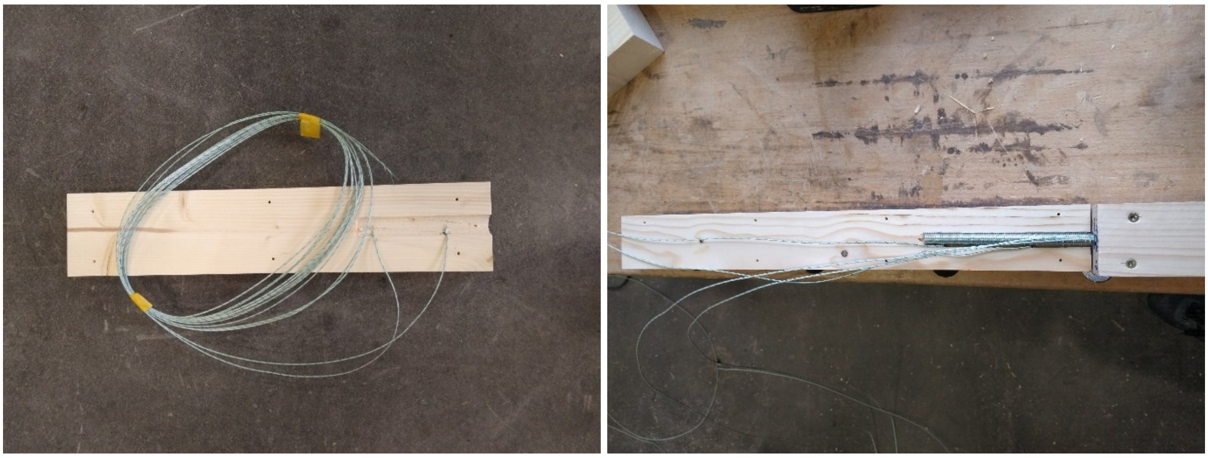

Figure 13: Inserting of the thermocouples

The two halves were then glued together again. Screws and screw clamps provided the necessary contact pressure. After a drying time of 7 days, the screws were removed and then the rods were inserted. For this purpose, lateral holes with a diameter of 8 mm were drilled at a distance of 10 mm from each end of the borehole. Adhesive was applied via one side until the adhesive emerged at the vent hole in the other half of the test specimen. The drilled holes were then sealed with wooden dowels. The adhesive is applied using a compressed air cartridge gun. The correct mixing ratio of resin and hardener is ensured by the static mixers provided by the manufacturer.

Finally, the screw holes were filled with Conlit to prevent fire penetration into the test specimens (see Figure 14).

Figure 14: left: Screwing together of the two specimen halves, right: Sealing of the screw holes

2.2.4 Ceiling element

The test specimens of all three test series are tested within a fire test. For this purpose, the test specimens were connected to form a ceiling element using screws. The fire exposed side had an even surface. Figure 15 shows the top view of the planned ceiling test specimen.

Three solid wooden beams with a length of 2.5 m and a cross-section of 60 mm x 120 mm were used as load-bearing elements. The individual test specimens were screwed to the sides of these. The test specimens of test series 2.1 were positioned in the center (marked blue in the figure) and the test specimens of test series 2.2 in the edge area of the ceiling (marked orange). Beams with a 100 mm x 100 mm cross-section were installed between the test specimens of the two test series to exclude mutual interference as far as possible. The test specimens of test series 2.3 were suspended from these "spacers" (marked red).

Figure 15: Sketch of the ceiling specimen for test series 2.1 (blue), test series 2.2 (orange) and test series 2.3 (red)

The construction-related joints and gaps were sealed with adhesive tape on the unexposed side to prevent smoke penetration during a fire. The openings for the thermocouples and corner connections were also sealed with silicone. For transport reasons, the ceiling was transported to the test facility in two halves and was finally assembled on site (see Figure 16).

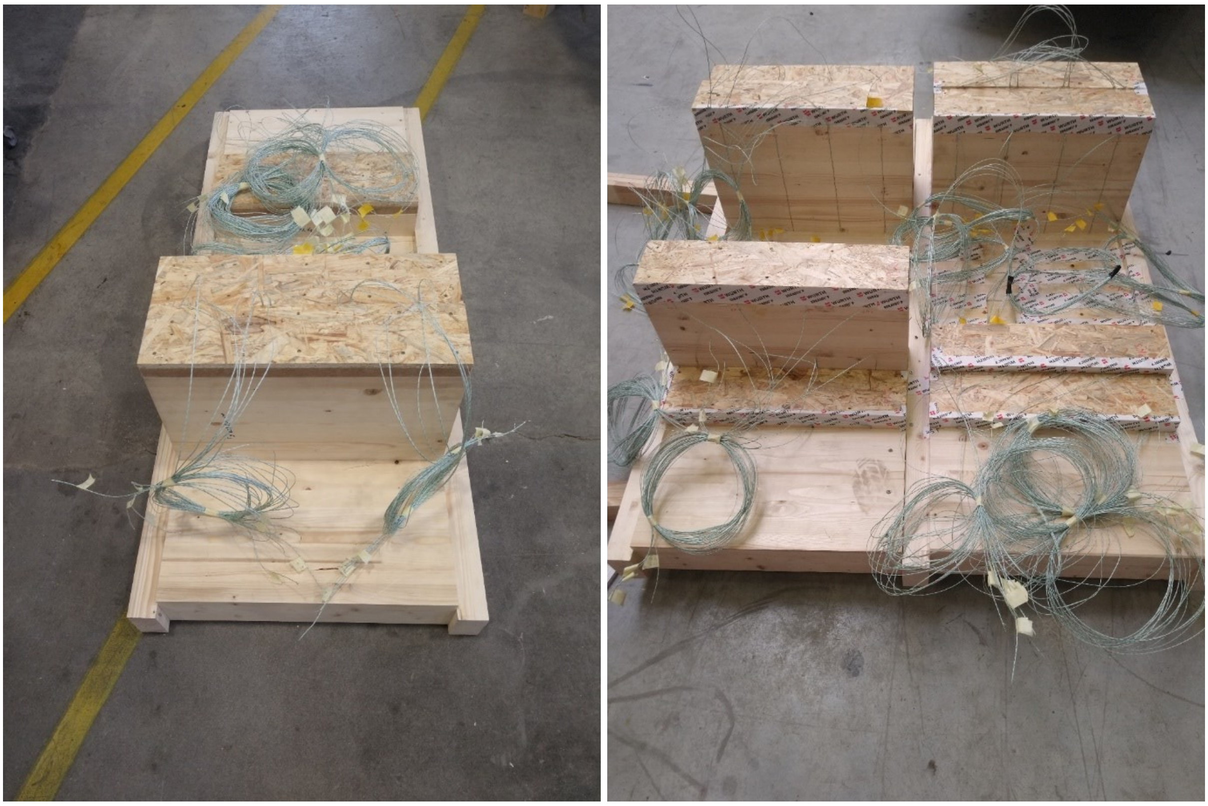
Figure 16: Mounted ceiling specimen

At the test site, the test specimens from test series 2.3 were fastened to the fire-exposed side of the ceiling with two screws each. The thermocouples were passed through pre-drilled holes in the ceiling. To protect the thermocouples from exposure to fire, ceramic wool was also clamped into the joint between the test specimens and the ceiling. Finally, the measuring plugs were attached to the thermocouples and the test specimen was placed on the furnace with a forklift (see Figure 17). The plans for test series 2 are shown in Appendix A. Defective or failed thermocouples are shown in Appendix B.5, C.6 and D.3.

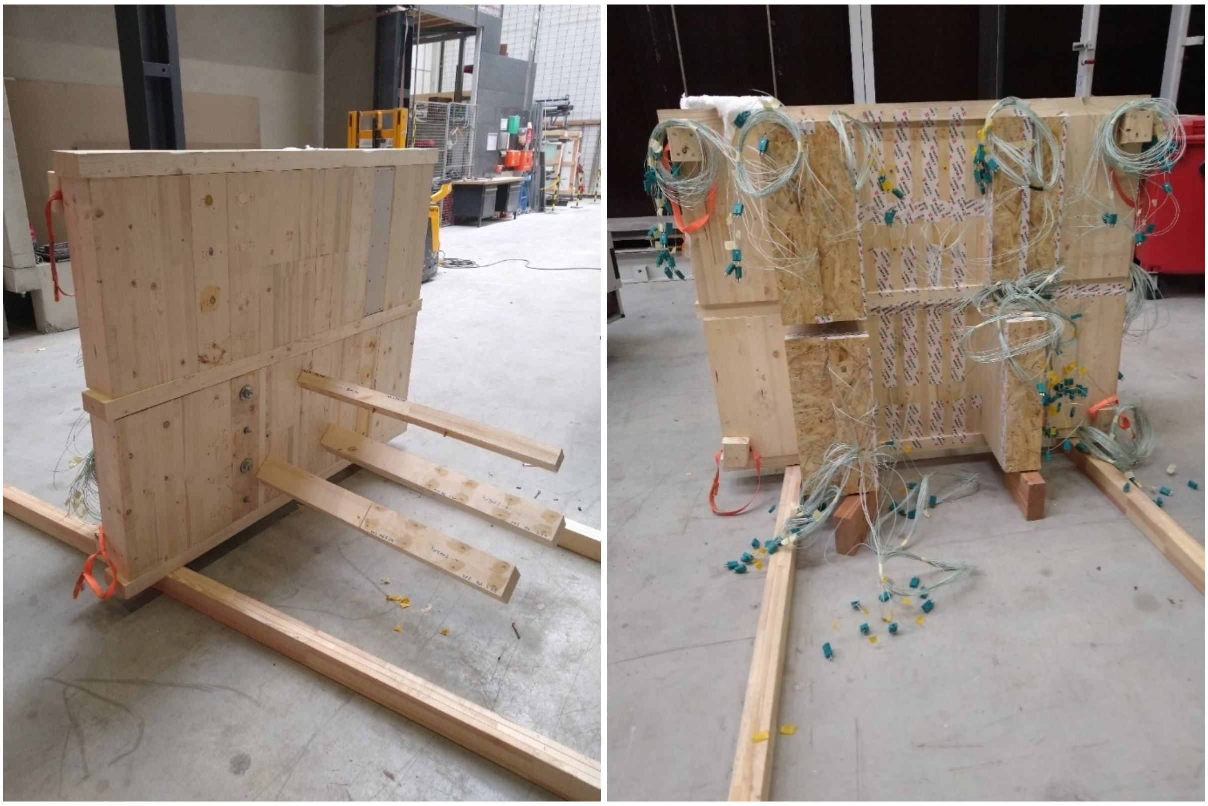

Figure 17: Finished specimen before the fire test (left: side exposed to the fire, right: unexposed side)

2.3 Testing Process

The ceiling specimen was exposed on one side with the Standard Fire Curve. The data on the duration of the test and the extinguishing process can be found in Table 1.

Table 1: Testing data

Protocol	
Beginning Test	15:13
End Test	16:13
Burner off	16:14
Lifting of ceiling	16:16:25
Extinguishing of fire exposed side - Start	16:16:30
Extinguishing of fire exposed side - End	16:20:30
Extinguishing of fire unexposed side - Start	16:21
Extinguishing of fire unexposed side - End	16:22

During the test, the air pressure in the oven and the temperature were measured using thermo plates. There were four plates in a uniform alignment at a distance of approx. 200 mm from the surface of the specimen. The thermo plates were approx. 1500 mm apart and protruded approx. 500 mm into the furnace chamber (see Figure 18).

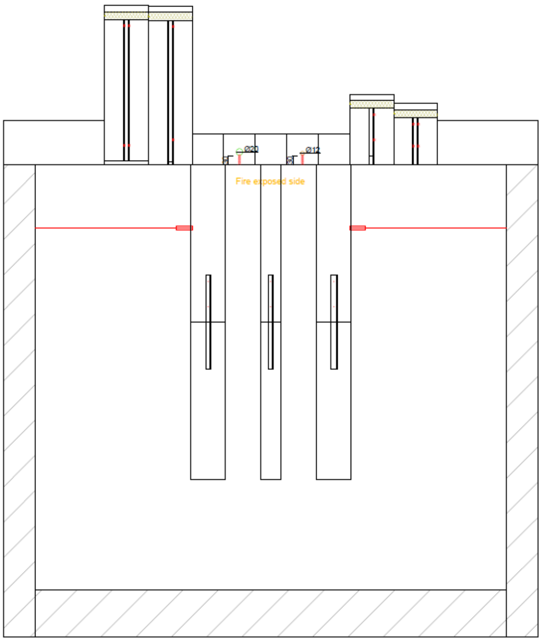

Figure 18: View of the furnace with built-in specimen and thermo plates (red)

The data of the furnace temperature as well as the permissible deviation are shown in Figure 19. The furnace was operated using a gas burner.

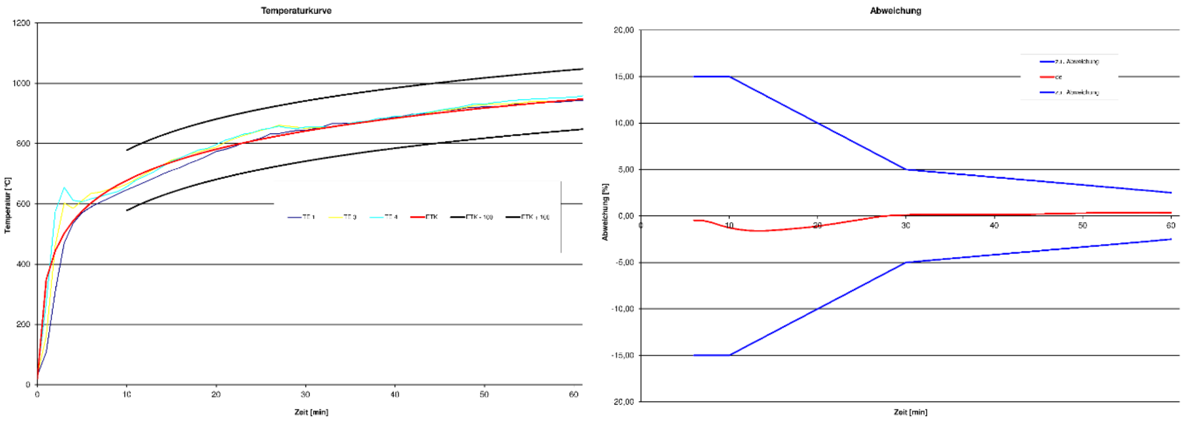

Figure 19: left: Air temperature during the test, right: Deviation of the Standard Fire Curve

During the test, smoke was passing through some joints. This was reduced by covering the relevant areas with mineral wool mats. After 61 minutes the burner was switched off. The ceiling was lifted off the furnace and extinguished on the bottom side, which was exposed to the fire with a water hose. After extinguishing the bottom side, the test specimen was put on the ground to extinguish it from the top (see Figure 20).

Figure 20: left: Specimen during the fire test with slight plumes of smoke; right: Lifting of the ceiling after the fire test

After cooling, the charcoal layer was removed after seven days for a follow-up examination of the individual test specimens using a steel brush attachment on a drill. It was already evident that all the rods in test series 2.1 and 2.2 were visible at the surface and there was no longer any wood covering (see Figure 21). The test specimens from test series 2.3 were already entirely burned during the test, so an examination was not possible.

Figure 21: View of fire exposed side after cooling on the left and after cleaning of the charcoal layer on the right

3 Results in test series 2.1

The test specimens are named with three digits (see Table 2). The first one stands for the test series, the second for the borehole diameter and the third for the specimen number within the series.

Table 2: Naming of specimens in test series 2.1 and 2.3

Tests		Borehole diameter [mm]		Specimen number
1	2.1	0	0	1
2	2.3	1	14	2
		2	18	
		3	22	
		4	26	

3.1 Charring rate

The average charring rate was determined using the two long sides of the test specimen. For this purpose, the residual height of both test specimen halves (left side without thermocouples, right side with thermocouples) was determined and the charring depth calculated based on the original height of 100 mm. The measurement locations were on the left side 5 cm from the side edge, in the center, 5 cm from the joint and directly at the joint. On the right side, the charring depth was measured at the channels of the thermocouples and 5 cm from the side edge (see Figure 22). There is a continuous black discoloration in the channels milled for the thermocouples, which is why it is assumed that a slightly increased charring has taken place. This is also partly reflected in the higher average charring rates in the area of the thermocouples. In addition, smoke penetration was seen during the test.

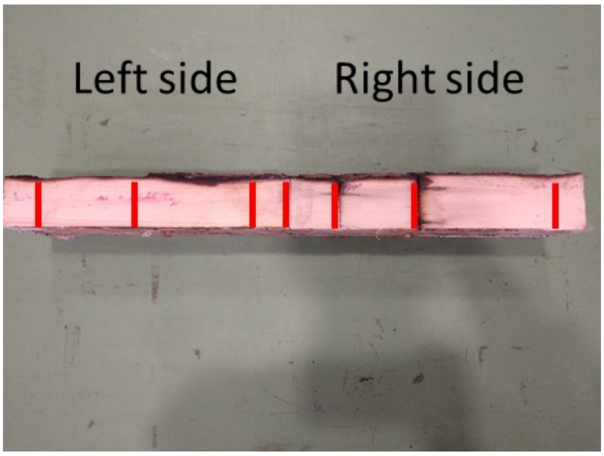

Figure 22: Measurement points of char depth (red)

Since the ceiling was lifted off the furnace in minute 64 after the start of the test, this time was used as a reference for determining the charring rate. The charring rates determined are shown in the table below. The average charring rate on both sides is higher than based on the one-dimensional charring rate of 0.65 mm/min from EN 1995-1-2. [3] It is assumed that the many joints between the test specimens have enabled increased charring. The charring depth was determined exactly in this joint area. Therefore, it is possible that the charring rates in this area are higher than in the middle of the specimen. The same effect occurred with the test specimens of test series 2.2.

Specimen 111 has the highest charring rates (see Table 3). It can also be seen that the average charring rates increase when the charring depths at the temperature measurement points where the channels were milled are included.

Table 3: Charring rates for test series 2.1

	Left side [mm/min]	Right side (without thermocouples) [mm/min]	Right side (with thermocouples) [mm/min]
SP101	0,75	0,76	0,79
SP111	0,77	0,81	0,83
SP121	0,75	0,75	0,75
SP131	0,77	0,76	0,79
SP141	0,78	0,70	0,73

Specimen 111 is also the only specimen in which the rod was present in the borehole after the fire test, but fell off when the charcoal layer was removed (see Figure 23). The remaining specimens are shown in Appendix B.3.

Figure 23: View of test specimens 111 – 141 (from left to right) after cleaning

3.2 Temperatures

The average temperature profiles of the individual test specimens are shown below. The experiment duration is on the horizontal axis while the mean temperature of the measurement points is on the vertical axis. The curves of the individual temperatures for each test specimen and measuring point are shown in the Appendix B.4.

For the measuring depth of 6 mm, similar curves are shown for all test specimens (see Figure 24). The 300 °C-isotherm as the charring limit of wood is exceeded after about eight minutes, which corresponds to a charring rate of 0.75 mm/min and agrees well with the measured charring rates. As already mentioned, a higher penetration in the joints is seen as the cause of the high charring rate.

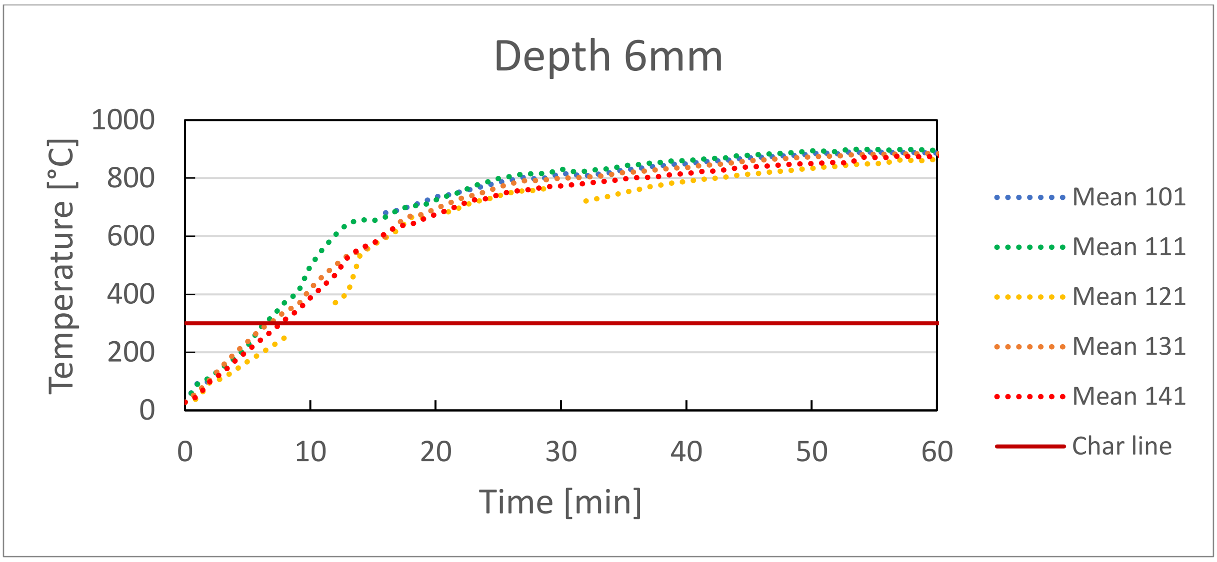

Figure 24: Measured temperature for a depth of 6 mm from the fire exposed side

For a measuring depth of 12 mm, the 300 °C - isotherm is reached after an average of 16 minutes, which corresponds to a charring rate of 0.75 mm/min. The curves of all test specimens still show a similar temperature development (see Figure 25).

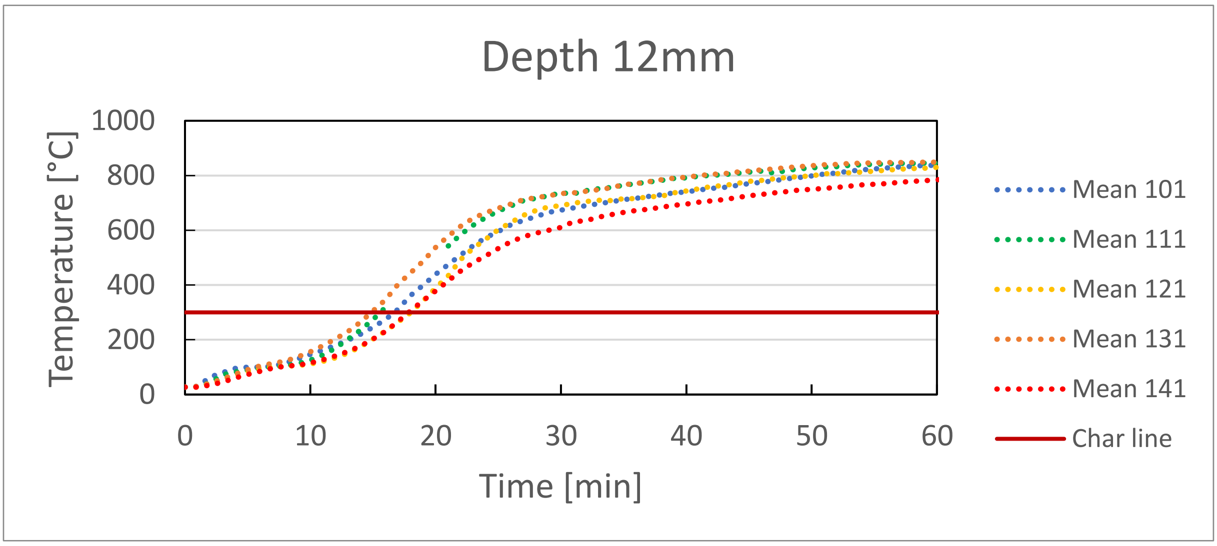

Figure 25: Measured temperature for a depth of 12 mm from the fire exposed side

With the thermocouples positioned at a depth of 18 mm, the charring limit is reached after around 23 minutes, resulting in a charring rate of 0.78 mm/min. The temperatures are relatively similar for all test specimens (see Figure 26).

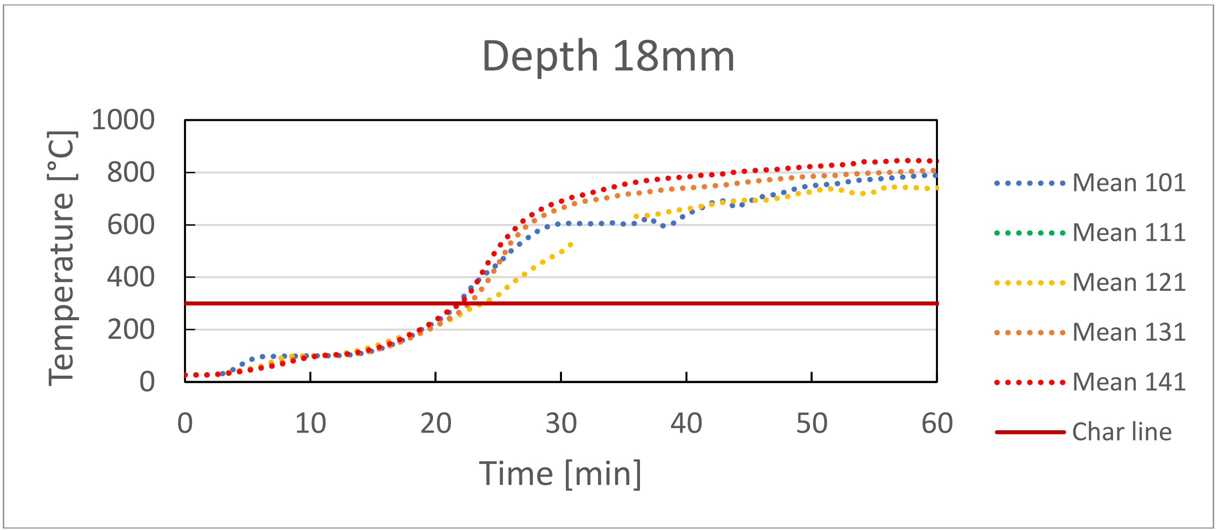

Figure 26: Measured temperature for a depth of 18 mm from the fire exposed side

For a depth of 24 mm, the temperature curves of the individual test specimens are further apart (see Figure 27). Exceeding of the 300 °C – isotherm is in a range of approx. 26 minutes to 36 minutes. It can be assumed that as the fire progresses, the charring in the joints will increase, resulting in higher temperatures. However, since this does not happen evenly, but depends on the properties of the wood (influence of knots etc.) as well as the joint spacing, different charring rates appear plausible. Above all, the test specimens 111 and 121 reach the charring limit more quickly, which corresponds to the comparatively high charring rates at the measuring points.

An influence of the rod diameter or the glue line thickness on the charring rate cannot be shown on the basis of the available data.

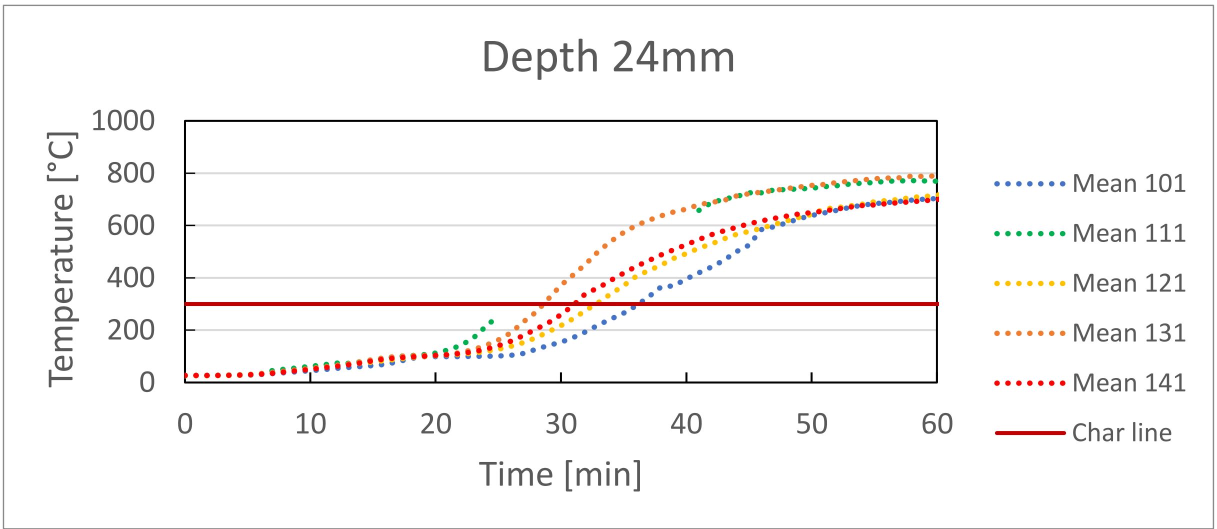

Figure 27: Measured temperature for a depth of 24 mm from the fire exposed side

At a depth of 30 mm, there is no temperature for test specimen 131, since the thermocouple did not deliver any data at a distance of 50 mm from the joint. At a distance of 130 mm the milling was incorrectly set at a depth of 24 mm (see Figure 28).

The temperature curves also show large differences for reaching the 300 °C - isotherm. In the earliest case, it is reached after approx. 38 minutes. In the latest case for test specimen 141, it is reached only after almost 52 minutes. It also has the lowest charring rate. With this time duration there would be a charring rate of 0.59 mm/min, which is below the 0.73 mm/min charring rate measured from the burnt specimen. Two effects could be the causes for the low charring rate here. The high specific heat capacity of steel creates a cooling effect, since comparatively more energy has to be supplied to heat it up. Since the volume of the rod increases with the square of the diameter, more energy is required to achieve the same temperature increase. In addition the high thermal conductivity can distribute the heat to the rear area of the specimen. In the case of test specimen 141, the diameter is larger with 20 mm. Unfortunately, a comparable measurement was not possible with test specimen 131 due to the missing thermocouple in this depth. Another explanation can lie in the location of the thermocouple. It is located in the middle directly on the edge of the borehole. There is an increased charring on the edges of the test specimen. In the middle of the test specimen there are lower charring depths and therefore lower temperatures were measured, which do not correspond to the measured values.

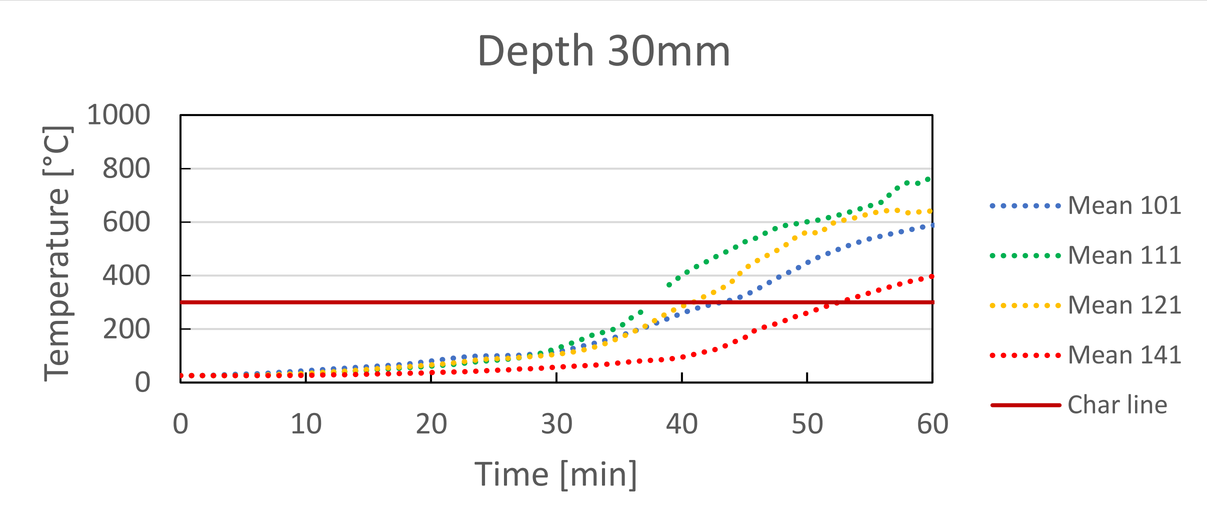

Figure 28: Measured temperature for a depth of 30 mm from the fire exposed side

It is assumed that the rod diameter has a minor influence on the temperature distribution inside the specimen. A larger diameter can lower the charring rate because of the cooling effect and the high thermal conductivity of the steel. However, this scenario only takes place in the direct surroundings of the rod. Other parameters such as the joints and the anisotropic parameters of wood play a greater role. More experiments with larger rod diameters would be useful in order to demonstrate an effect in terms of the specific heat capacity and the cooling effect.

4 Results in test series 2.2

Before the fire tests, moisture measurements were carried out on the test specimens of test series 2.2. The results are given in Table 4 and show that the test specimens have reached equilibrium moisture content.

Table 4: Moisture content of specimens 1-8

	Moisture [%]	τ [%]
SP1	11,3	1,1
SP2	11,4	2,5
SP3	11,7	1,3
SP4	11,7	4,1
SP5	12,5	2,2
SP6	12,0	2,9
SP7	12,2	2,3
SP8	11,7	2,9

4.1 Charring rate

To determine the charring rates after the test, the individual test specimens from test series 2.2 were divided into four equal parts for each rod. For this purpose, blocks with side lengths of 150 mm each were cut from the original test specimens. The sides have been numbered from 1 - 4 as seen in Figure 29.

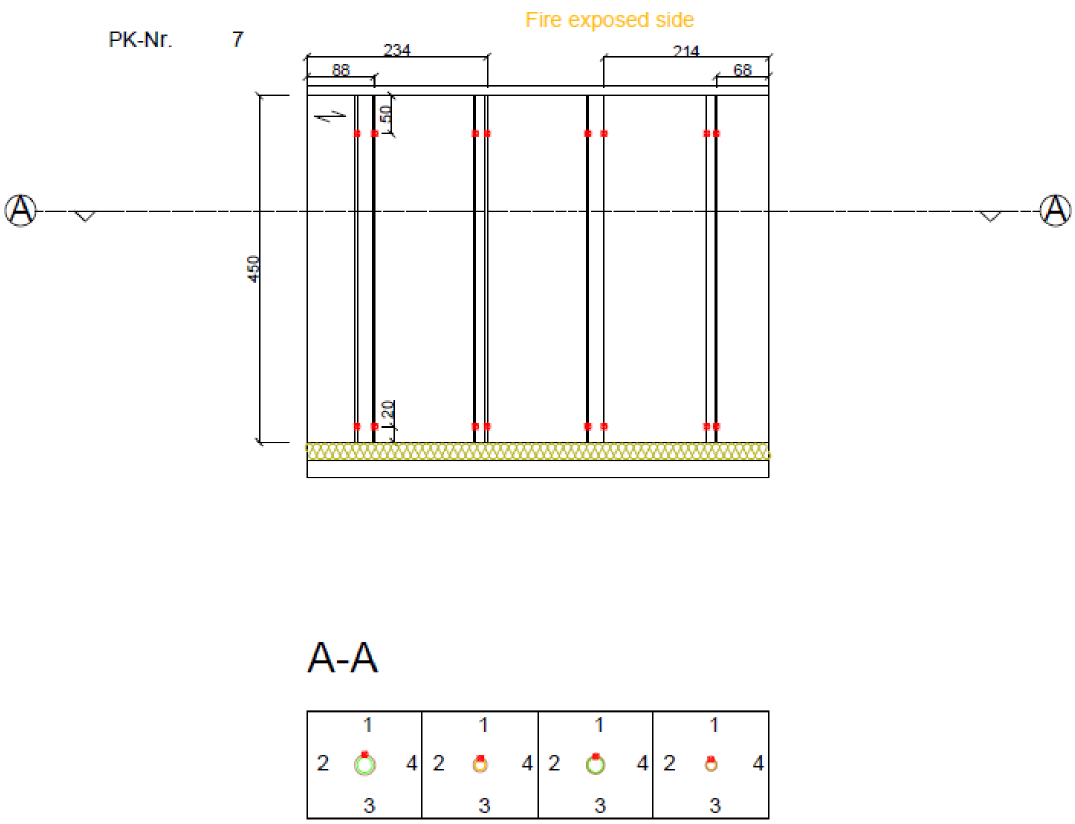

Figure 29: View of the cutting lines and the numbering of the four sides

Since test series 2.1 showed higher charring on the side surfaces of the test specimens, which were also present in this test series, side surfaces 1 & 3 were excluded from the determination of the average charring rate. The following figure shows side 2 of test specimen 6 with a borehole diameter of 26 mm. In this section, side 1 is on the left edge and side 3 is on the right edge of the specimen. A larger charring depth can be seen at both edges (see Figure 30).

Figure 30: View of side 2 of specimen 6 with higher charring on the edges

By measuring the residual height of the respective side of the test specimen, conclusions could be drawn about the charring depth. With a duration of 64 minutes until the ceiling was lifted off the furnace, the resulting charring rate could be calculated. The average charring rates determined are shown in Table 5. The low charring rate for specimen 5 can be explained with the gypsum plasterboard on the fire exposed surface which reduced the charring until its failure. The pictures of each specimen after the fire test and after cutting them for the re-examination are shown in C.4.

Table 5: Charring rates in test series 2.2

[mm/min]	12_1	12_3	20_1	20_3	Mean value
SP1	0,67	0,76	0,74	0,71	0,72
SP2	0,71	0,70	0,74	0,67	0,71
SP3	0,66	0,66	0,66	0,67	0,66
SP4	0,68	0,70	0,69	0,73	0,70
SP5	0,69	0,66	0,67	0,74	0,69
SP6	0,64	0,63	0,62	0,63	0,63
SP7	0,42	0,55	0,45	0,58	0,50
SP8	0,62	0,67	0,66	0,67	0,66

4.2 Temperatures

During the tests, the temperatures at the edge of the borehole were measured at a distance of 50 mm from the wooden surface facing the fire and 20 mm from the side away from the fire. In the case of specimens 1 & 7, additional thermocouples were placed directly at the rod. The following temperature diagrams show the temperature development of the individual measurement points. The diagrams of the individual test specimens are shown separately in Appendix C.5. The thermocouples are named based on the diameter of the rod, the thickness of the adhesive joint and the measurement location (B: edge of the borehole; S: steel).

The thermocouples were inserted through boreholes with a diameter of 2 mm and a length of 8 mm. Despite the pre-drilling with a drill press and the small borehole depth, an exact positioning couldn`t be guaranteed. The reason for this can be knots and the uneven grain structure of the wood. Therefore, after the tests, the test specimens were split alongside the rod in order to check the charring rates as well as the position of the thermocouples.

The resulting differences in the temperature curves du to differing positions of the measurement points make it difficult to compare the test specimens with one another. However, general statements can be made about the individual effects of the coverages. The exact positions of the measuring points are used for a later numerical simulation, which means that they can be validated accordingly with the material parameters.

In the creep tests under temperature load carried out in test series 3, a temperature limit of 69° C. was determined for Adhesive 1. Above this temperature, it can be assumed that the load-bearing capacity of the adhesive is reduced to such an extent that failure occurs under mechanical stress. This limit is displayed on the charts to show when it was exceeded and the effectiveness of the various coverages.

4.2.1 Influence of measuring points

Figure 31 shows the temperature curve for test specimen 1 on the side exposed to the fire. The dashed lines show the curves for the measurements on the rod while the other lines are for the borehole edge. The naming is based on the test specimen number (SP1), the rod diameter (12 mm or 20 mm), the glue line thickness (1 mm or 3 mm) and the position (borehole b or steel rod s). In almost all cases, the temperatures at the steel rod are higher than that at the measuring points at the edge of the borehole. An exception is the rod with a diameter of 20 mm with a 3 mm glue line thickness (20_3). The reason for this is a deviating measuring point due to a borehole that was not straight. The measuring point (20_3_S) shifts from the planned position directly at the rod to 6 mm away from the rod into the wood, which means that the temperature curve is comparatively low. At the same time, the measuring point (12_3_B) that was actually planned at the edge of the borehole is located directly at the rod, which means that the temperature rises more in comparison.

After an average of approx. 14 minutes, the temperature limit of the adhesive is exceeded at a depth of 50 mm when the rod is not covered.

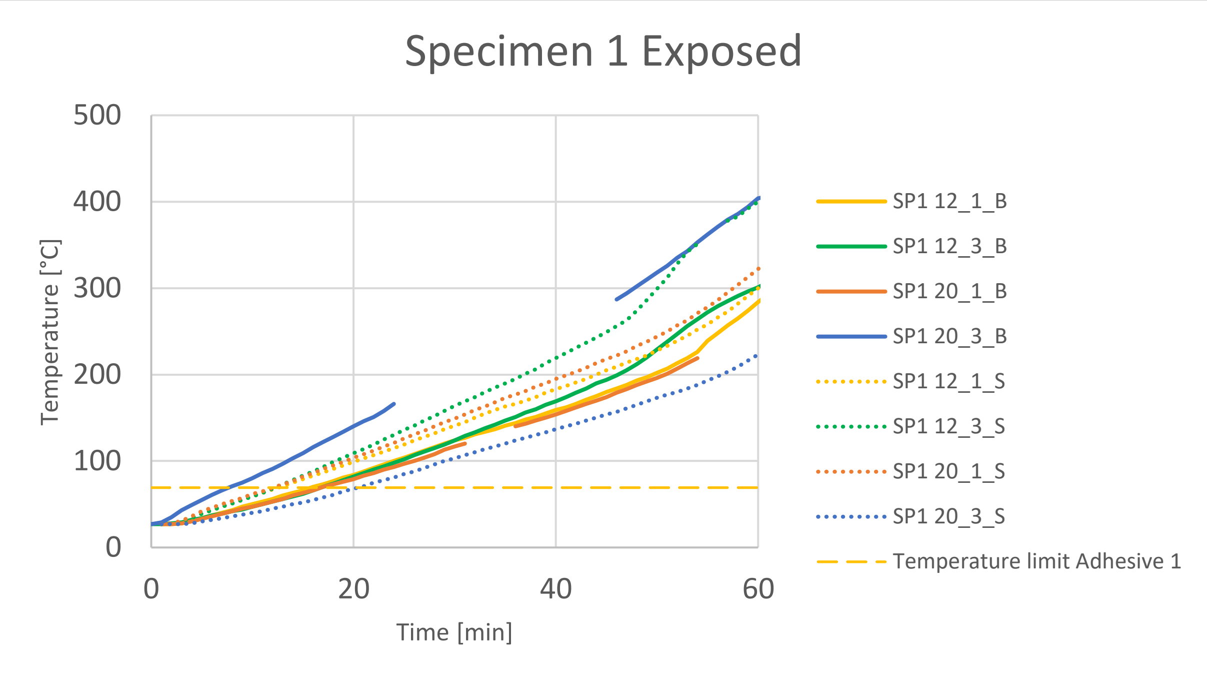

Figure 31: Measured temperatures of Specimen 1 on the fire exposed surface

On the unexposed side, after 60 minutes in a depth of 130 mm, temperatures of over 100 °C are reached, causing some of the plastic spacers to melt (see Figure 32).

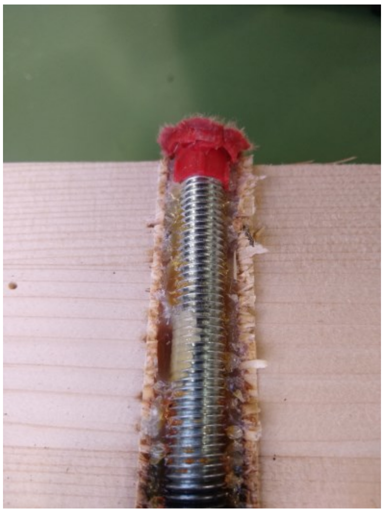

Figure 32: Melting of plastic cap on the unexposed surface

The temperature curves show that after a fire duration of approx. 25 minutes, the temperature limit of the adhesive must be expected to be exceeded at a depth of 130 mm if the rod is not covered (see Figure 33). The graphs do not show any significant influence of the glue line thickness on the thermal development. For the rod with a diameter of 20 mm and a glue line thickness of 3 mm, however, comparatively low temperatures are measured for the measuring point on the rod (20_3_S). The measuring point here deviates by 8 mm from its originally planned position. Due to the additional distance from the rod, less heating can be assumed at this point. Otherwise, for a rod diameter of 20 mm, the graphs show a tendency for faster heating.

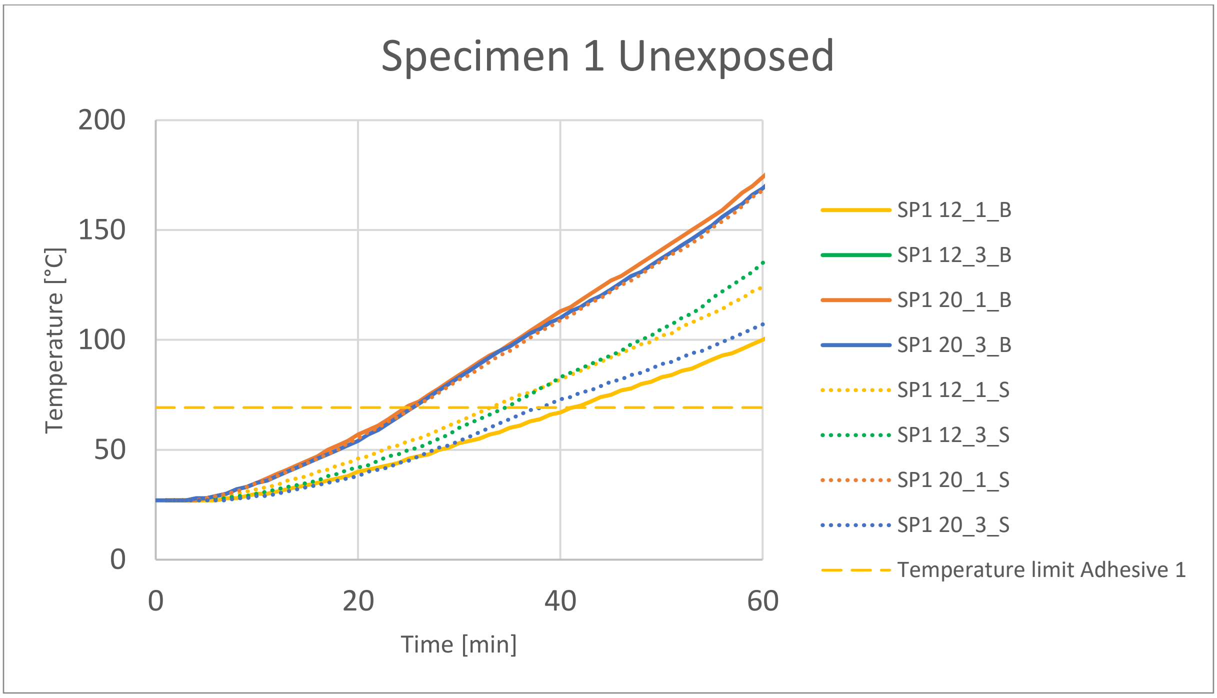

Figure 33: Measured temperatures of Specimen 1 on the unexposed surface

Test specimen 7 was designed with a cover made of a 12.5 mm gypsum plasterboard on the fire exposed surface. As a result, the exceeding of the temperature limit at a depth of 50 mm is extended by 22 minutes to approx. 36 minutes compared to test specimen 1 (see Figure 34). There is also a point in time in the graphs when the temperature rises faster. It is assumed that the gypsum plasterboard fell off in the range of 25 minutes to 30 minutes. The temperature is measured at a depth of 50 mm of the wooden specimen, which is why this increase is only shown in the graph with a delay. Since higher temperatures already prevail in the furnace at this point in time, there is a faster increase than for test specimen 1. An influence of the rod diameter or the glue line thickness cannot be derived. The deviations of the temperature curves of the same measuring depth can also be related to a different point in time when the gypsum plasterboard fell off partially.

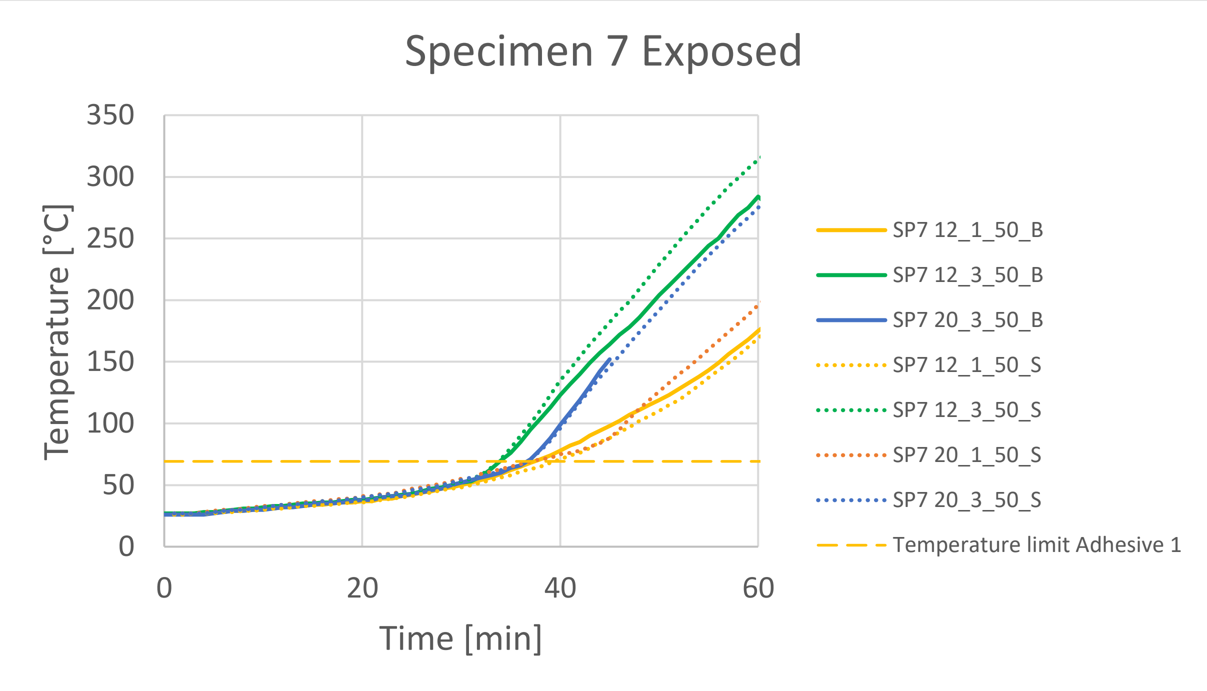

Figure 34: Measured temperatures of Specimen 7 on the exposed surface

At a measuring depth of 430 mm, no heating is evident after a fire duration of 60 minutes (see Figure 35). For this reason, no information can be given on the influences of the rod diameter, glue line thickness or measuring point.

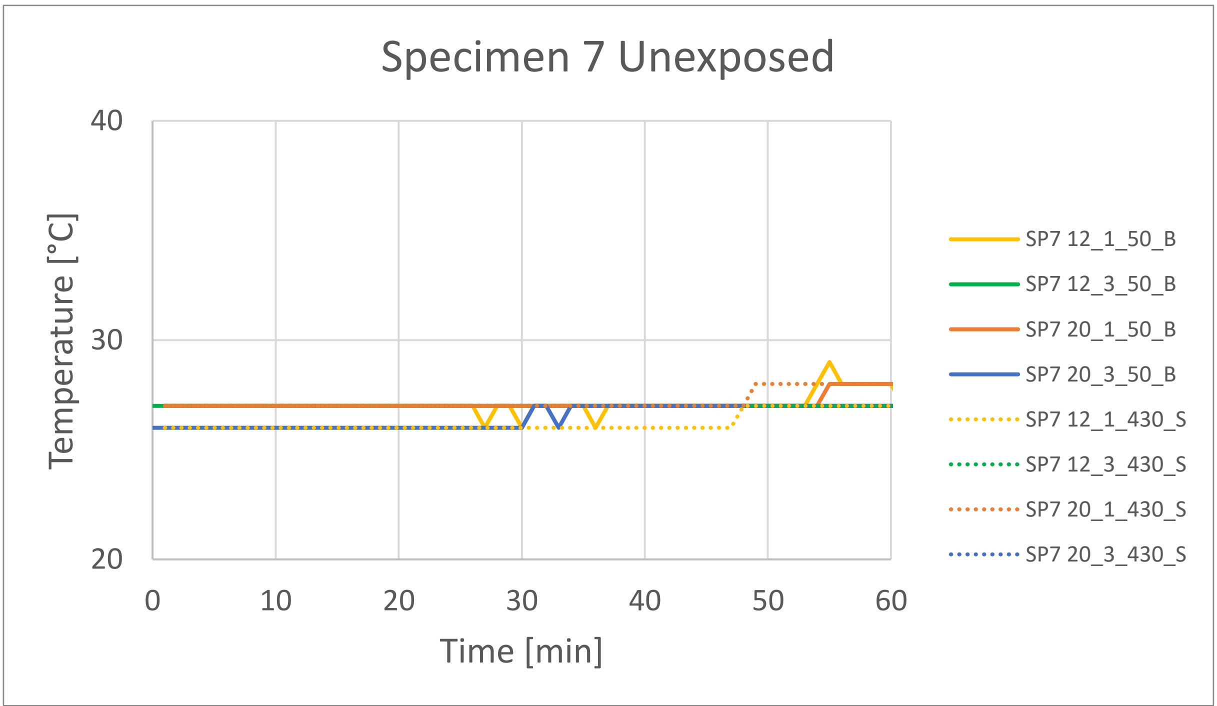

Figure 35: Measured temperatures of Specimen 7 on the unexposed surface

Overall, no big influence of the rod diameter or the glue line thickness could be determined on the basis of the available measurement data. This is mainly due to the different positions of the measuring points, which makes a comparison difficult. However, if there was a large deviation with a displacement of the measuring point away from the rod into the wood, there was always a lower temperature rise. On the other hand, when the measuring point was moved towards the rod, an increase in temperature was determined, which is why it is assumed that the rod is largely responsible for the heat transport into the adhesive joint and that appropriate covering measures must therefore be planned to prevent thermal load. At a measuring depth of 50 mm, specimen 1 also shows a tendency towards higher temperatures on the rod than on the edge of the borehole.

4.2.2 Influence of wooden coverage

The influence of the coverage of the rod on the temperature curve is considered in this chapter. Test specimens with the same surface or fire protection covers are compared. The temperature curves for the individual test specimens are presented in the Appendix C.5.

For test specimens 1 and 8 there is a leveled surface without any coverage of the rod. The only difference is the test specimen length of 150 mm and 450 mm. Similar temperatures are measured over the duration of the test at a depth of 50 mm on the side exposed to the fire (see Figure 36). The only exception here is the measuring point of the rod with a diameter of 20 mm and a glue line thickness of 3 mm (SP1 20_3_B), since the real measuring point lies directly at the rod. Furthermore, the curves of test specimen 8 at both measuring points with a glue line thickness of 1 mm deviate from the remaining curves as the test progresses (SP8 12_1_B and 20_1_B). In the case of the M12 rod, the measuring point is 5 mm further away from the rod, resulting in a comparatively lower temperature. For the M20 rod, a 5 mm displacement in the direction of the fire exposed surface is measured, resulting in a greater temperature rise.

The critical adhesive temperature for Adhesive 1 is exceeded within 15 minutes.

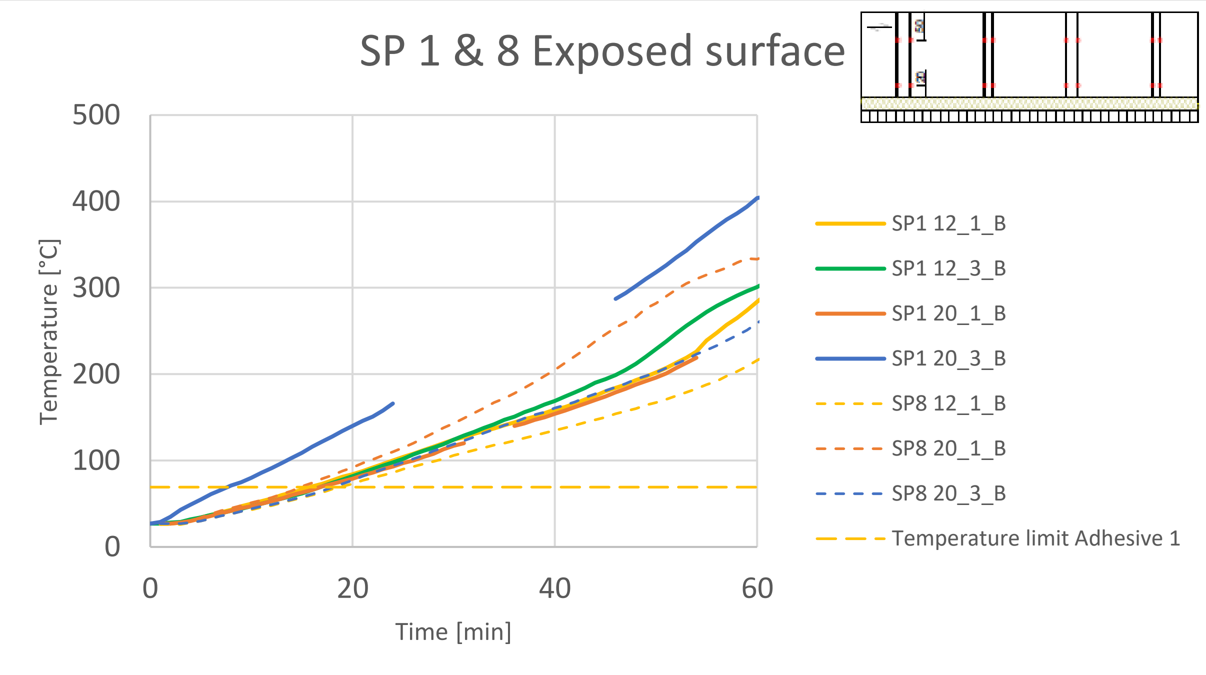

Figure 36: Measured temperatures of Specimens 1&8 on the fire exposed surface

When comparing the measuring points on the unexposed surface, no significant increase in temperature can be observed for test specimen 8, since the embedment length is 300 mm longer (see Figure 37).

Test specimen 1 exceeds the temperature limit after about 25 minutes. There is only a different temperature profile for measuring point SP1 12_1_B. However, this measurement point is only shifted 3 mm to the edge of the borehole, which may be related to the lower slope, but does not explain the extreme deviation.

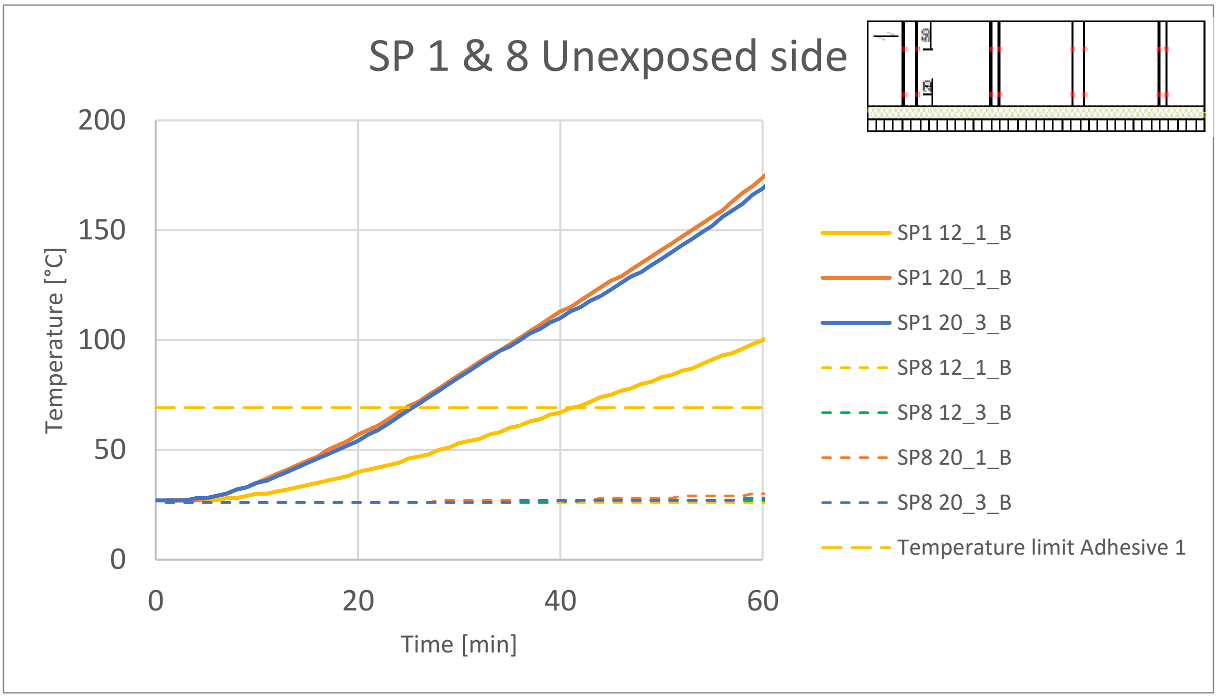

Figure 37: Measured temperatures of Specimens 1&8 on the unexposed surface

If the rod is covered with a 1 mm thick wooden plug, the temperature limit is exceeded in the range of 28 - 32 minutes at a measurement depth of 60 mm behind the surface exposed to the fire (see Figure 38). Compared to an unprotected rod, the time increases by at least 13 minutes. For test specimen 5 with a rod diameter of 12 mm and a glue line thickness of 1 mm (SP5 12_1_B), the temperature limit is already exceeded after around 21 minutes. Based on the evaluated deviations, there is a shift of the measuring point by 16 mm in the direction of the side exposed to the fire and by 1 mm in the direction of the rod, which contributes to the faster temperature rise. An influence of the rod diameter on the temperature development cannot be determined on the basis of the available data.

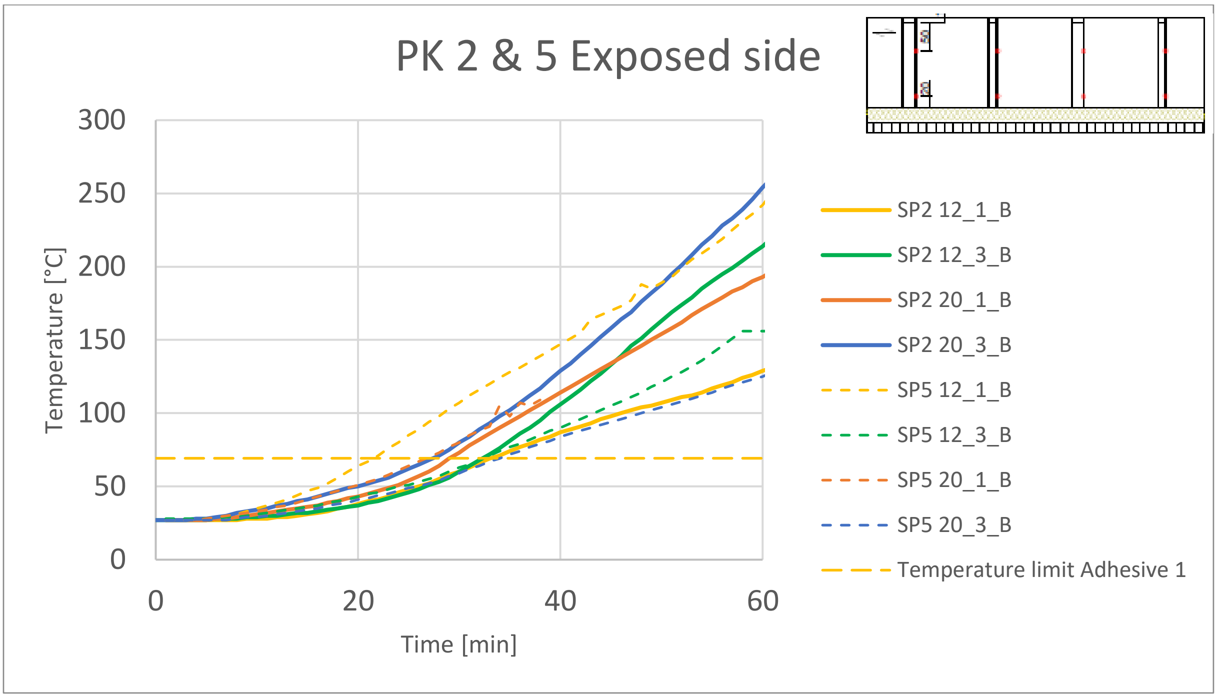

Figure 38: Measured temperatures of Specimens 2&5 on the fire exposed surface

At a measuring depth of 140 mm from the surface exposed to fire, the temperature limit at the edge of the borehole is only reached for test specimen 2 after approx. 51 minutes (see Figure 39). Overall, the temperature of 100 °C is not exceeded. For a measuring depth of 440 mm, no significant change in the temperature is determined for specimen 8. The two thicker rods show a tendency towards better heat transfer for test specimen 2, since the temperatures are higher.

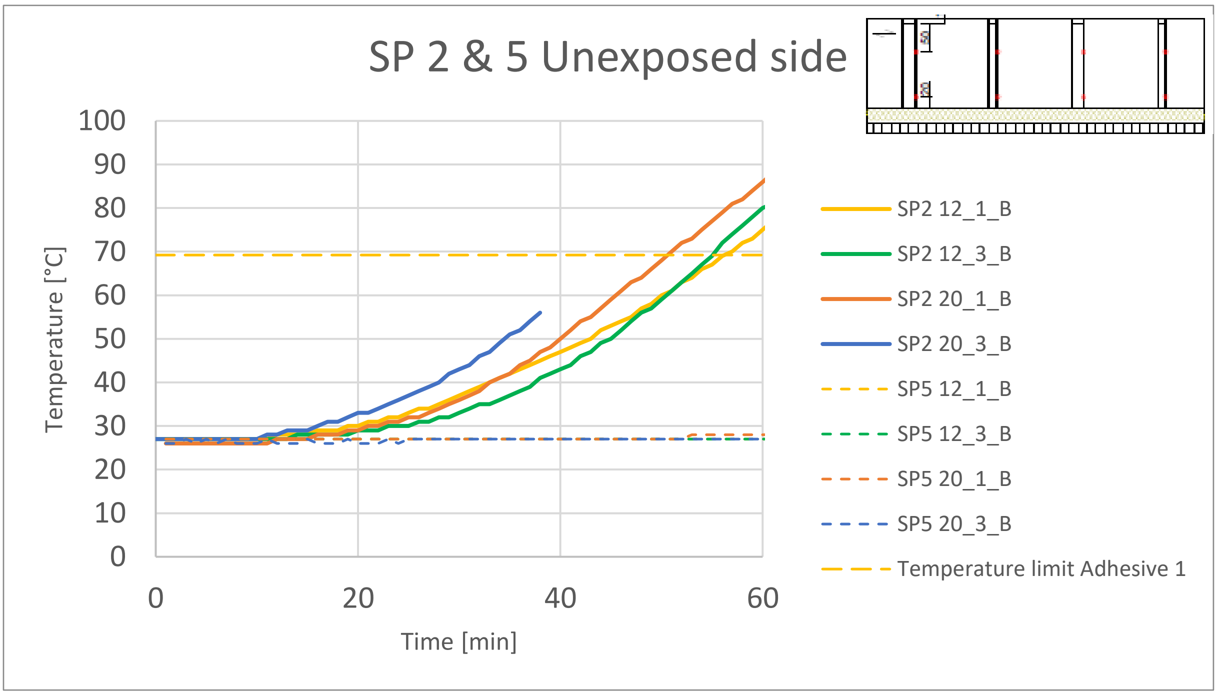

Figure 39: Measured temperatures of Specimens 2&5 on the fire exposed surface

If the rod is covered with 30 mm thick wooden plugs, the temperature limit is reached after approx. 60 minutes at a measuring depth of 50 mm behind the plug (see Figure 40). The only exception is the measuring point of test specimen 3 with a rod diameter of 12 mm and a glue line thickness of 1 mm (12_1_B). There is a deviation from the planned position of 8 mm in the direction of the fire exposed side. However, the position is also shifted by 4 mm in the wooden test specimen away from the rod, which cannot explain the steep increase. As there is a rapid increase in the temperature curve here, similar to test specimen 7, it is assumed that the glued-in plug fell out of the borehole due to the thermal load, which means that its protective effect is lost and the rod is exposed to a greater temperature directly. At measuring point SP3 20_3_B, there is probably a measurement error at the beginning, since the start temperature is too high for the ambient temperature. However, the progression is similar to the other curves and levels with them at minute 45.

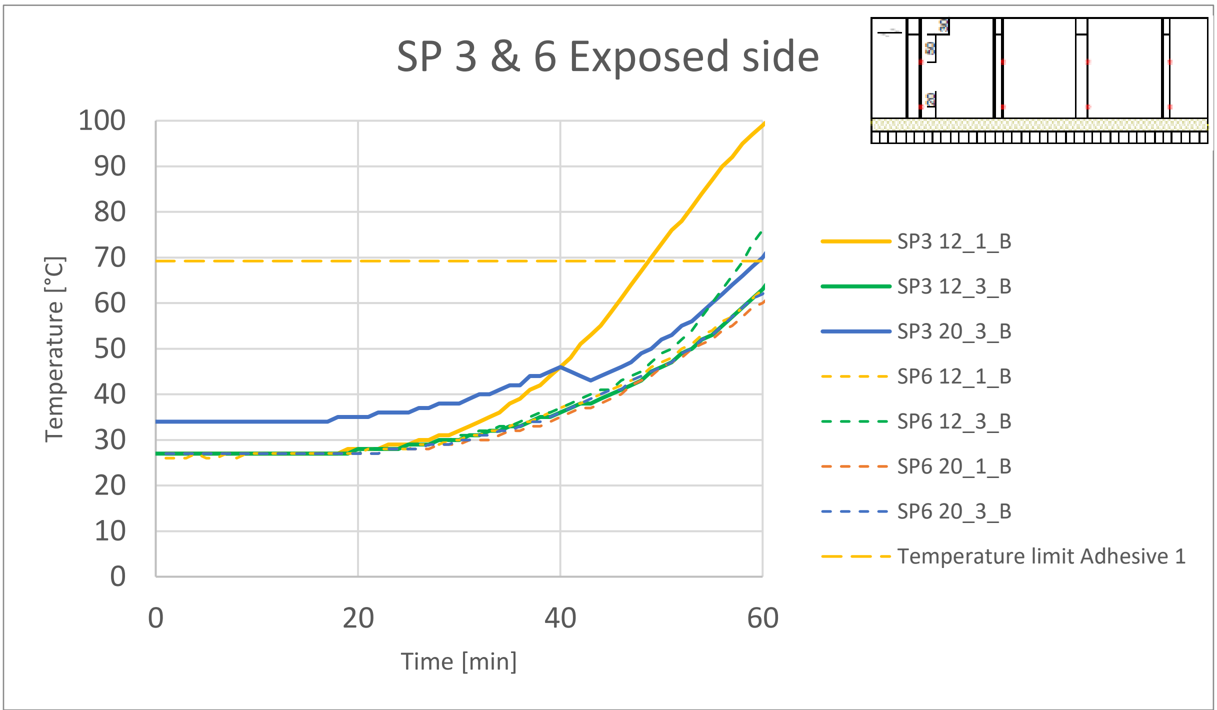

Figure 40: Measured temperatures of Specimens 3&6 on the fire exposed surface

For both measuring depths of 160 mm and 460 mm behind the fire exposed surface, the temperature limit is not exceeded in either test specimen (see Figure 41). However, no significant increase can be observed with test specimen 6, whereas with test specimen 3 a slight increase in temperature can be observed from minute 20 onwards. Furthermore, in test specimen 3 there is a comparatively greater temperature rise in the rods with a diameter of 20 mm.

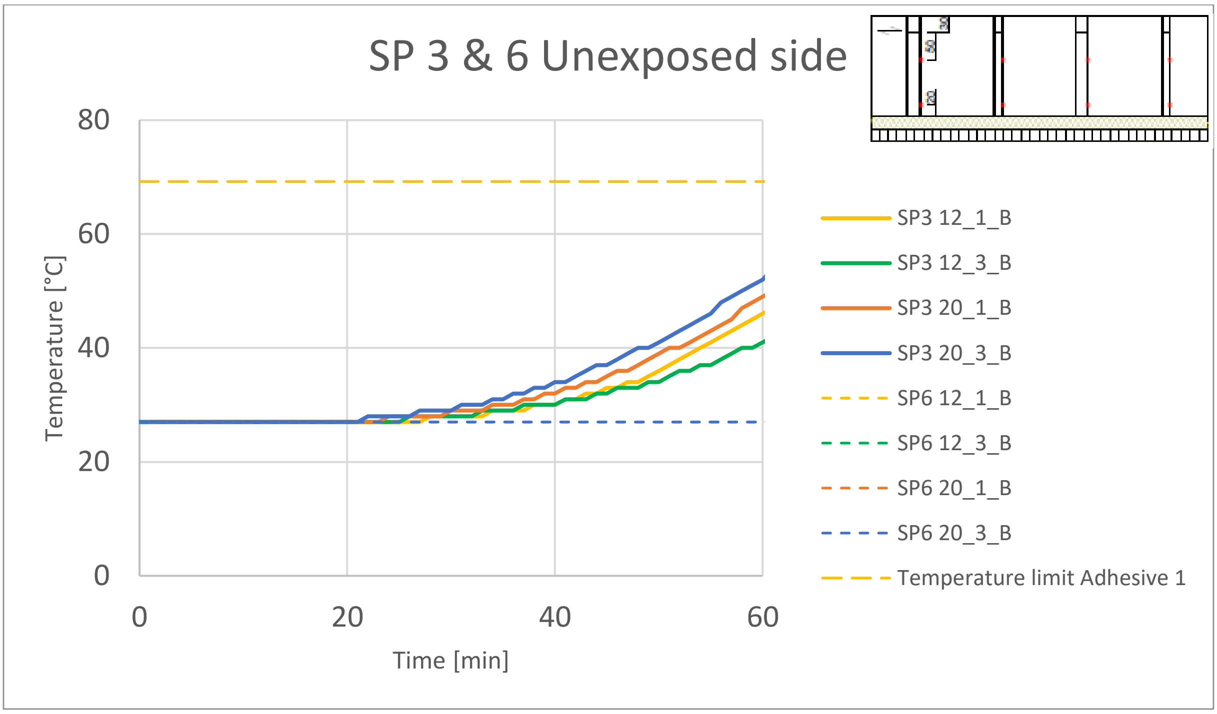

Figure 41: Measured temperatures of Specimens 3&6 on the unexposed surface

Within specimen 4, all four measuring points failed completely during the test for the depth of 50 mm on the fire exposed surface. Only incomplete data could be evaluated for the rods with a glue line thickness of 3 mm.

The comparison of test specimen 4 with flat washers and nuts at the fire exposed side, which stick out 2 cm into the furnace, with the test specimen 8, in which the rod was leveled with the surface, reveals increased temperature curves (see Figure 42). The temperature limit of 69 °C is reached after just under 5 minutes at a measuring depth of 50 mm. In the case of the unprotected test specimen with a leveled surface, the temperature limit is exceeded approx. 10 minutes later. The free exposed steel thus ensures a greatly increased heat input.

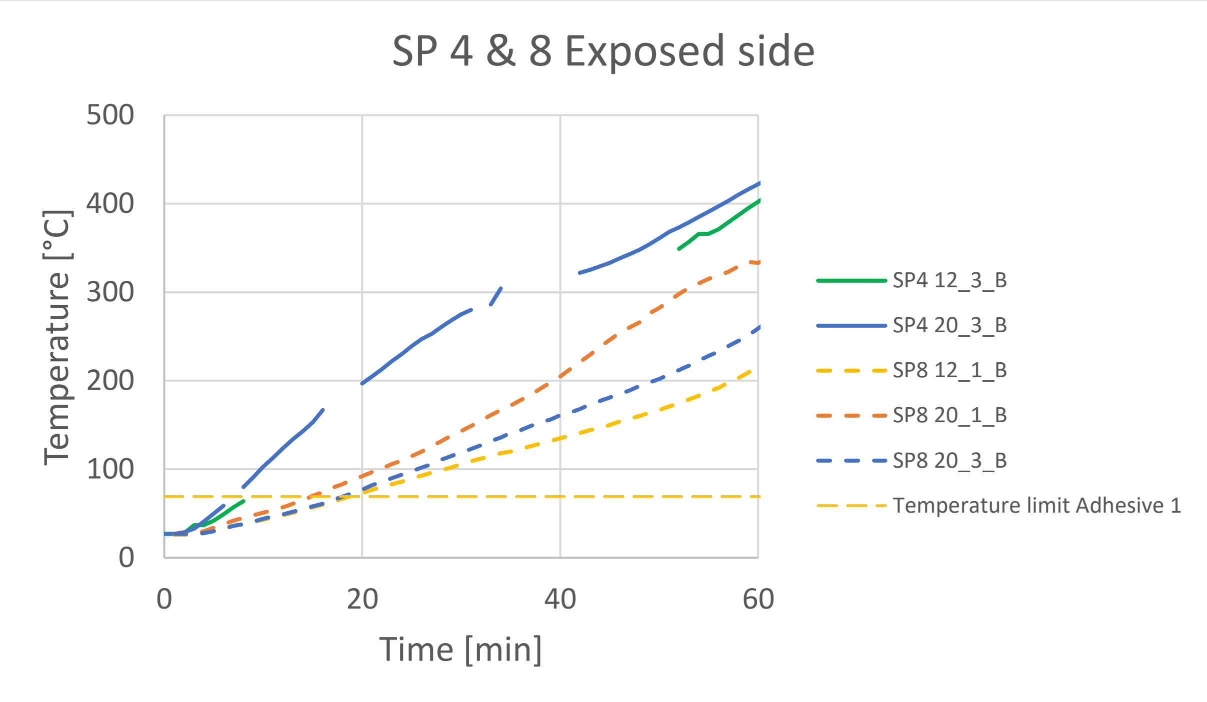

Figure 42: Measured temperatures of Specimens 4&8 on the fire exposed surface

The temperature hardly increases on the unexposed surface in both test specimens (see Figure 43). However, for test specimen 4, a stronger increase and a higher final temperature can be seen with the rod diameter of 20 mm. Here, too, the exposed rods appear to result in greater heat input, which results in a faster heating for a depth of 430 mm.

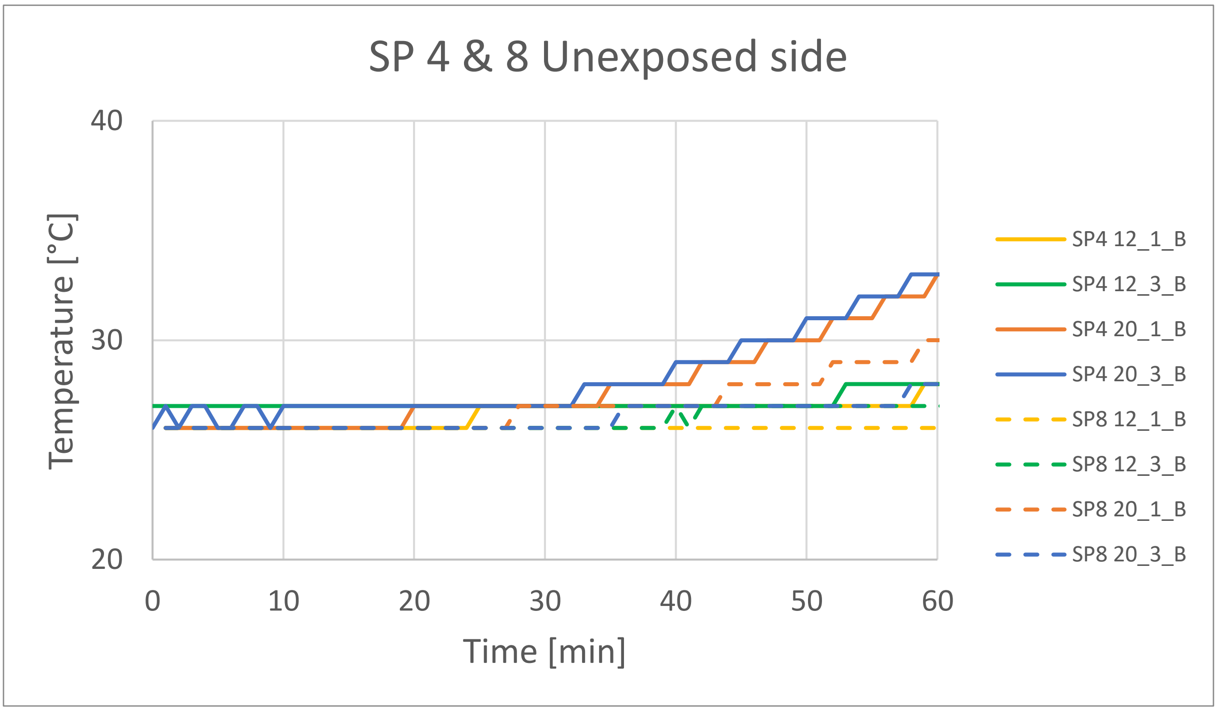

Figure 43: Measured temperatures of Specimens 4&8 on the unexposed surface

Overall, the tests have shown that the covering of the rod on the fire exposed side has a strong influence on the temperature development for glued in rods bonded perpendicular to the grain direction. The adhesive temperature limit of 69 °C is reached at a depth of 5 cm after approx. 15 minutes without protection or covering, after approx. 30 minutes with a wood covering of 10 mm and after approx. 60 minutes with a wood covering of 30 mm. A 12.5 mm gypsum plasterboard protects the adhesive at this depth for up to approx. 35 minutes.

At measuring depths of 130 mm, the temperature limit is reached after 25 minutes with unprotected test specimens. If there is a 10 mm wooden covering, the protection time doubles to 50 minutes and with a 30 mm wooden covering, after 60 minutes of exposure to fire, it is not to be assumed that this temperature will be exceeded.

At a measuring depth of 430 mm, the temperature limit is never exceeded. There is also no change in temperature due to the fire in most cases. A slight increase in temperature in the area of 10 °C for rods with a diameter of 20 mm could only be measured when the rods stick out directly in the furnace.

The temperature curves on the unexposed surface suggest that larger rod diameters are responsible for a faster heat input with higher test durations.

5 Results in test series 2.3

The specimens of test series 2.3 were named using the same method as in test series 2.1.

There were two measuring points on the rod for each test specimen. The measuring points with the initial A were located at a distance of 130 mm and with the initial B at a distance of 50 mm from the joint.

The figure below shows the measured temperature profile of SP211 of test series 2.3. In this specimen, both thermocouples have partially failed. Values for measuring point B were only recorded after almost 32 minutes. For this reason, an analysis of the graphs is difficult to carry out. Based on the curve, however, it can be assumed that the 300 °C - isotherm was exceeded in the 30-minute range and the surrounding wood should have been completely burned (see Figure 44).

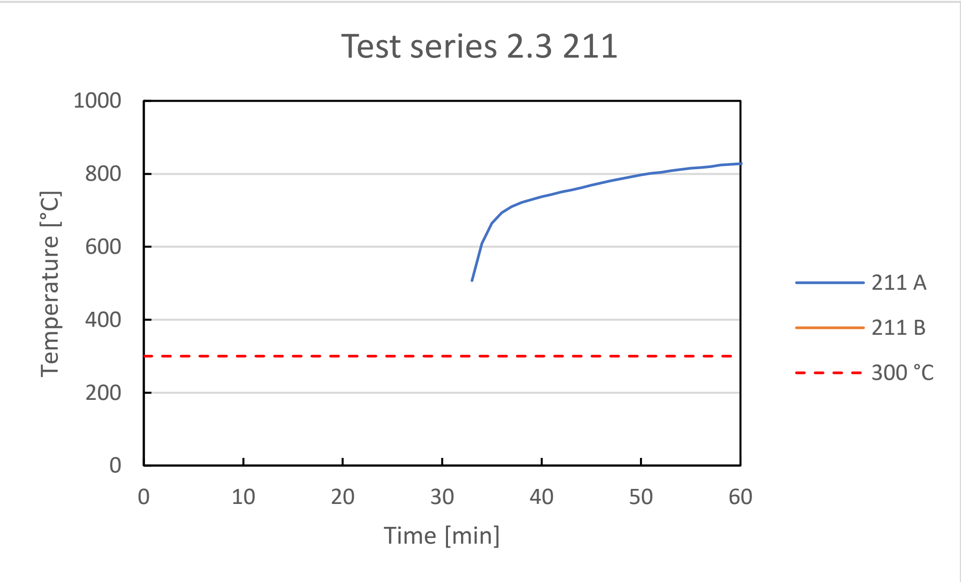

Figure 44: Measured temperatures of Specimen 211

On the basis of the tests of test series 3, the critical temperature limit for the two adhesives tested was derived. When this temperature is exceeded failure must be expected. These are 69 °C for Adhesive 1 and 79 °C for Adhesive 2.

The temperature curves show an almost identical curve for both measuring points, as they were installed at exactly the same depth in specimen 212. The joint between the two halves seems to have no influence on the temperature development. The deviation can be explained by the inhomogeneous structure of the wood, which does not allow for an absolutely even charring (see Figure 45). Also, it is expected that local temperature differences in the furnace were present.

The 300 °C - isotherm as the charring limit of wood is exceeded by both measuring points after approx. 50 minutes. By separating the test specimens to insert the thermocouple, there is a shorter side length of 98 mm, which results in a wood cover of 42 mm with a borehole diameter of 14 mm. This wooden coverage is sufficient for Adhesive 1 to exceed the temperature limit after approx. 28 minutes and for Adhesive 2 after about approx. 31 minutes.

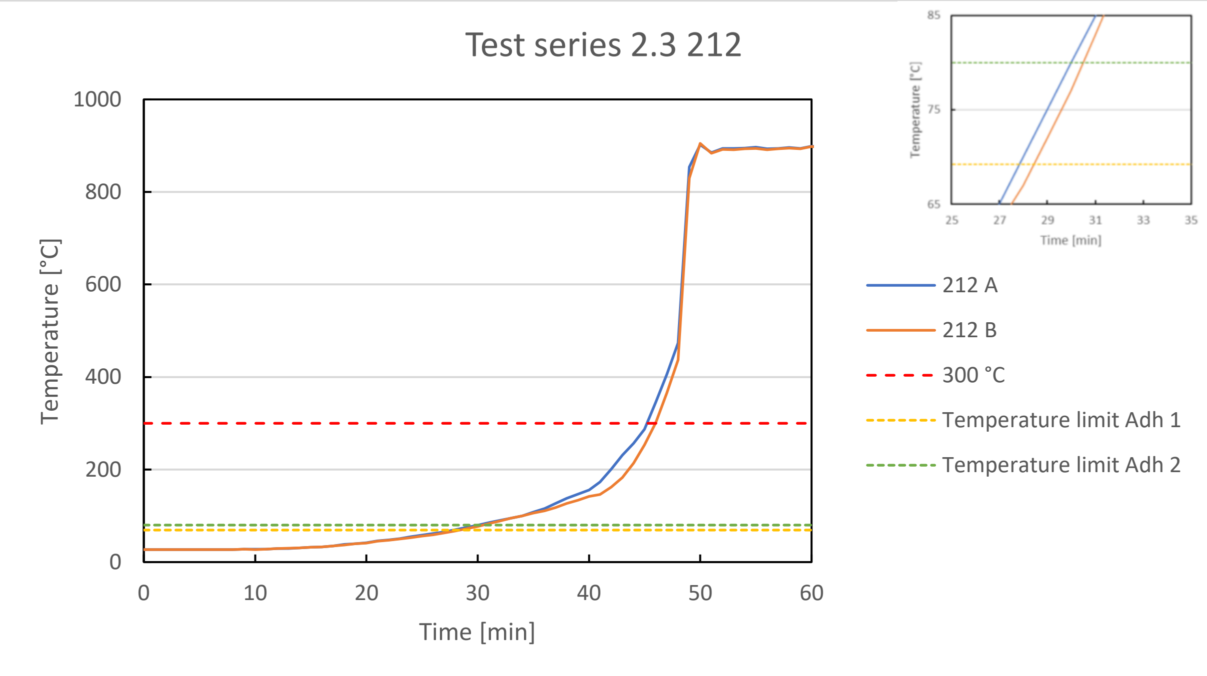

Figure 45: Measured temperatures of Specimen 212

A similar temperature profile is seen for test specimen 231 (see Figure 46). The two measuring points deliver an almost identical temperature profile until the 300 °C - isotherm is reached. This line is only exceeded by measuring point 231 B two minutes later than for measurement point A, which may be due to uneven burning of the wood in front of the measuring point.

Due to the larger diameter of the rod and the resulting borehole of 22 mm, the test specimen has an overall smaller wood cover of only 38 mm, which protects the glue line from the effects of heat. For this reason, the critical temperature limits are exceeded earlier than for specimen 212, at approx. 27 minutes for Adhesive 1 and approx. 30 minutes for Adhesive 2. Compared to test specimen 212, the wooden coverage is 4 mm less. However, the temperature limits of both adhesives are only reached one minute earlier, which could be related to the high heat capacity of the steel with a cooling effect and to the uneven charring of the wood specimen.

Since a removal of the specimens wasn't possible there were no remains to determine the charring rates and no possibilities to compare them with the temperature measurements of the thermocouples.

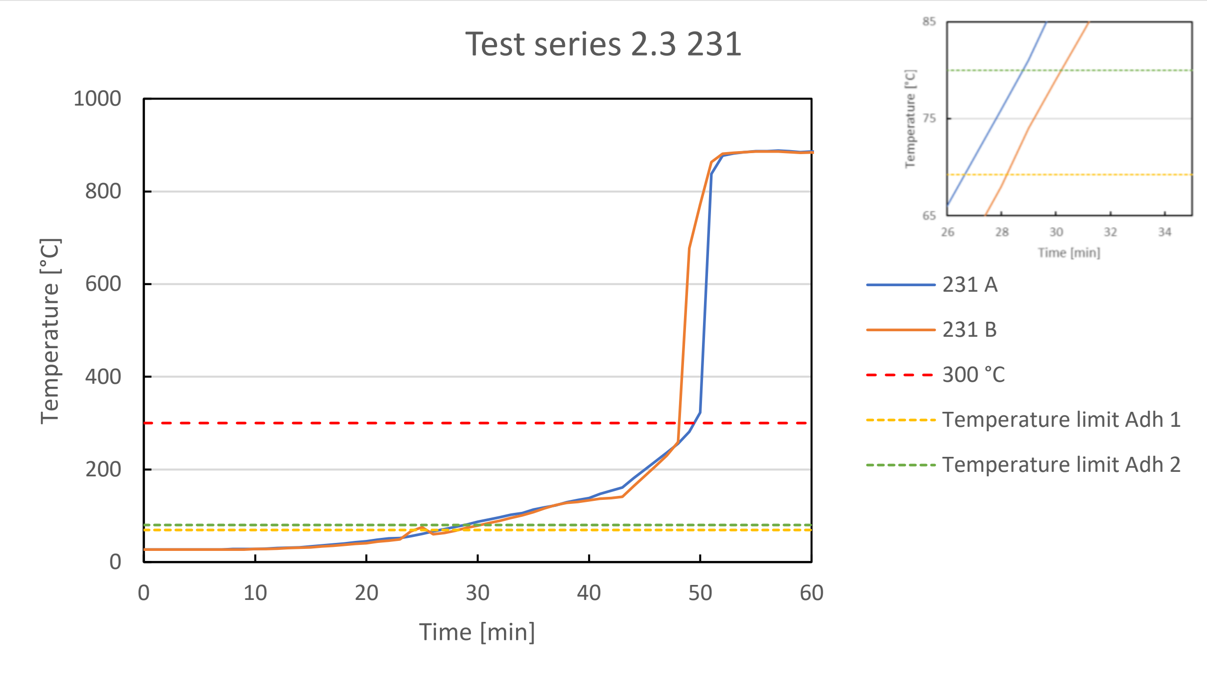

Figure 46: Measured temperatures of Specimen 131

6 Conclusion

It is shown that the position and the embedment length of the glued-in rod have a major influence on the temperature behavior of the connection.

The test results show that the rod diameter has a minor influence on the temperature distribution inside the specimen. The test with rods glued in parallel to the grain direction showed that a larger diameter can lower the charring rate because of the cooling effect and the faster heat distribution of the steel. It is to be assumed that this effect only takes place in the near surrounding of the rod. Other parameters such as the width of a joint and the position of knots or the grain direction in the wood are assumed to have a bigger influence. More experiments with larger rod diameters would be useful in order to demonstrate an effect in terms of the specific heat capacity and the cooling effect.

For the specimens with rods glued in perpendicular to the grain direction a comparison was hard to make due to differing temperature measurement points. The basic results nevertheless showed that the steel rod is essential for the heat transfer in the connection. For a bigger rod diameter of 20 mm, the graphs show a tendency for faster heating on the unexposed side.

Therefore, a coverage is always recommended to reduce the temperature input through the rod. With wooden plugs of 30 mm thickness the temperature limit of Adhesive 1 (69 °C) is only exceeded in a depth of 50 mm of the fire exposed surface after almost 60 minutes if a falling out of the plug is prevented. One gypsum plasterboard with a thickness of 12,5 mm can prevent the temperature limit to be reached in a depth of 50 mm behind the wooden surface for about 36 minutes.

For rods that are glued in parallel to the grain direction, a cover of wood is present normally due to its construction type. This cover should be of sufficient thickness to protect the glue line from heating above a critical temperature limit (dependent on the adhesive) and to ensure the load-bearing capacity of the adhesive.

For rods that are glued in perpendicular to the grain direction, the end of the rod should be protected additionally. The thickness and type of protection depend on the planned fire safety level.

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[1] *DIN EN 408:2012-10, Holzbauwerke_- Bauholz für tragende Zwecke und Brettschichtholz_- Bestimmung einiger physikalischer und mechanischer Eigenschaften; Deutsche Fassung EN_408:2010+A1:2012*

[2] *DIN EN 1995-1-1:2010-12, Eurocode_5: Bemessung und Konstruktion von Holzbauten_- Teil_1-1: Allgemeines_- Allgemeine Regeln und Regeln für den Hochbau; Deutsche Fassung EN_1995-1-1:2004_+ AC:2006_+ A1:2008*

[3] *DIN EN 1995-1-2:2010-12, Eurocode_5: Bemessung und Konstruktion von Holzbauten_- Teil_1-2: Allgemeine Regeln_- Tragwerksbemessung für den Brandfall; Deutsche Fassung EN_1995-1-2:2004_+ AC:2009*

A Plans test series 2

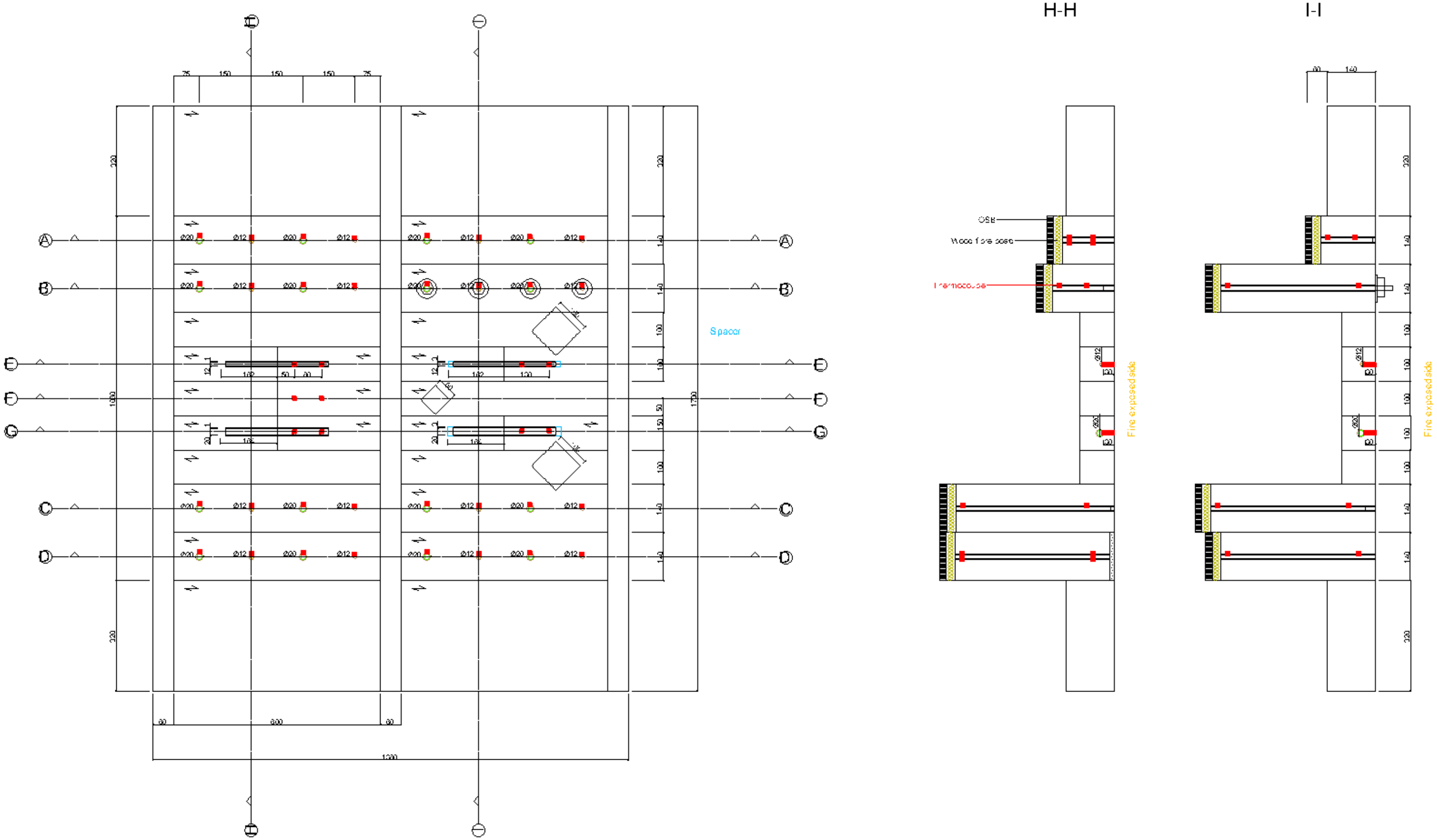


Figure 47: Top view and sections of test specimen in test series 2 (red: thermocouples)

B Test series 2.1

B.1 Glue date

Table 6: Gluing details in test series 2.1

Specimen	Glue date	Time
111	21.06.2021	12:00-12:10
121	21.06.2021	12:00-12:10
131	21.06.2021	12:00-12:10
141	21.06.2021	12:00-12:10

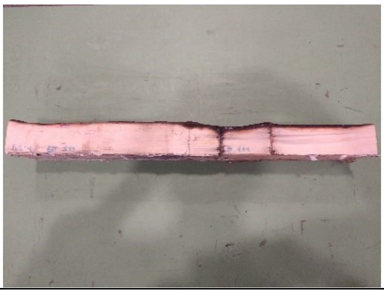
B.2 Density

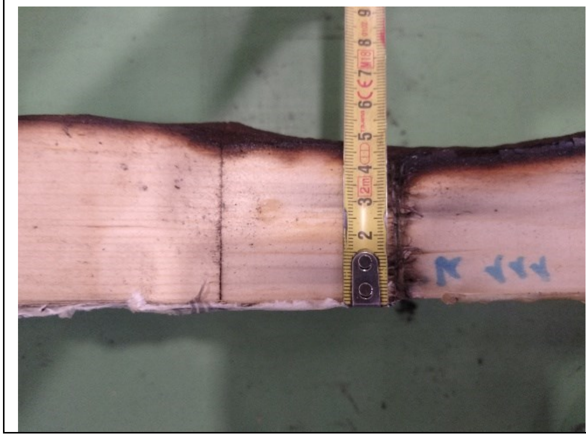
Table 7: Density in test series 2.1

	Timber							**Borehole**		**Rod**	
SP number	QS [mm]		Length [mm]	Side 1		Side 2					
				Mass [g]	Density [kg/m³]	Mass [g]	Density [kg/m³]	Diameter	Length	Diameter	Length
101	100	100	300	1304,8	434,9	1373,0	457,7	0	0	0	0
111	100	100	300	1307,6	435,9	1307,4	435,8	14	162	12	324
121	100	100	300	1292,2	430,7	1260,8	420,3	18	162	12	324
131	100	100	300	1287,6	429,2	1349,6	449,9	22	164	20	328
141	100	100	300	1256,2	418,7	1313,0	437,7	26	164	20	328

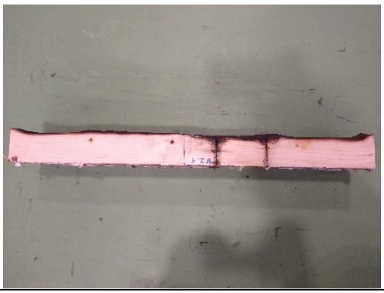
B.3 Specimen after fire test

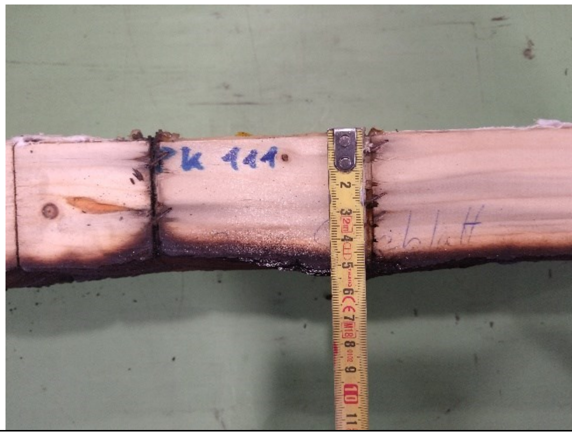
B.3.1 SP 101

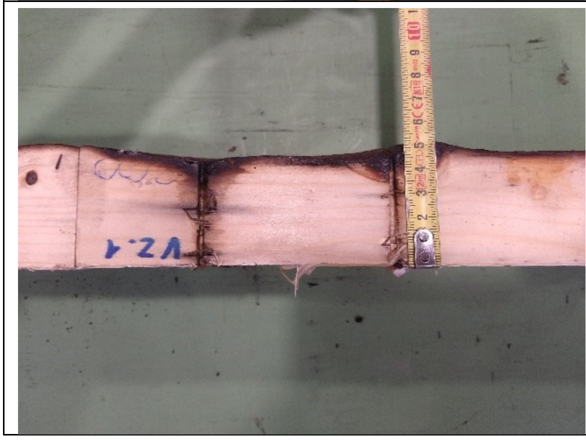
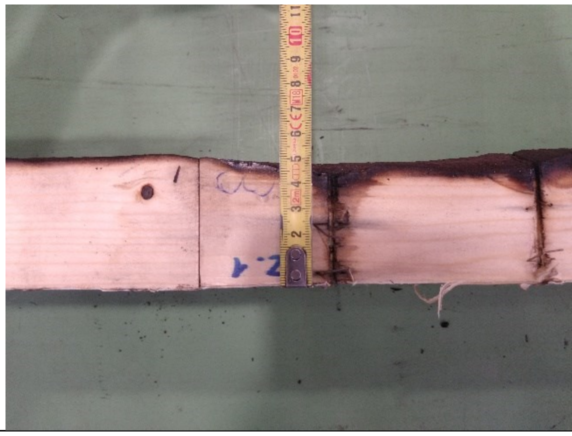





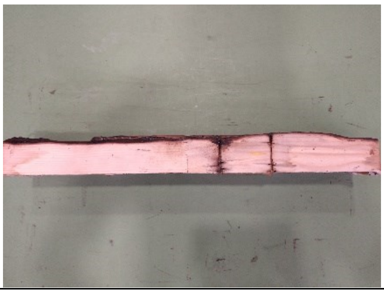

B.3.2 SP111

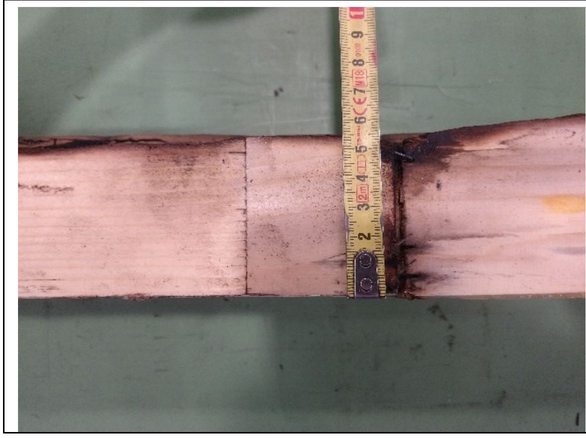
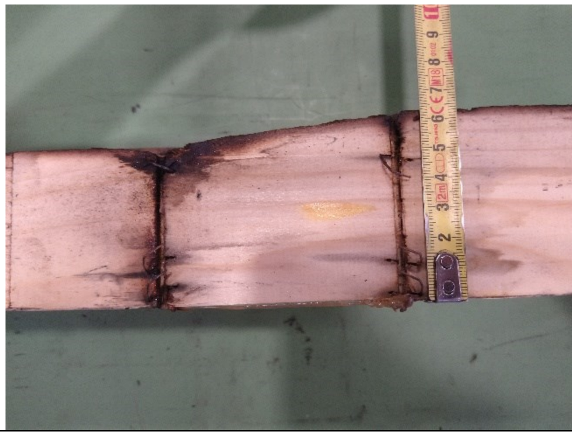





B.3.3 SP121

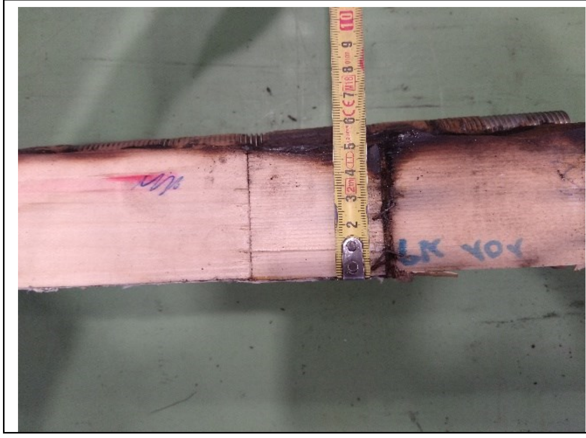
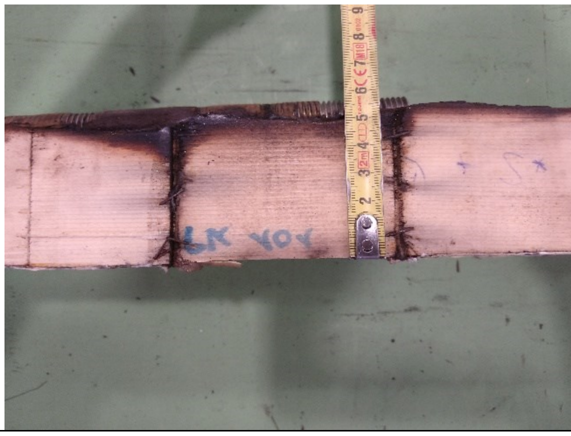



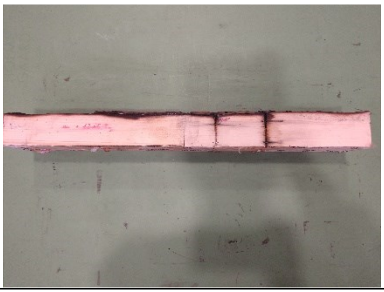
B.3.4 SP131

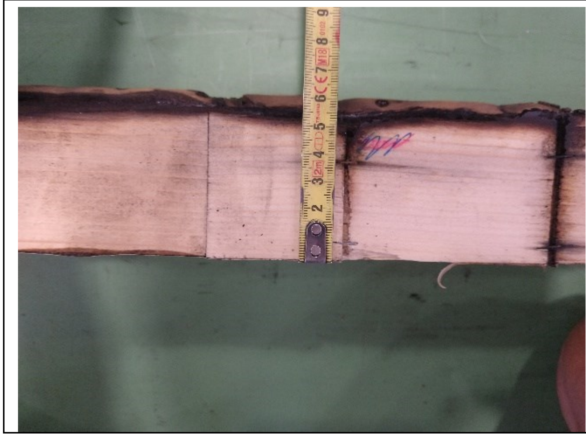


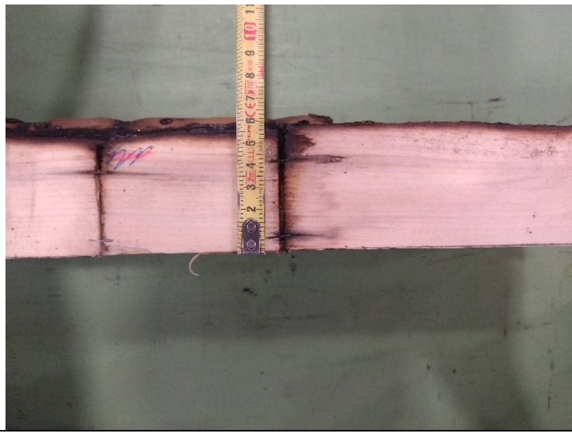


B.3.5 SP141







B.4 Temperature curves

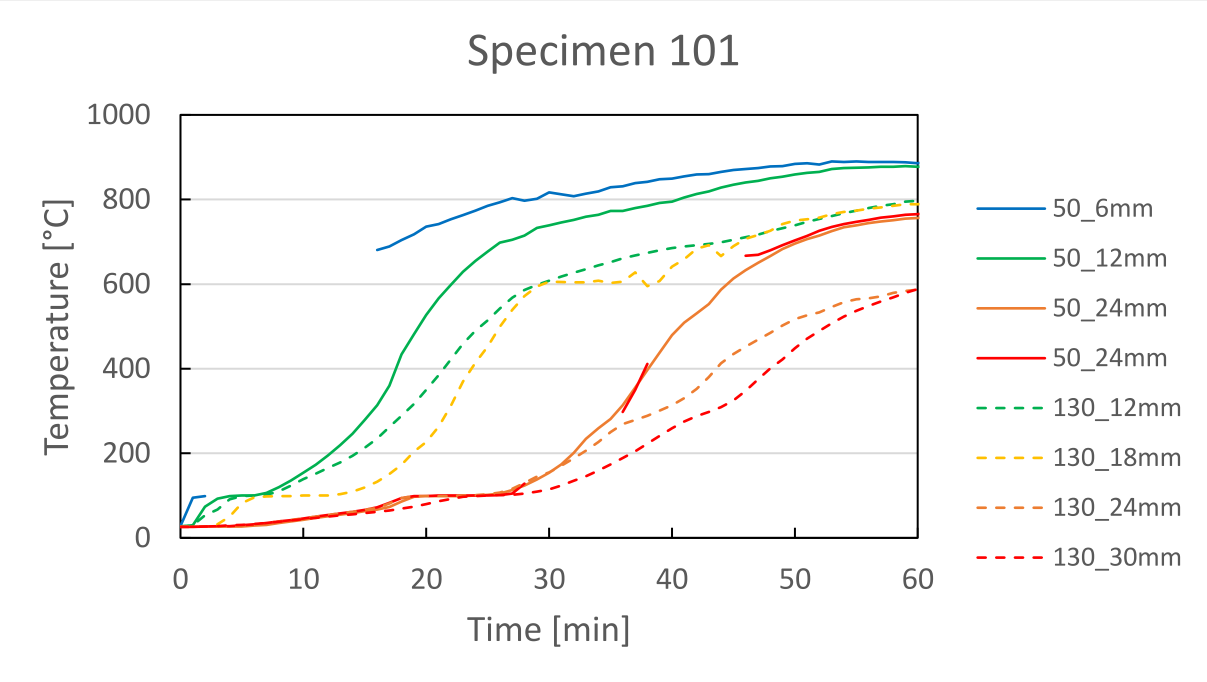


Figure 48: Temperature development in specimen 101 for the measurement positions in a distance of 50 mm and 130 mm of the joint

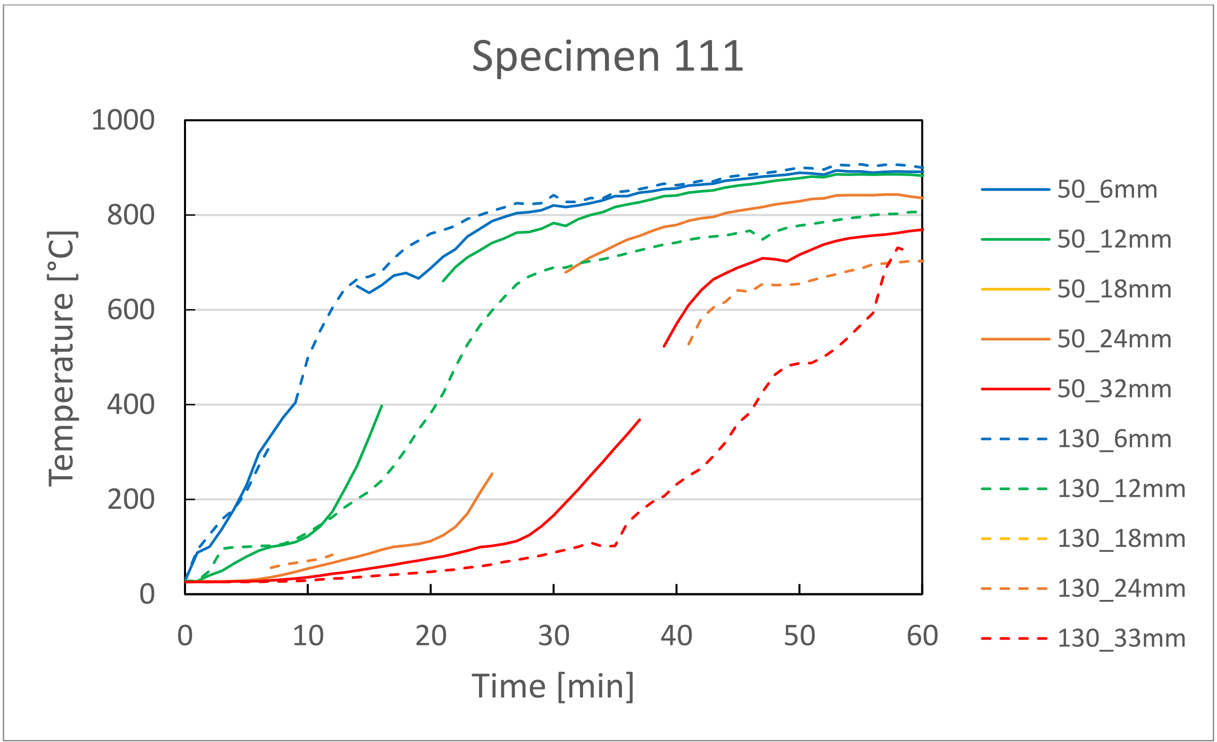


Figure 49: Temperature development in specimen 111 for the measurement positions in a distance of 50 mm and 130 mm of the joint

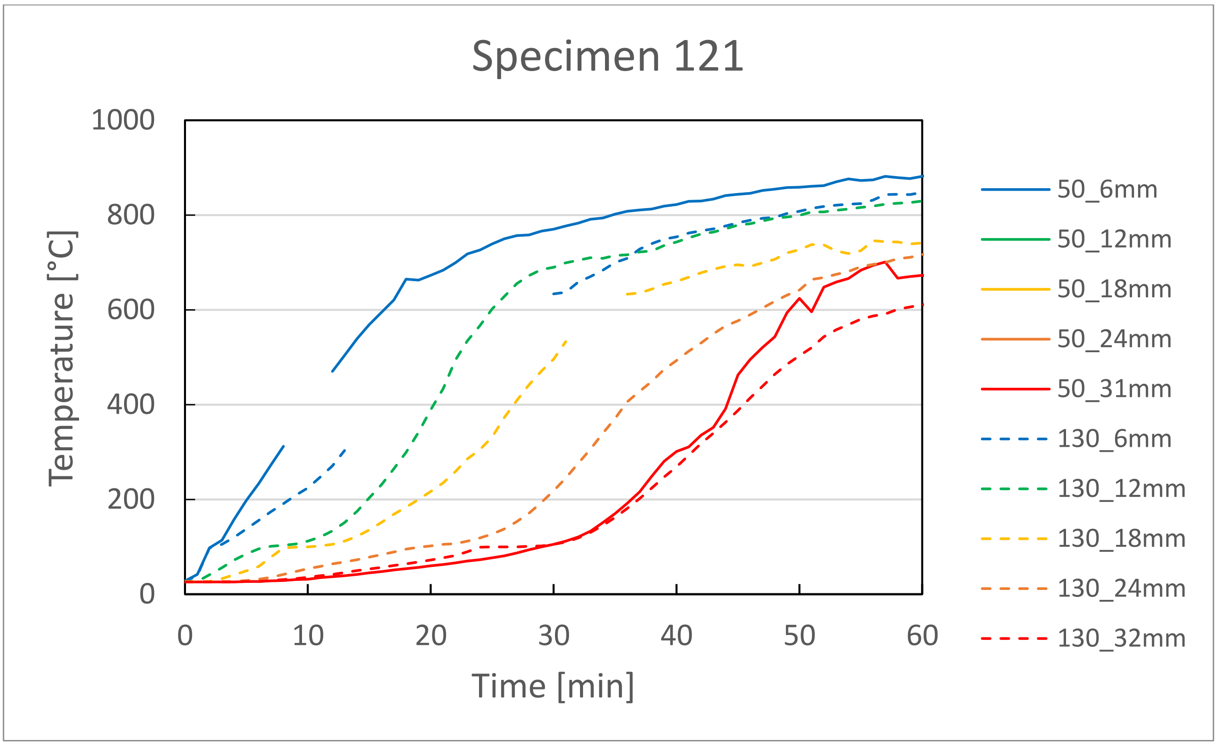


Figure 50: Temperature development in specimen 121 for the measurement positions in a distance of 50 mm and 130 mm of the joint

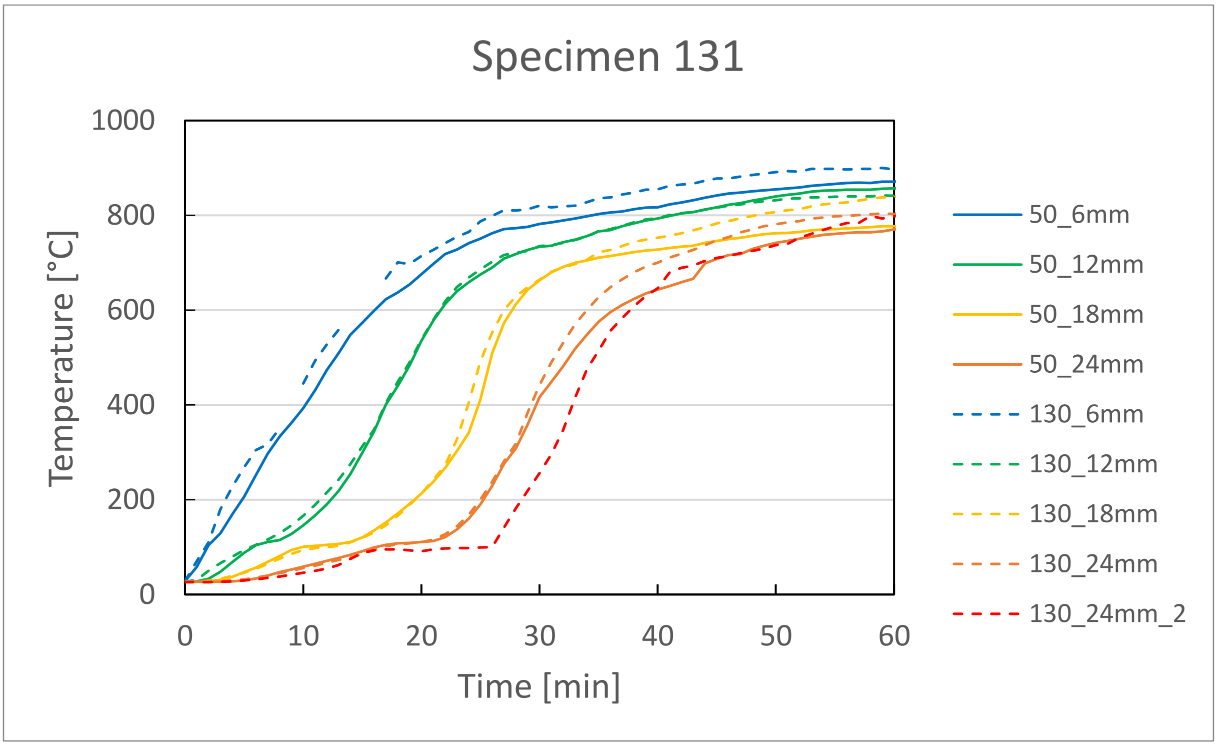


Figure 51: Temperature development in specimen 131 for the measurement positions in a distance of 50 mm and 130 mm of the joint

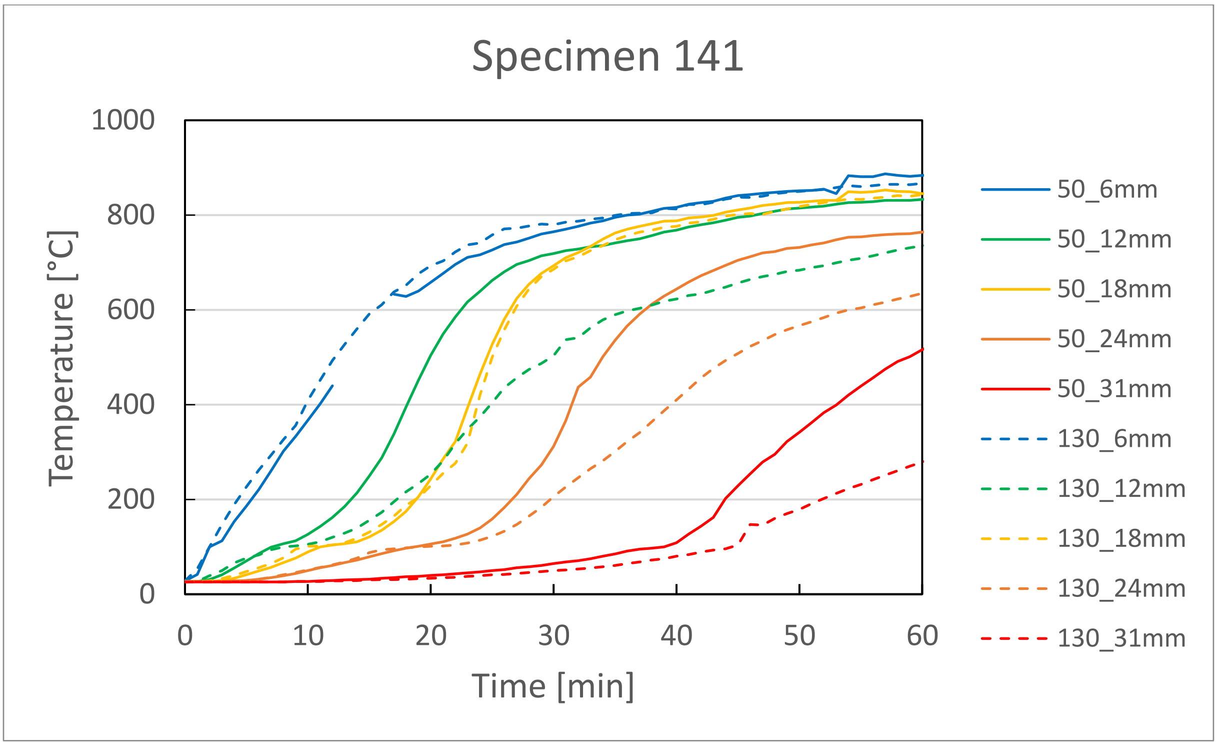


Figure 52: Temperature development in specimen 141 for the measurement positions in a distance of 50 mm and 130 mm of the joint

B.5 Failure Thermocouple

Table 8: Failure and details of measuring points in test series 2.1

Test series 2.1					**Measuring Point**	
Specimen	Number	Depth [mm]	Position [mm]	Board number	Partial failure	Failure
101	50_6	6	50	87	3	2
	50_12	12	50	88		
	50_18	18	50	89		
	50_24	24	50	90		
	50_30	30	50	91		
	130_6	6	130	92		
	130_12	12	130	93		
	130_18	18	130	140		
	130_24	24	130	95		
	130_30	30	130	96		
111	50_6	6	50	97	6	2
	50_12	12	50	98		
	50_18	18	50	99		
	50_24	24	50	100		
	50_30	30	50	101		

	130_6	6	130	102		
	130_12	12	130	103		
	130_18	18	130	104		
	130_24	24	130	105		
	130_30	30	130	106		
121	50_6	6	50	107	3	3
	50_12	12	50	108		
	50_18	18	50	109		
	50_24	24	50	110		
	50_30	30	50	111		
	130_6	6	130	112		
	130_12	12	130	113		
	130_18	18	130	114		
	130_24	24	130	115		
	130_30	30	130	116		
131	50_6	6	50	117	1	1
	50_12	12	50	118		
	50_18	18	50	119		
	50_24	24	50	120		
	50_30	30	50	121		
	130_6	6	130	122		
	130_12	12	130	123		
	130_18	18	130	124		
	130_24	24	130	125		
	130_30	30	130	126		
141	50_6	6	50	127	1	0
	50_12	12	50	128		
	50_18	18	50	129		
	50_24	24	50	130		
	50_30	30	50	131		
	130_6	6	130	132		
	130_12	12	130	133		
	130_18	18	130	134		
	130_24	24	130	135		
	130_30	30	130	136		
	Number			50	14	8
					0,28	0,16

C Test series 2.2

C.1 Glue date

Table 9: Gluing details in test series 2.2

Specimen	Glue date	Time
1	17.05.2021	14:00-15:00
2	17.05.2021	14:00-15:00
3	17.05.2021	14:00-15:00
4	17.05.2021	14:00-15:00
5	17.05.2021	14:00-15:00
6	17.05.2021	14:00-15:00
7	17.05.2021	14:00-15:00
8	17.05.2021	14:00-15:00

C.2 Density

Table 10: Density in test series 2.2

SP number	Timber				
	QS [mm]		Length [mm]	Mass[g]	Density [kg/m³]
1	140	150	600	5092	404,1
2	140	160	600	5738,2	426,9
3	140	180	600	6330,6	418,7
4	140	450	600	16393,1	433,7
5	140	460	600	17538,5	453,9
6	140	480	600	18008,7	446,6
7	140	450	600	16750,6	443,1
8	140	450	600	15872,3	419,9

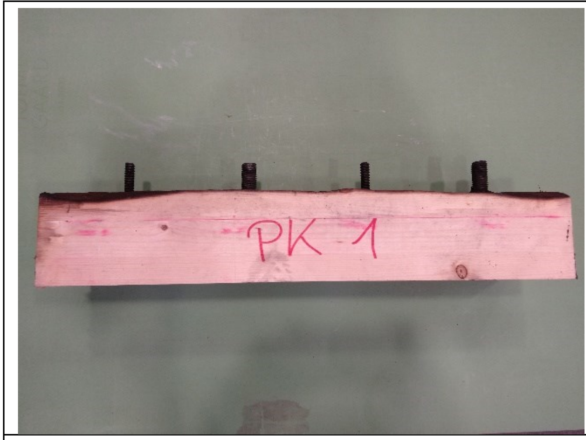
C.3 Specimen structure

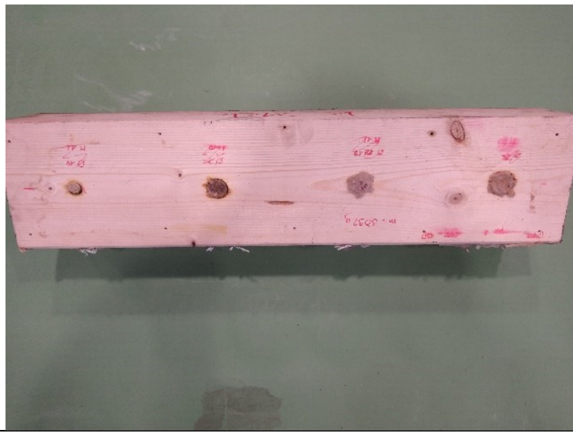
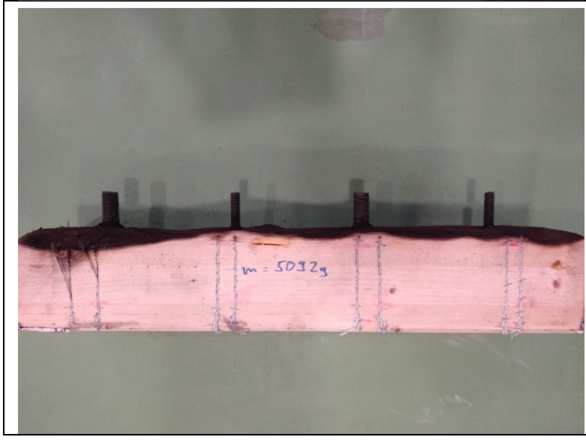
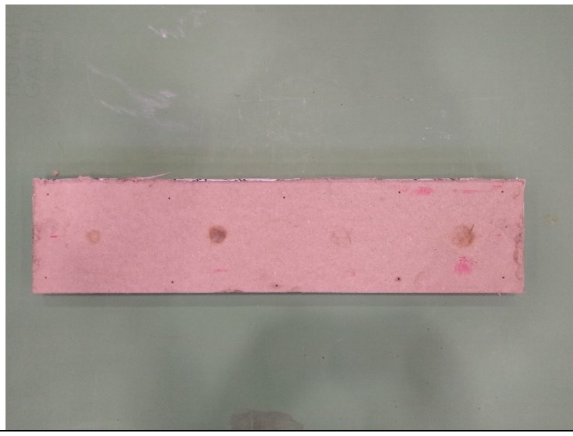
Table 11: Overview of test specimens in test series 2.2

SP number	Borehole					Rod				
	Length [mm]	Diameter 1 [mm]	Diameter 2[mm]	Diameter 3[mm]	Diameter 4[mm]	Length [mm]	Diameter 1[mm]	Diameter 2[mm]	Diameter 3[mm]	Diameter 4[mm]
1	150	26	18	22	14	150	20	12	20	12
2	160	26	18	22	14	150	20	12	20	12
3	180	26	18	22	14	150	20	12	20	12
4	450	26	18	22	14	470	20	12	20	12
5	460	26	18	22	14	450	20	12	20	12
6	480	26	18	22	14	450	20	12	20	12
7	450	26	18	22	14	450	20	12	20	12
8	450	26	18	22	14	450	20	12	20	12

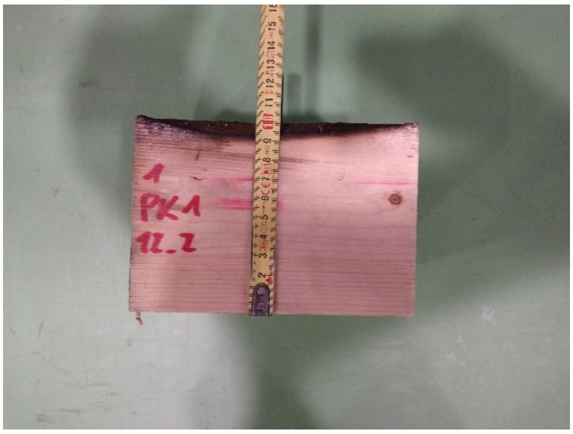
C.4 Specimen after fire test

C.4.1 SP1



12_2



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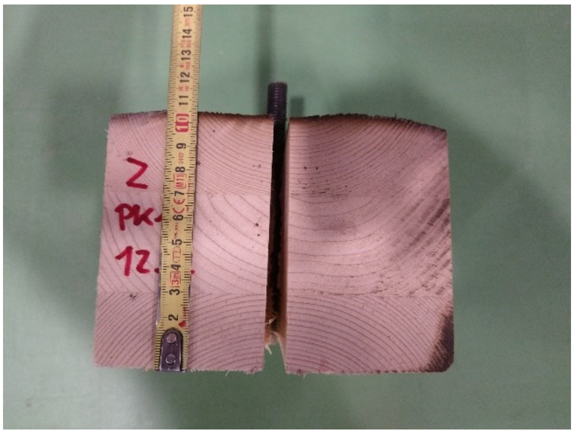

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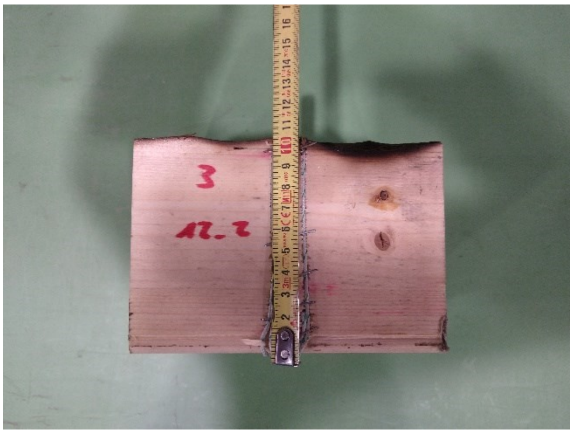

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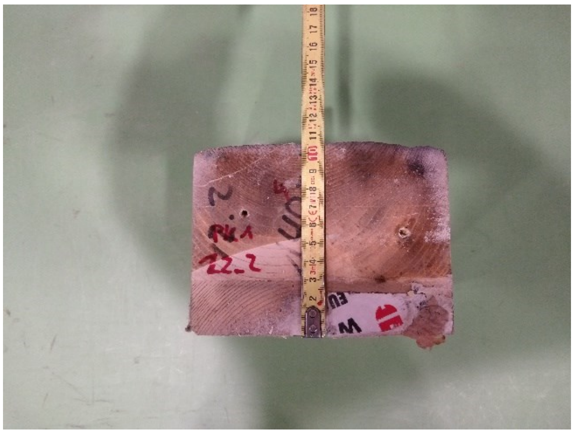

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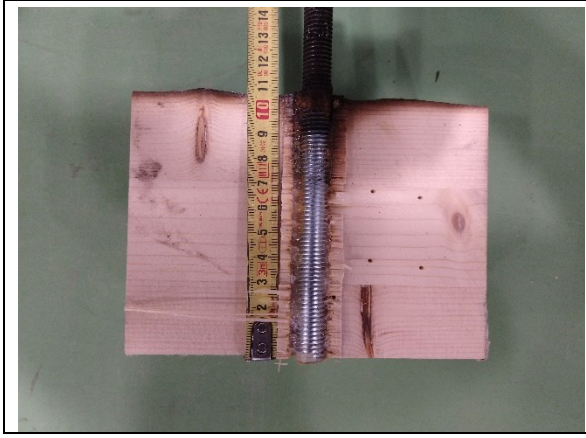

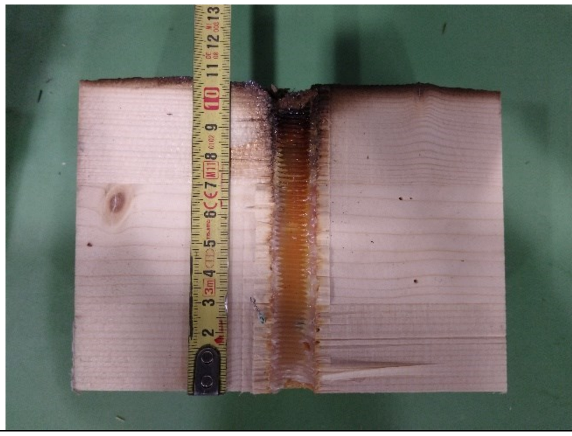

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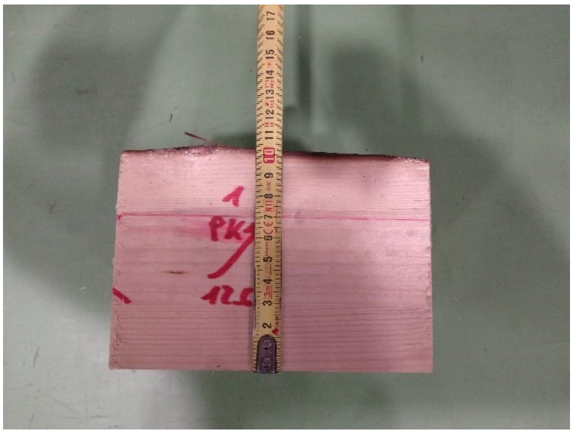

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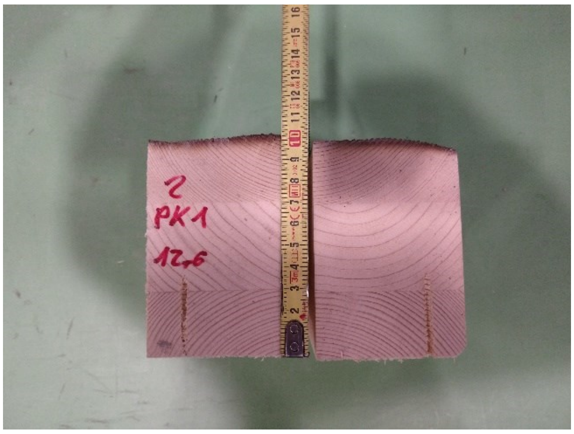

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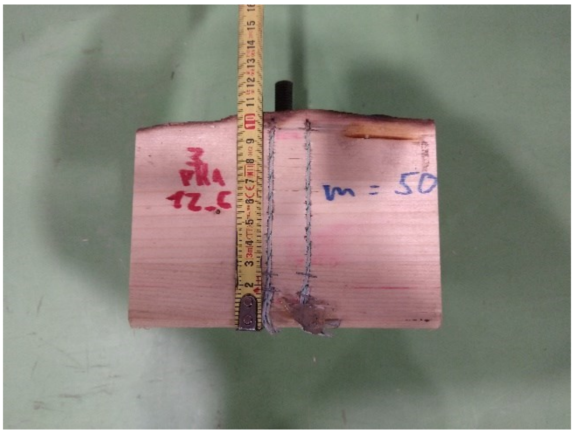

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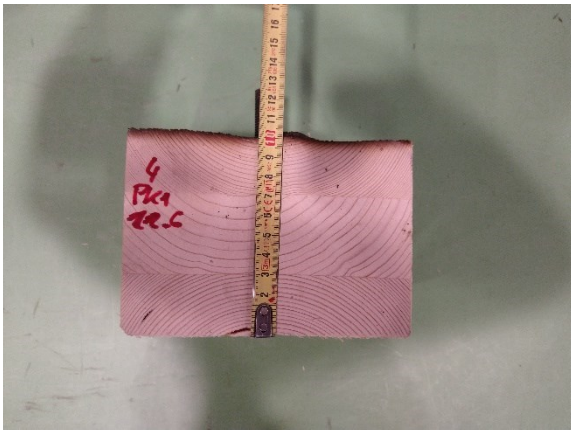

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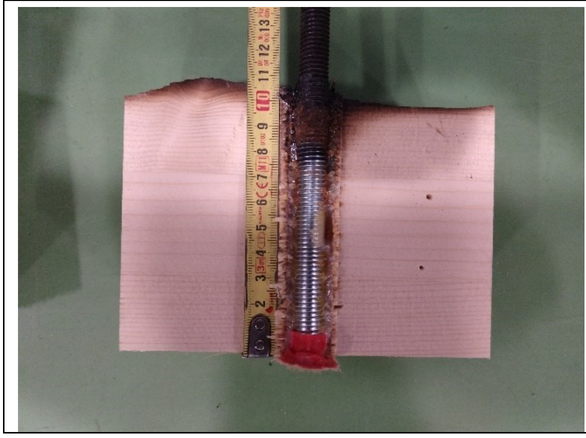

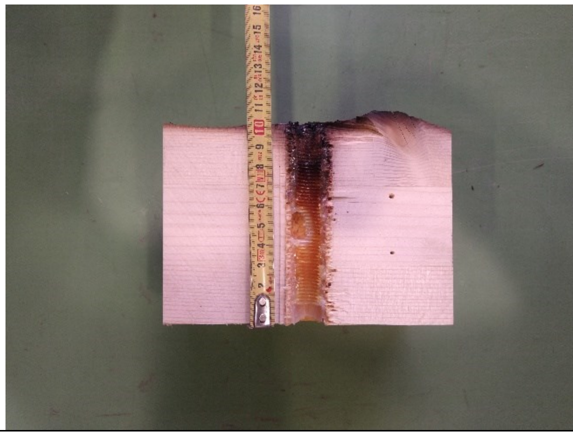

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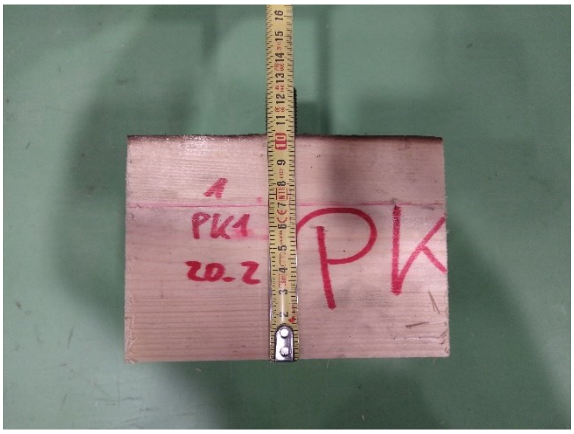

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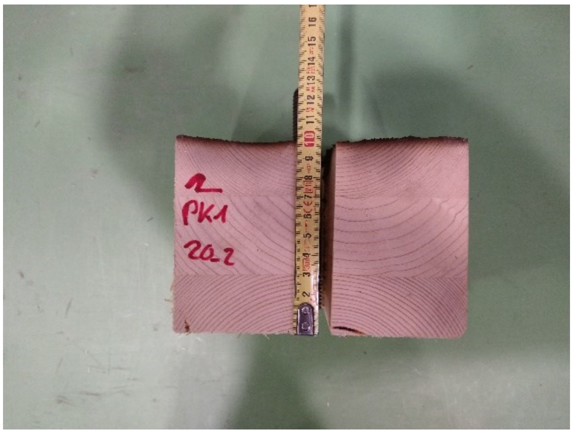

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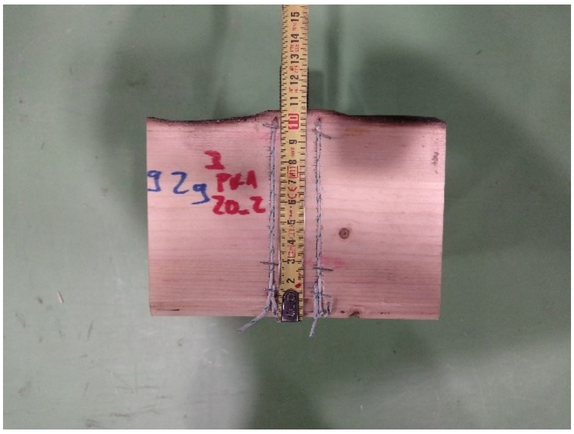

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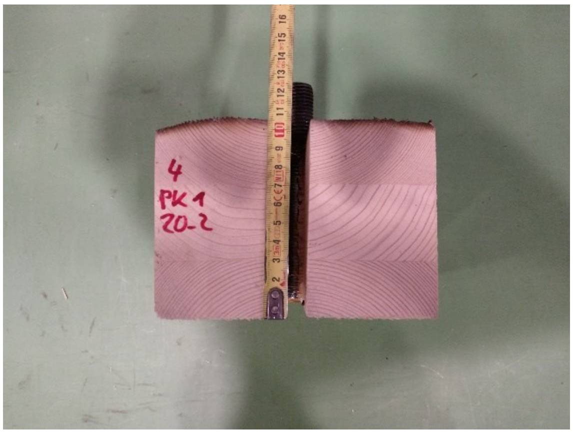

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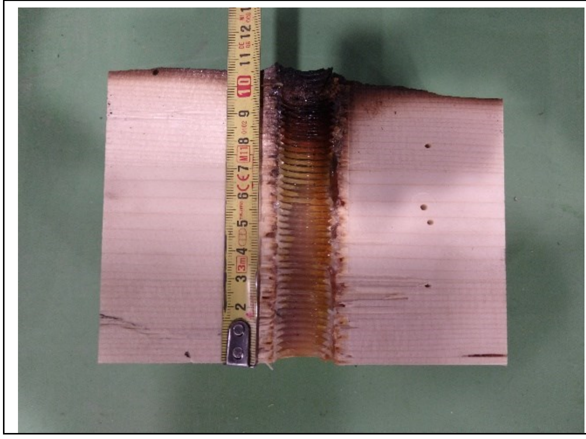

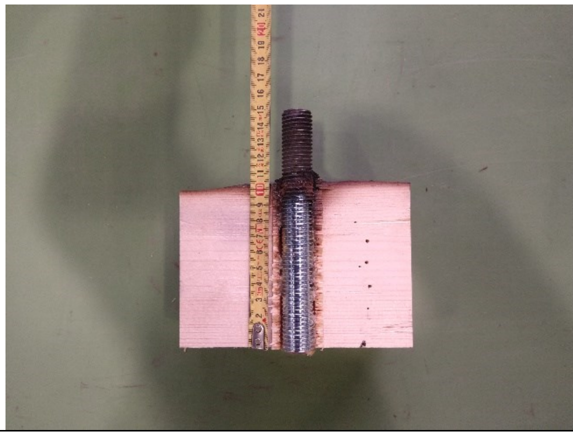

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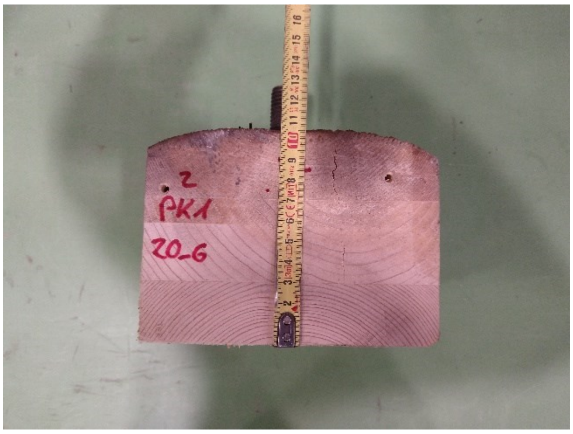

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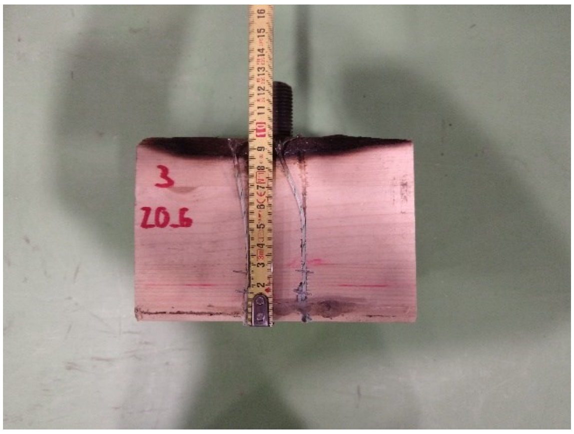

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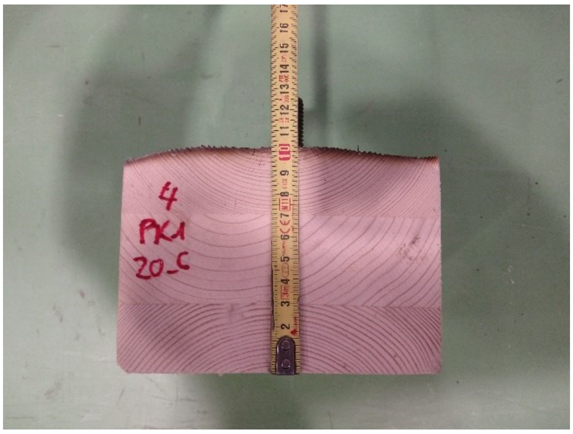

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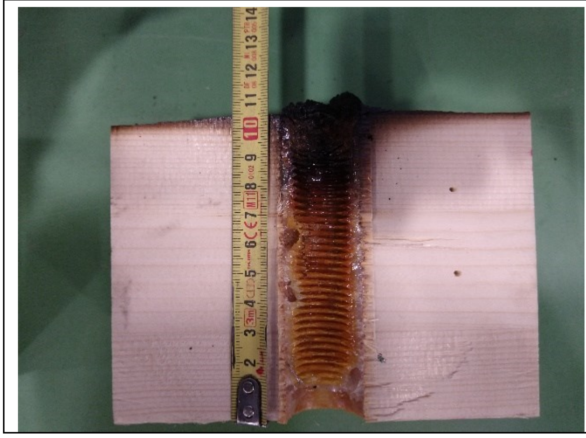
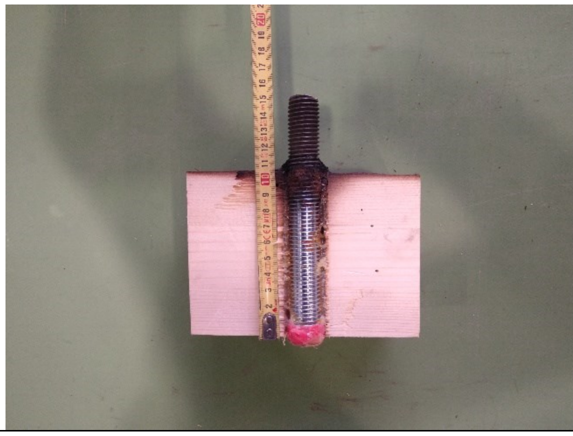
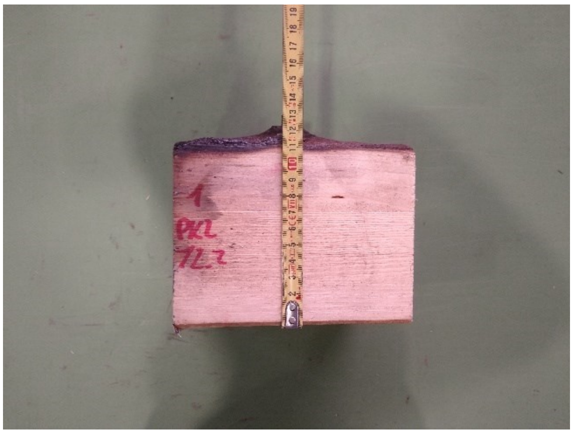
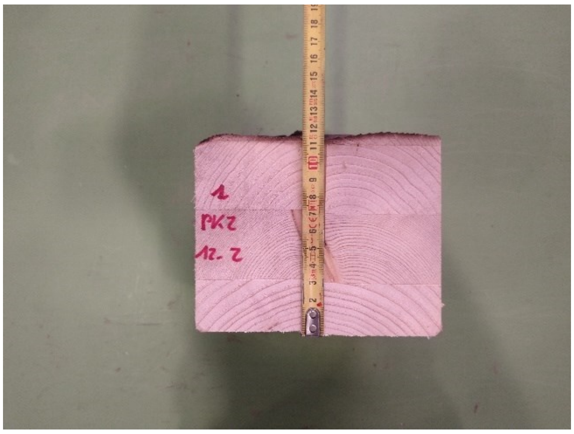
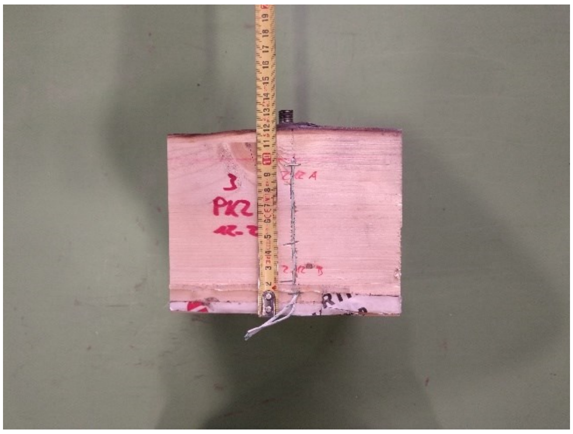
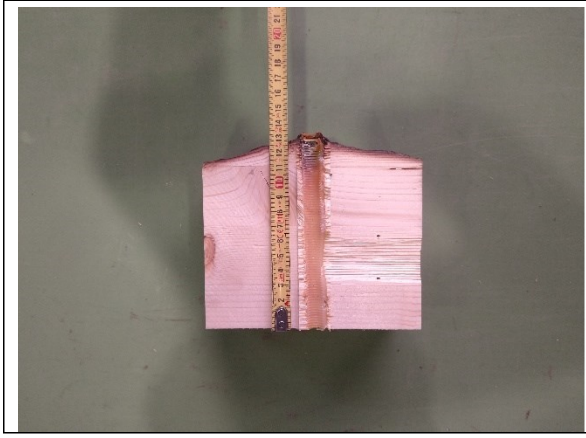
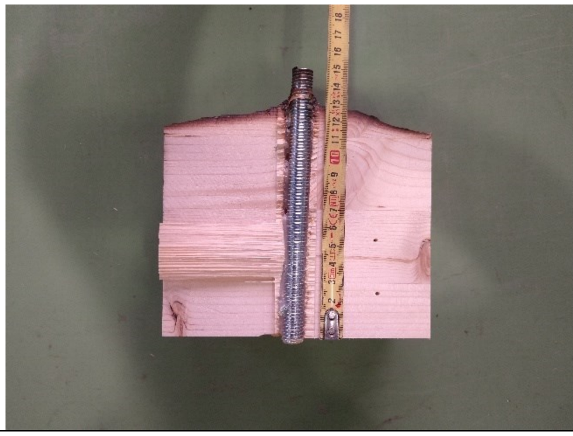




C.4.2SP2

12_2

 1	 2
 3	 4
	

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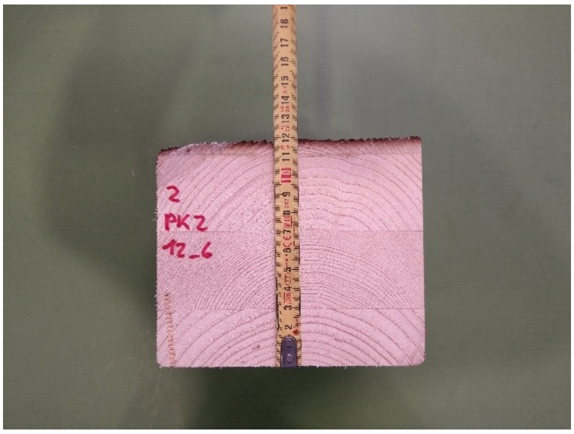

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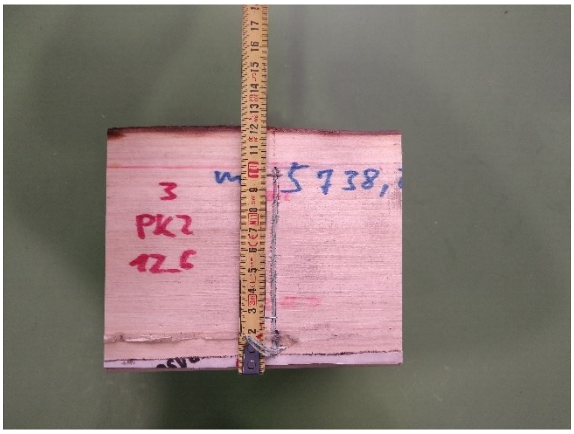

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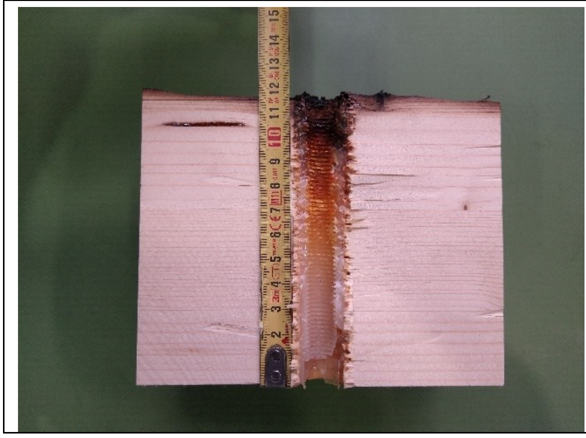

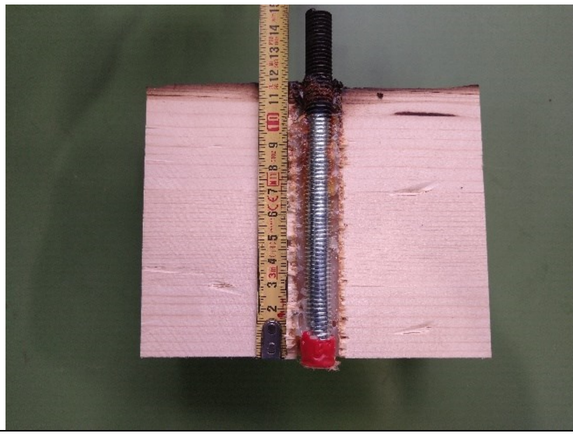

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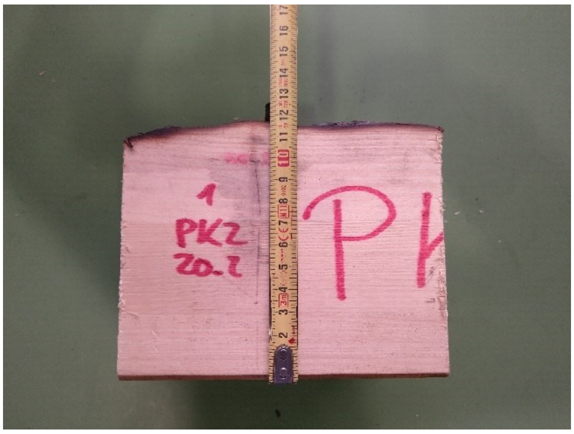

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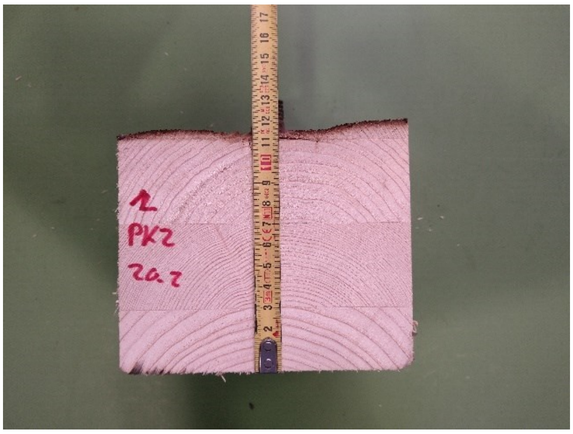

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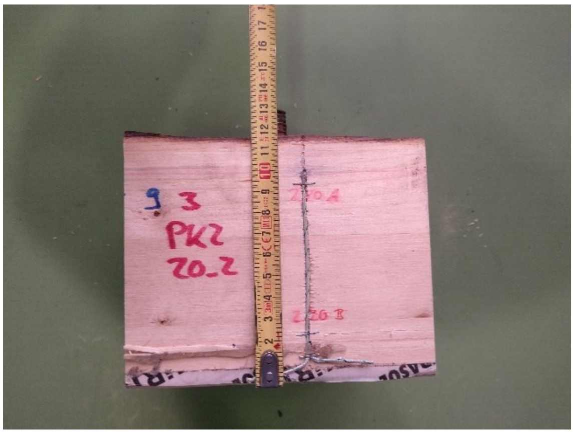

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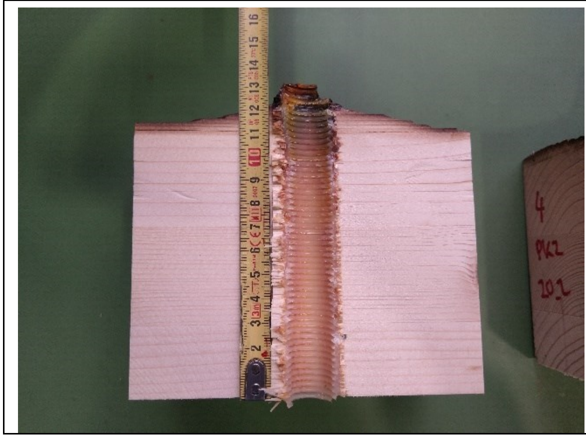

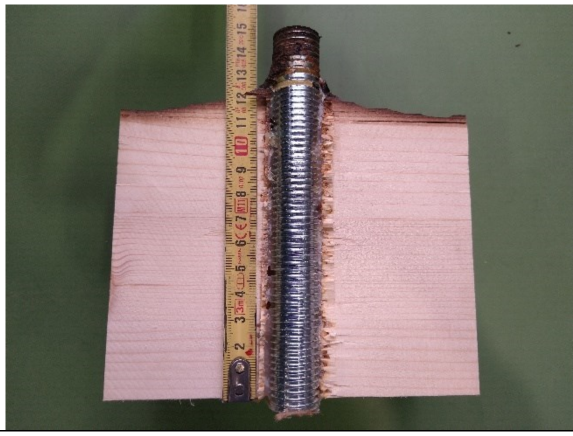

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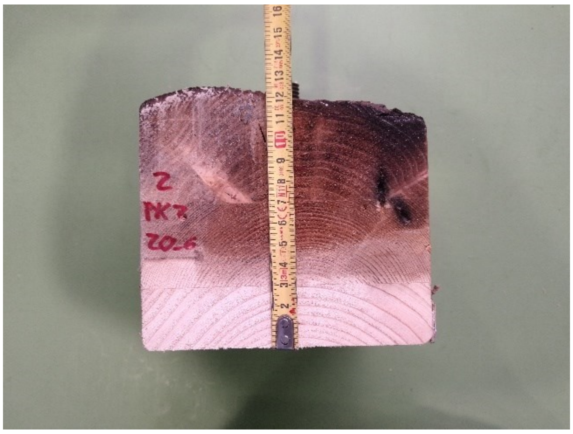

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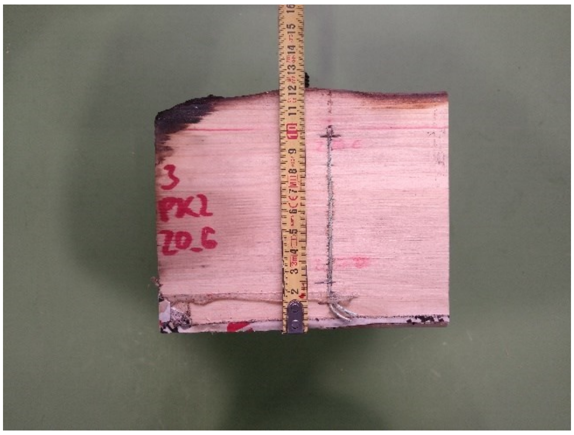

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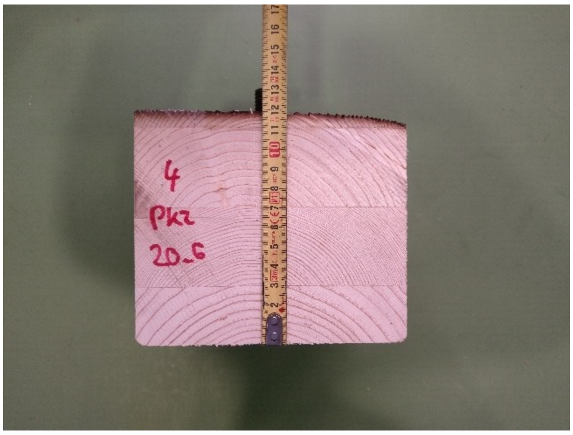

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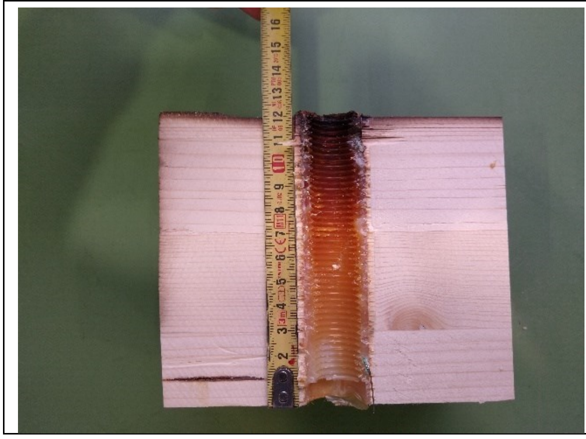

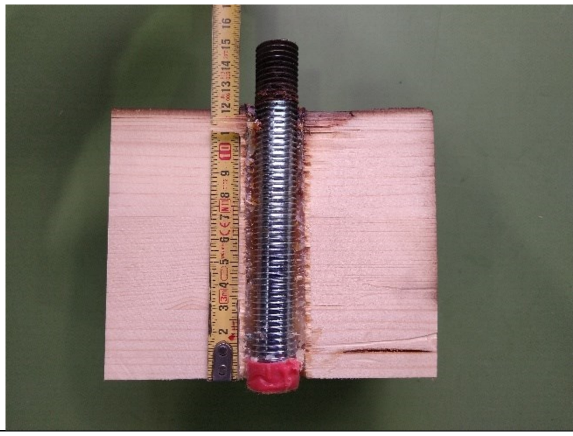

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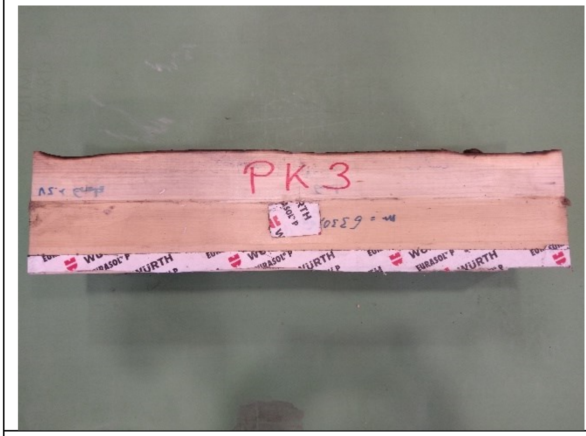

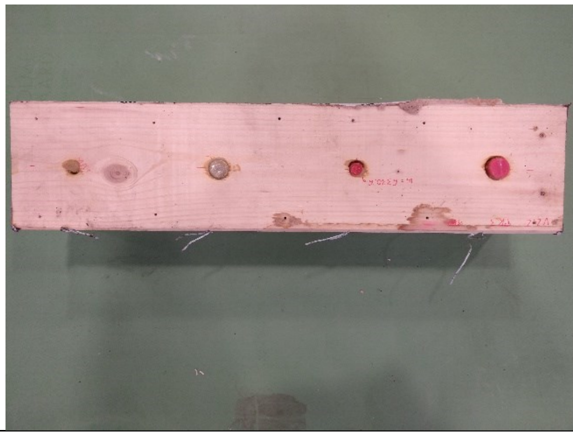

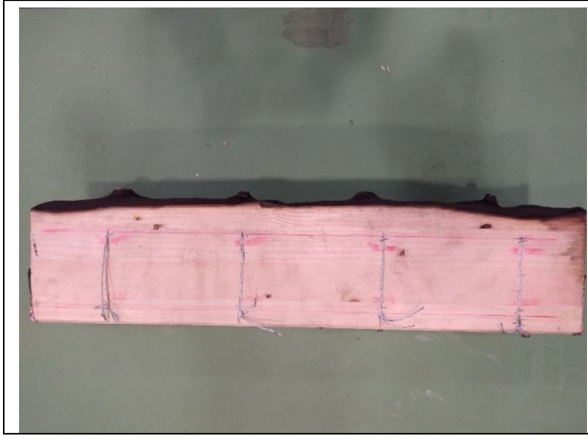

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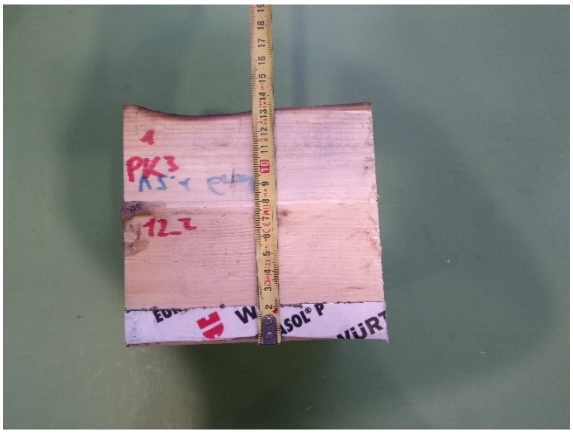
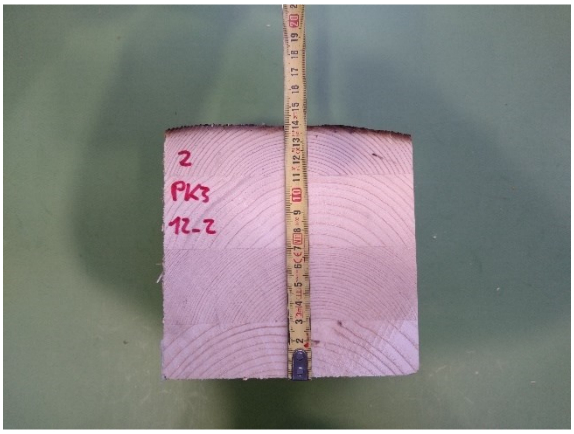
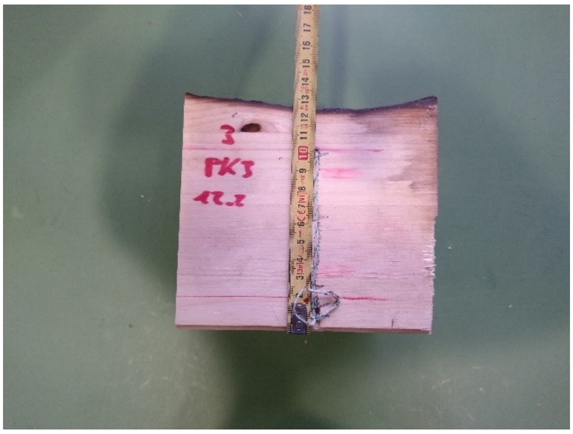
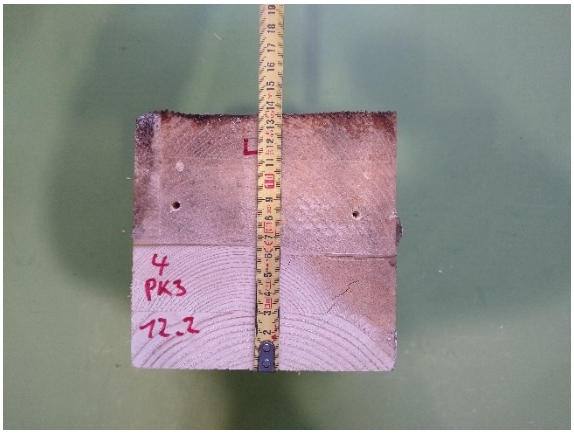
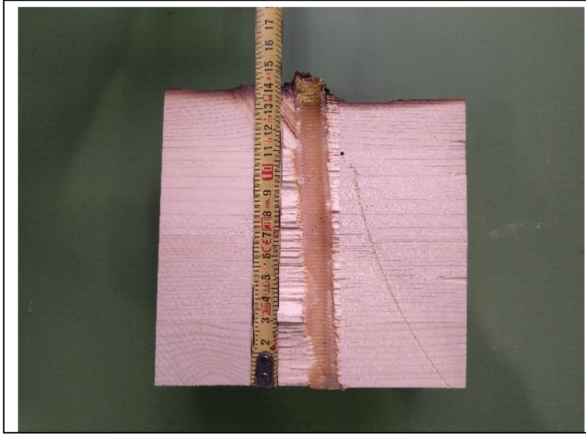
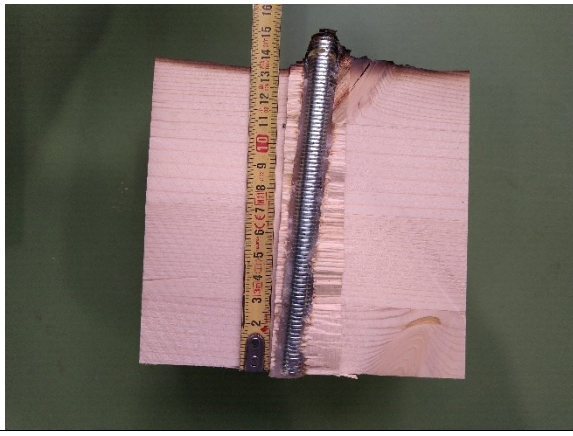
 1	 2
 3	 4
	

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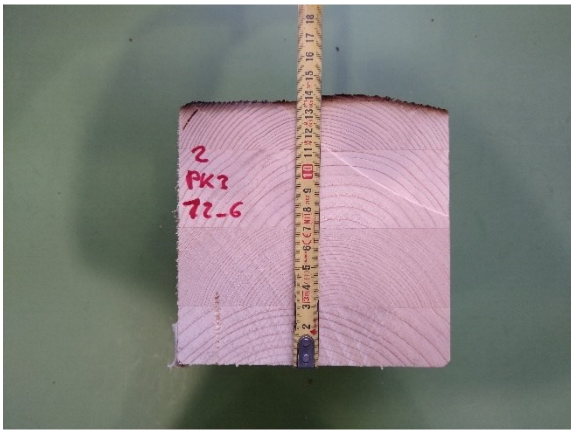
<td>

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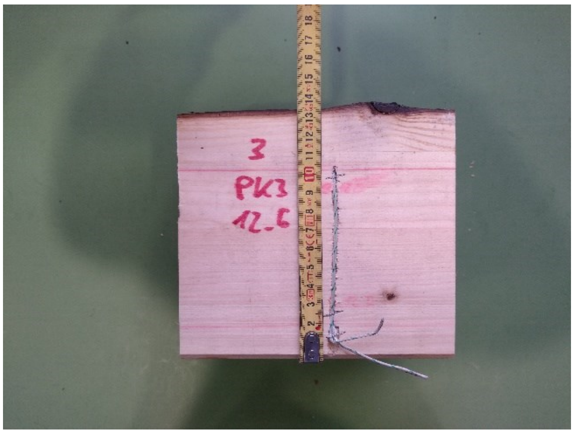
<td>

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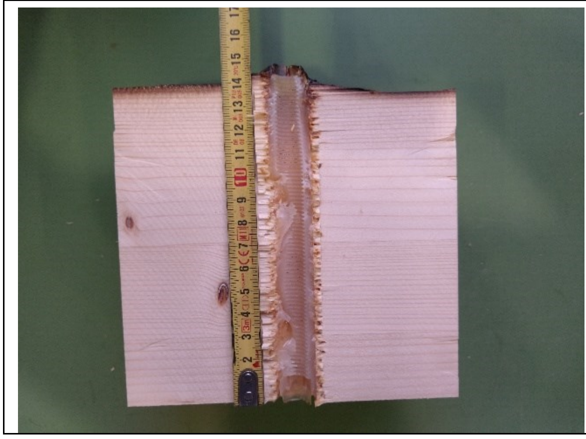
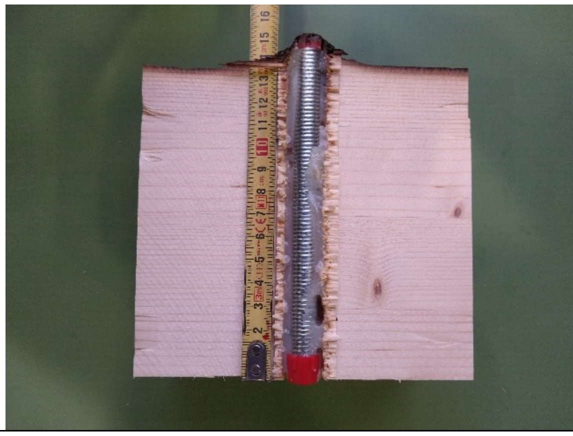
<td></td>
<td></td>
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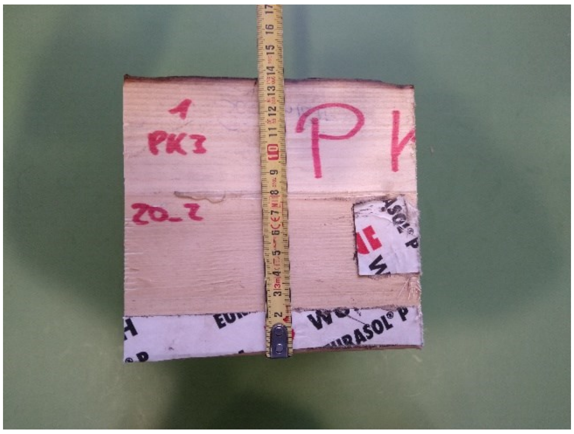

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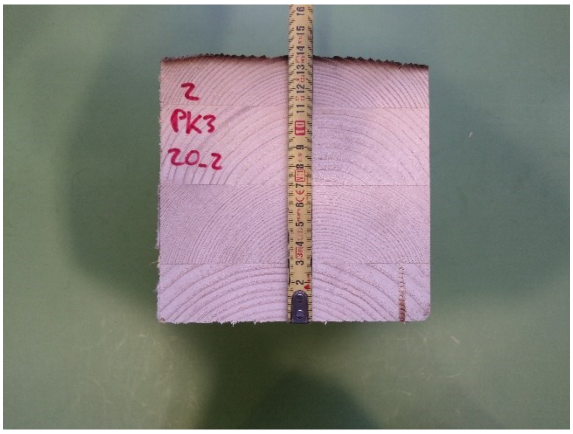

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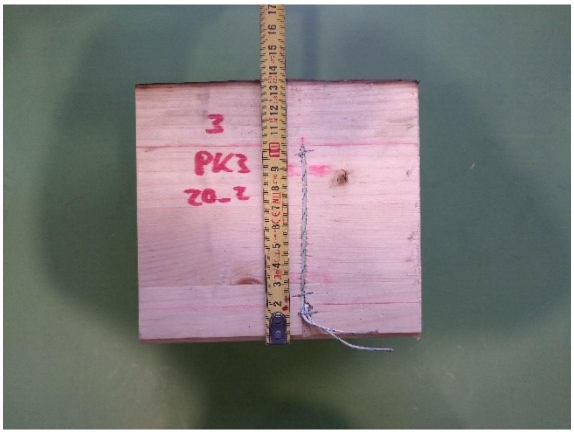

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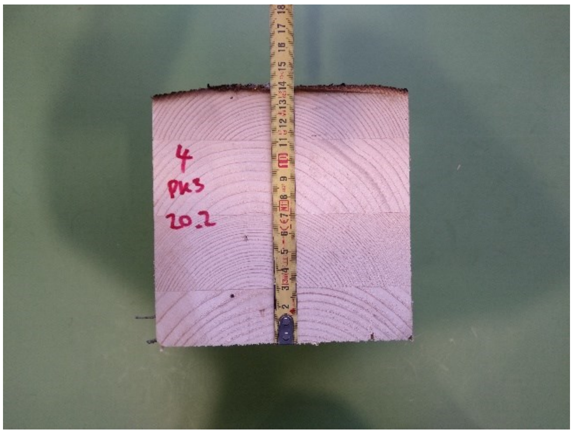

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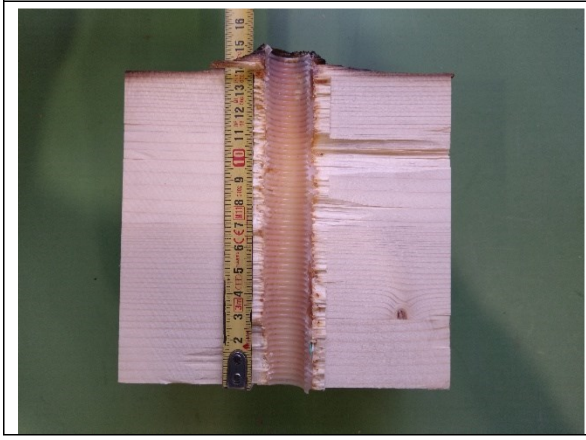

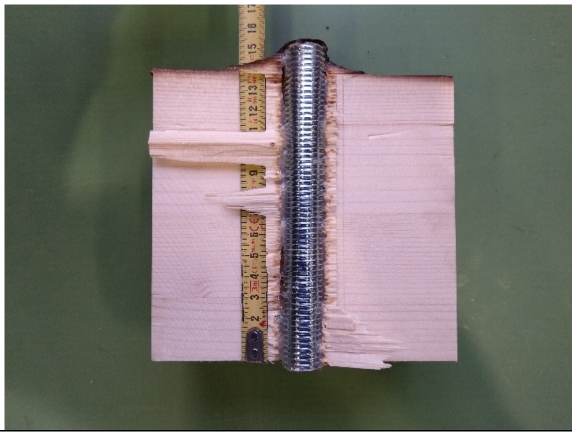

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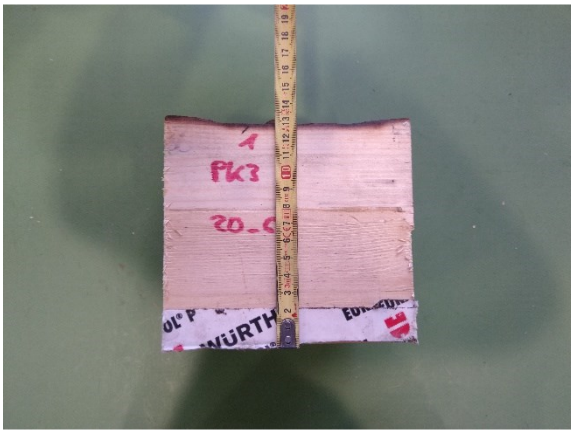

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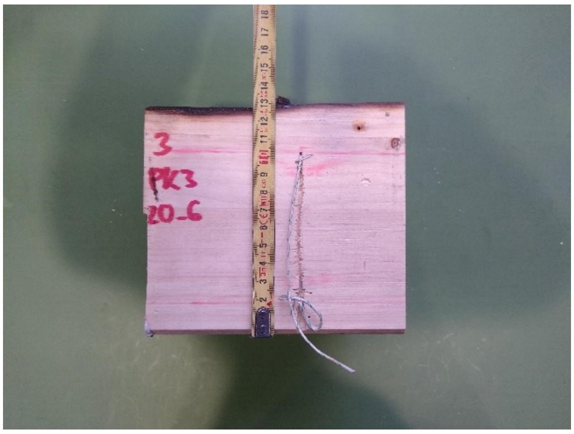

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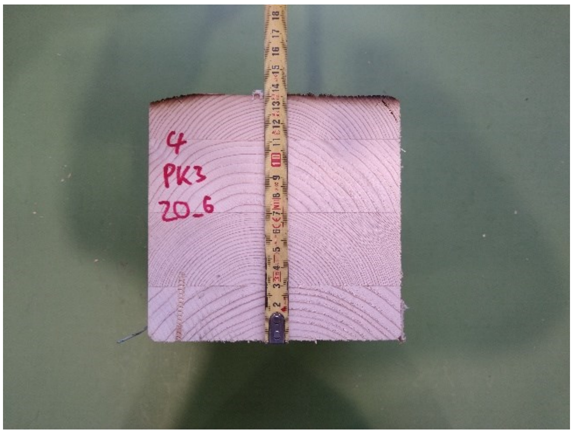

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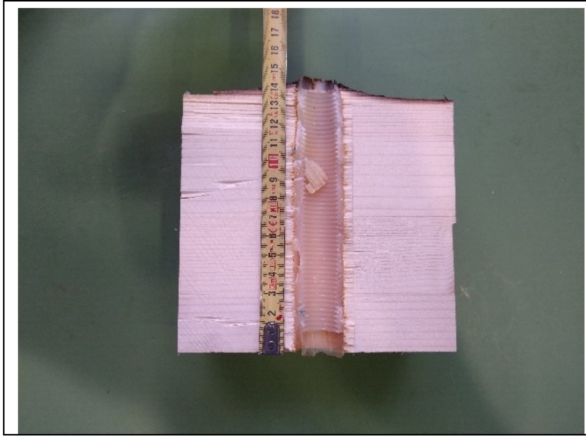

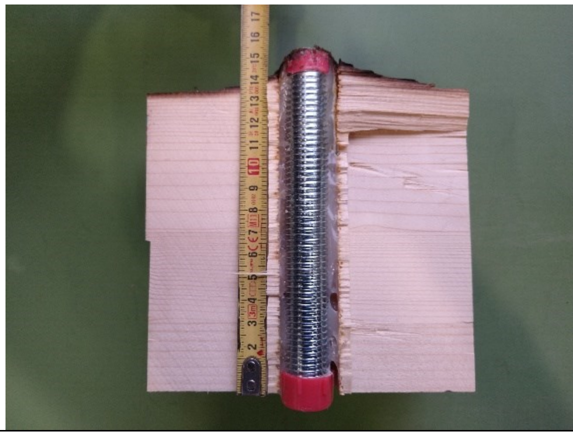

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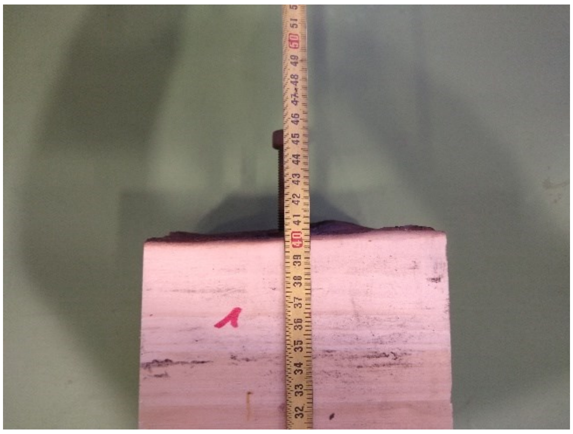

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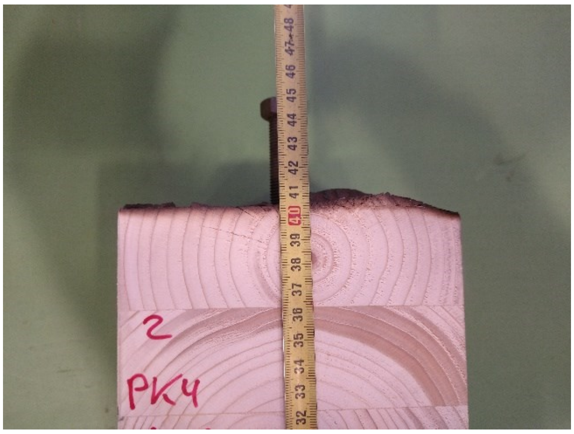

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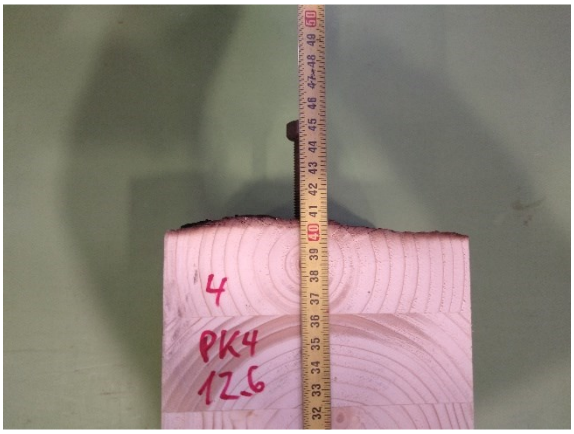

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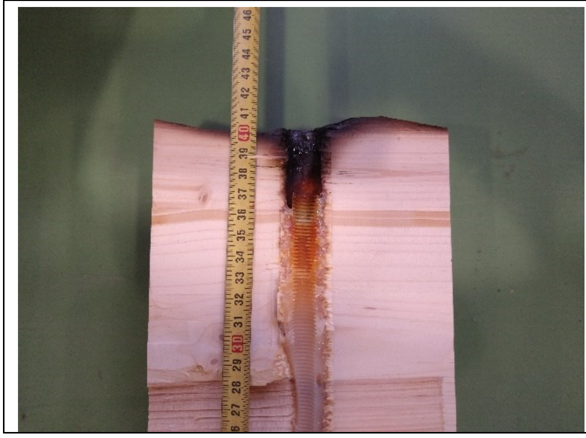

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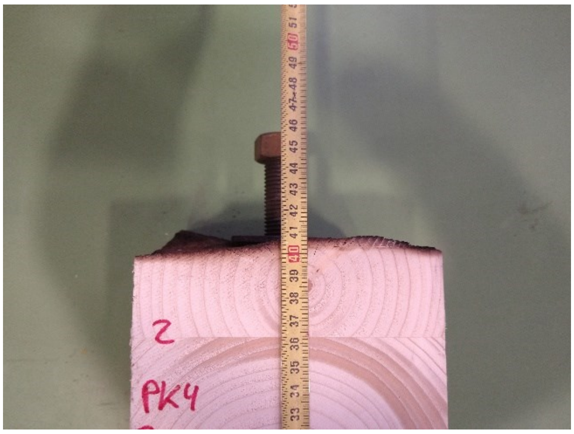
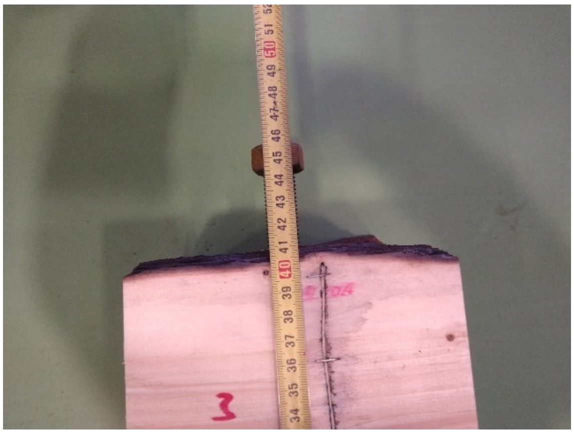
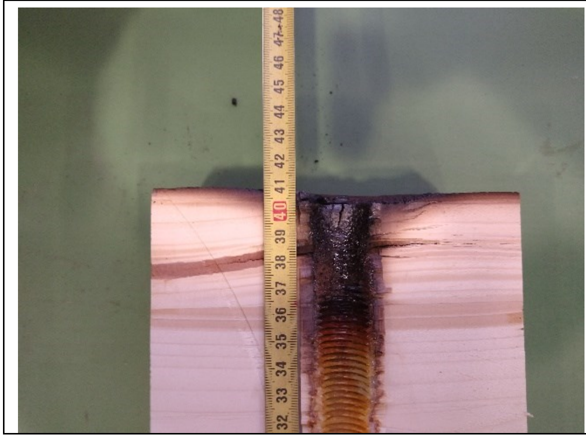
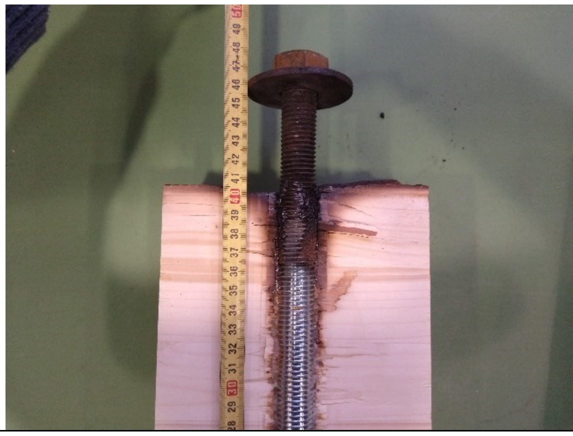
 1	 2
 3	 4
	

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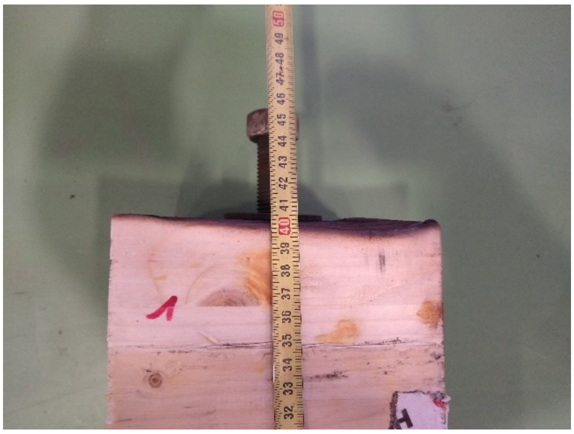
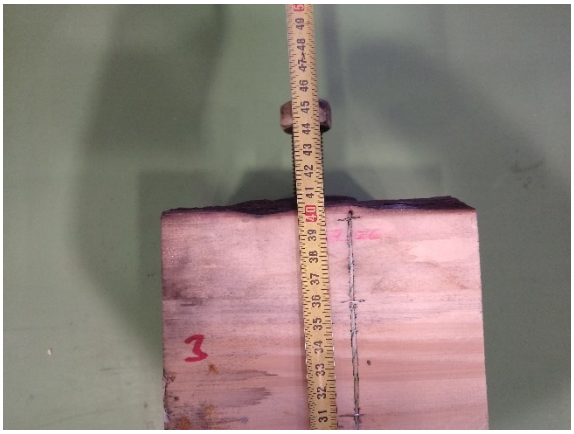
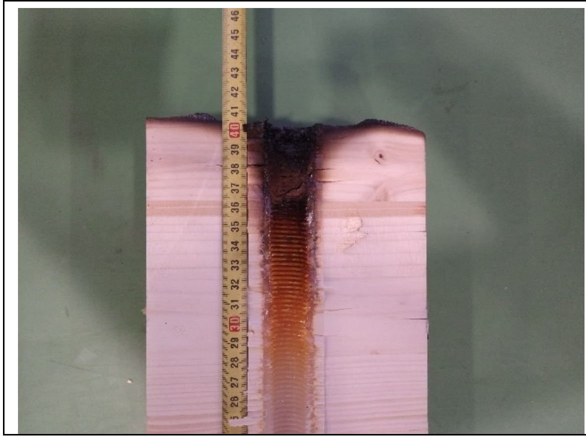
 1	 2
 3	 4
	

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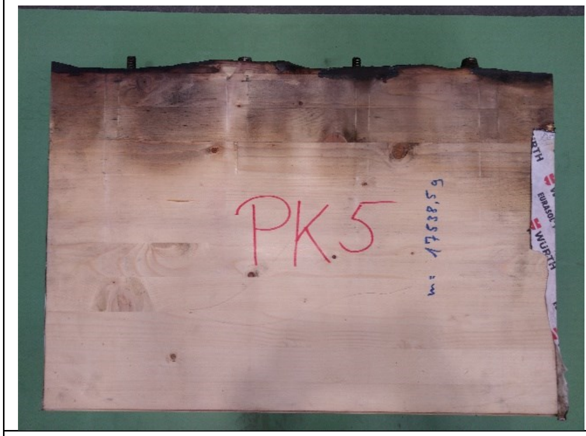

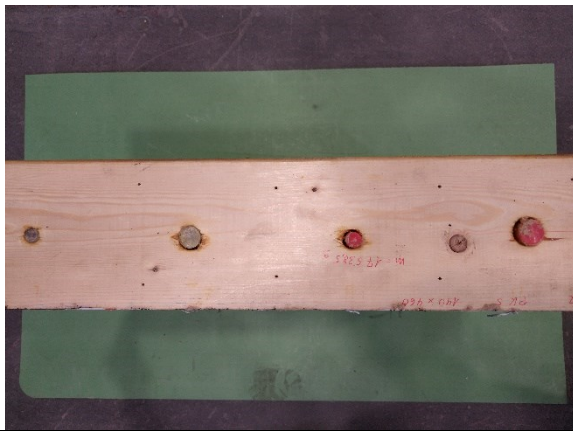

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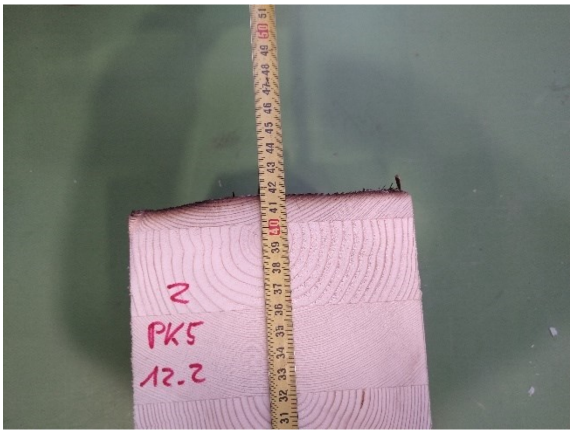

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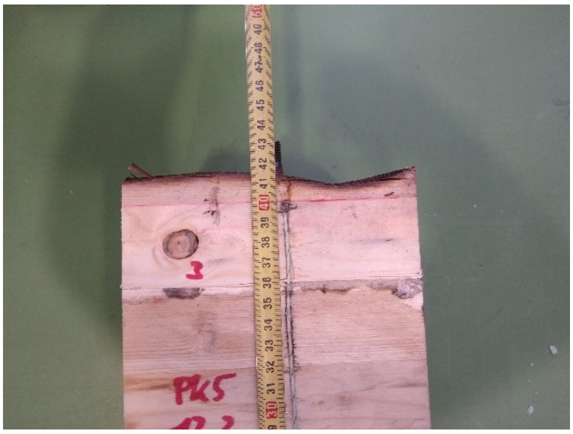

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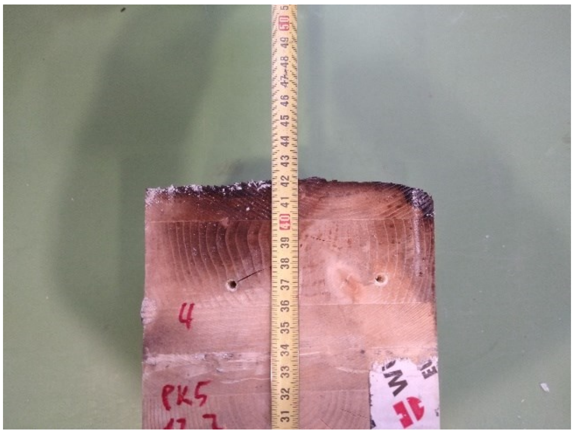

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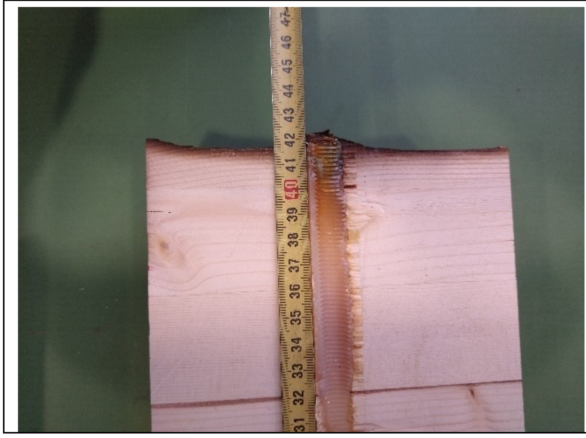

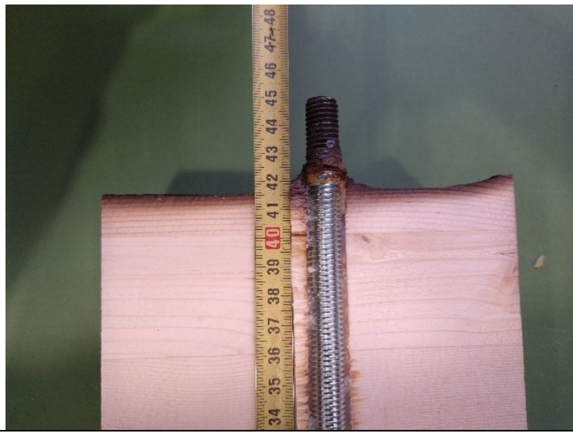

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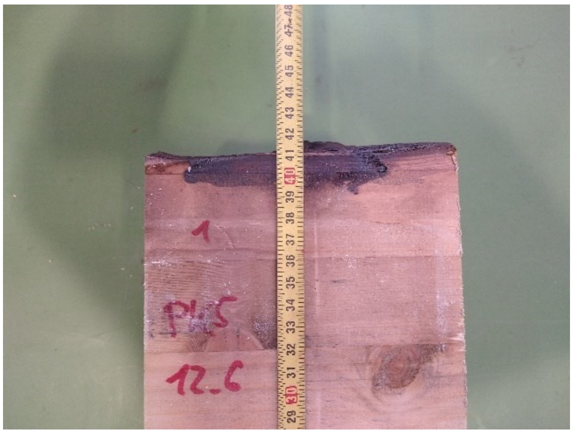

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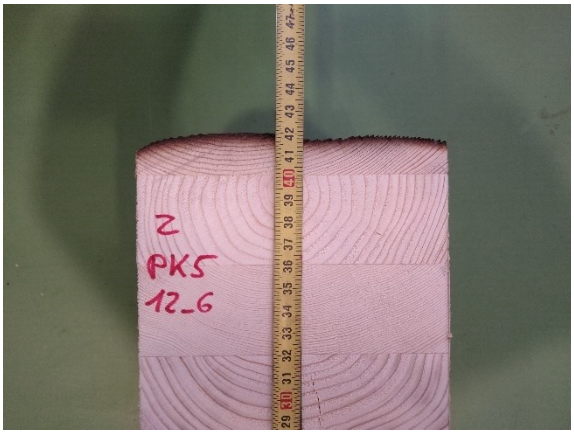

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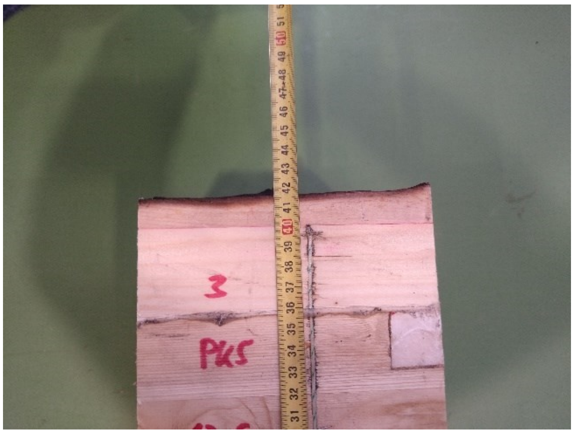

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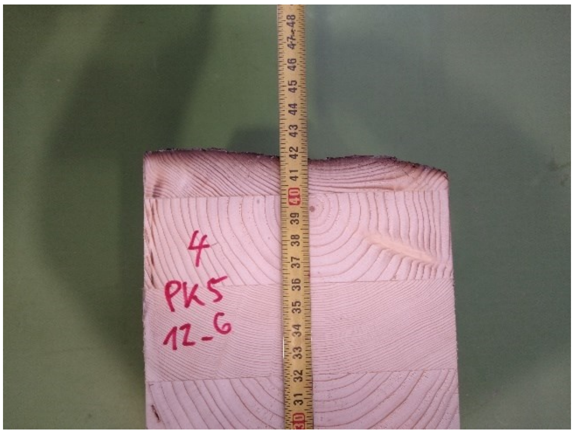

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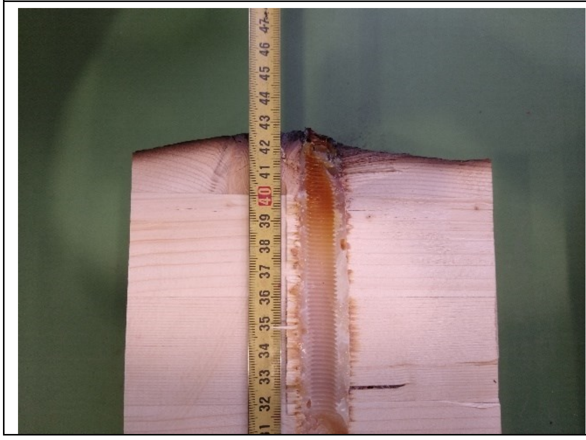

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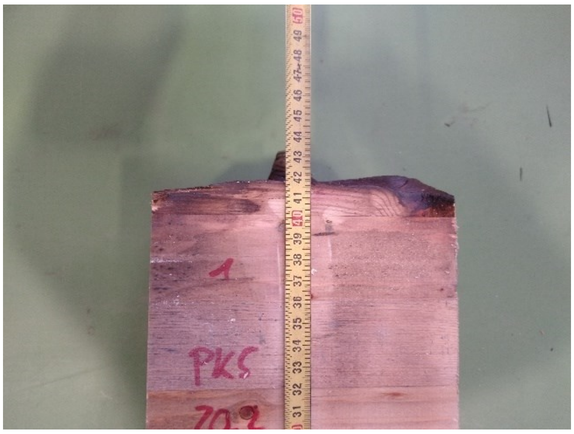

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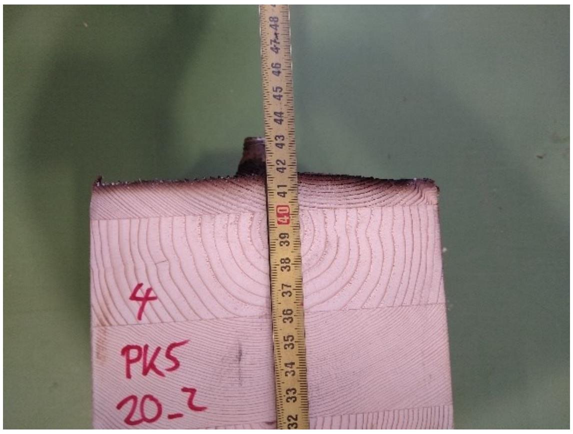

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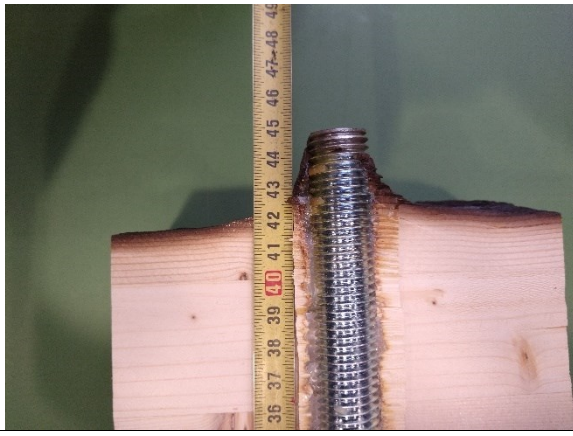

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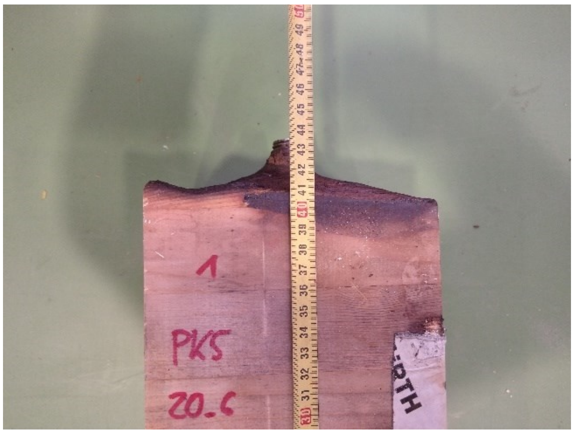

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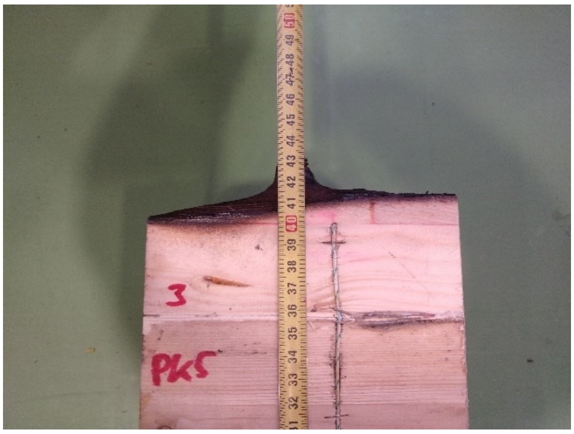

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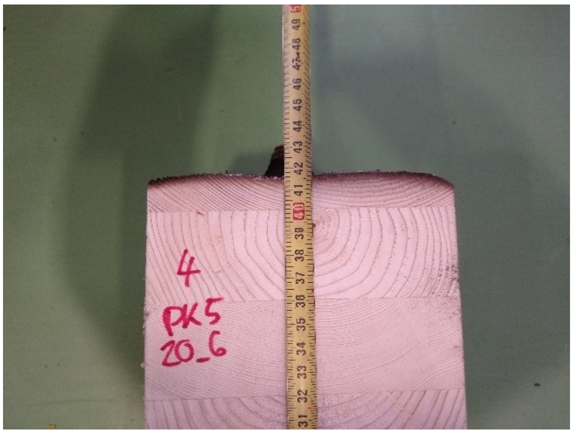

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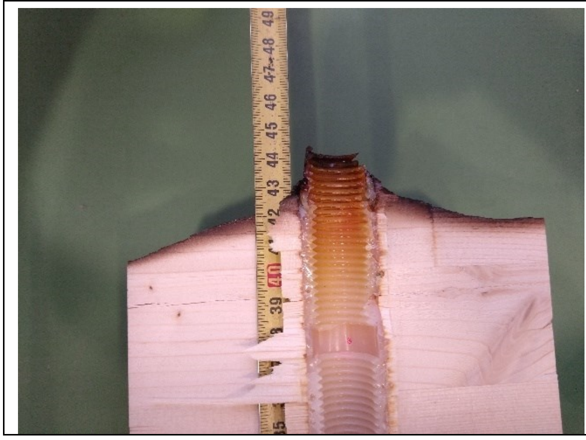

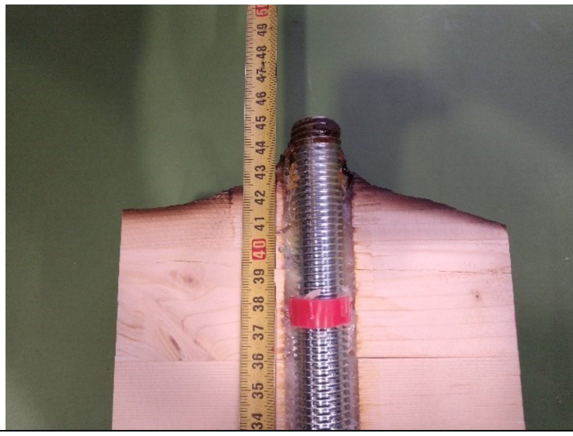

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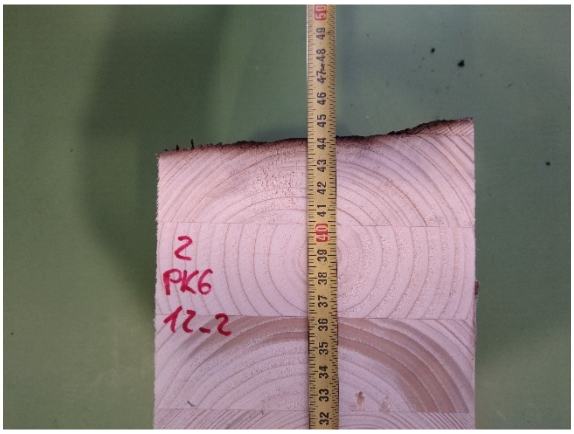

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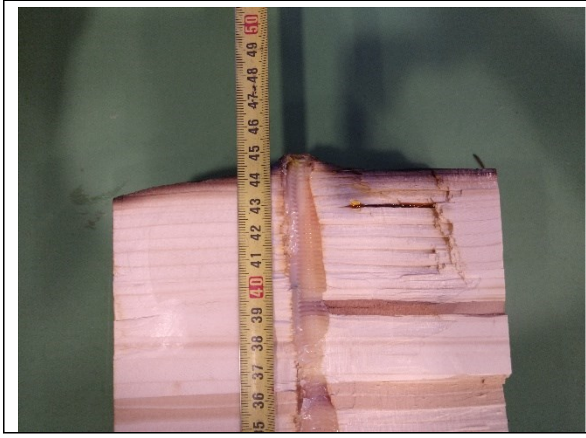

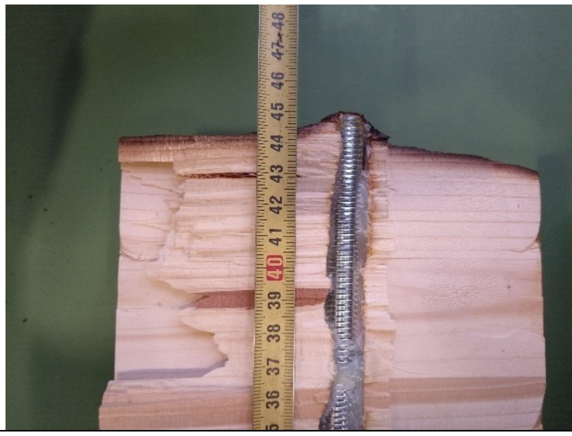

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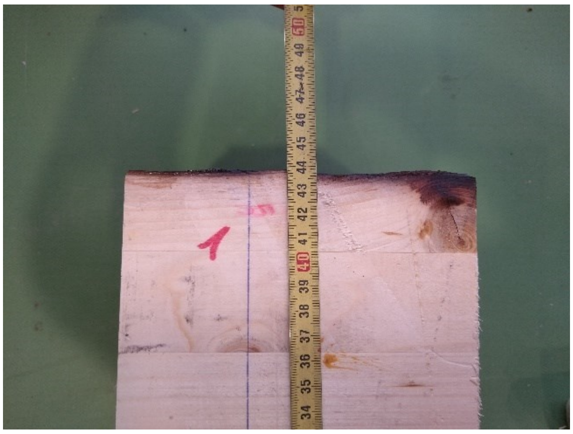

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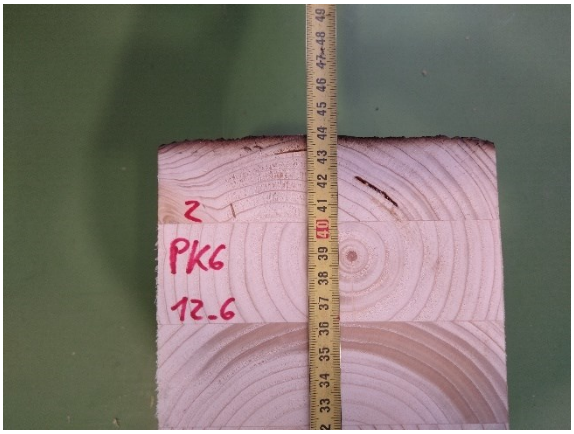

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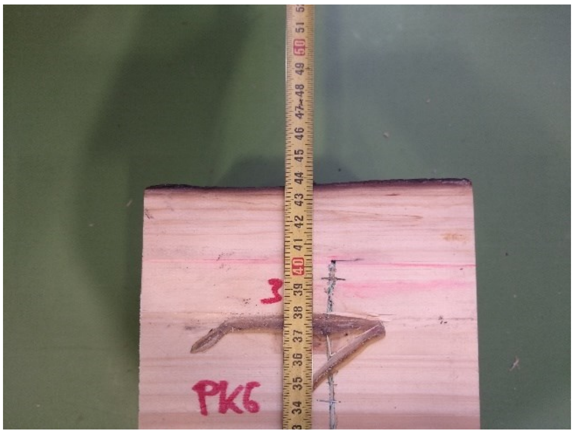

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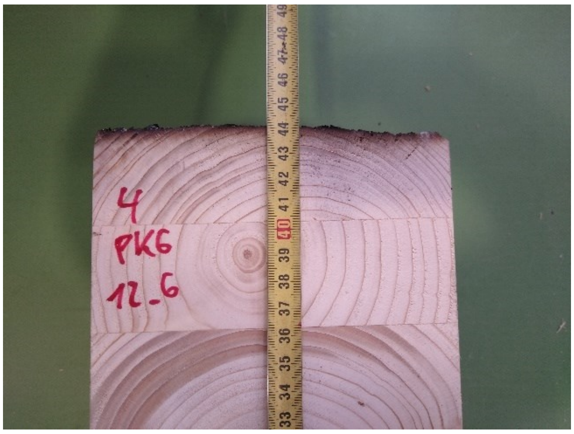

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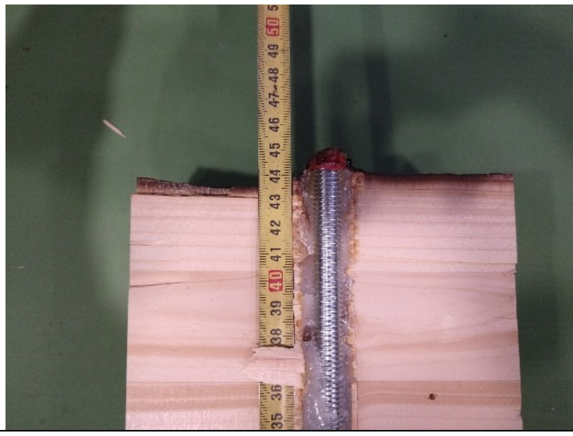

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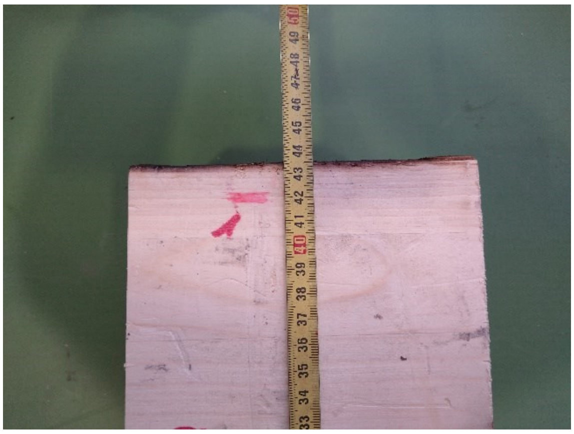
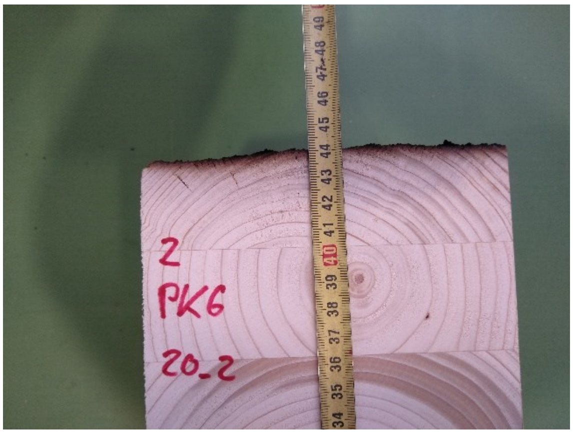
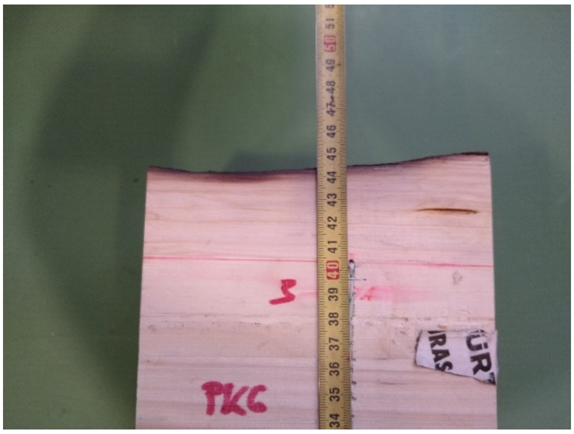
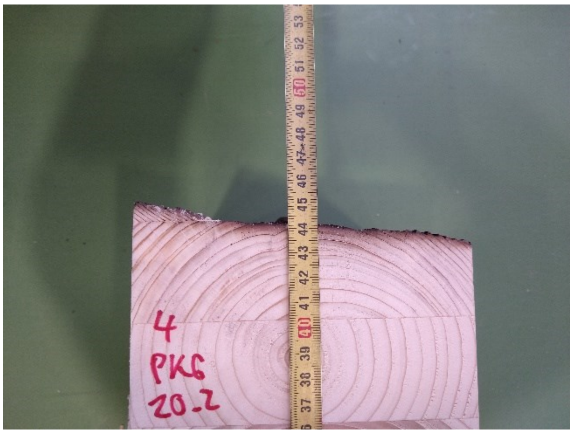
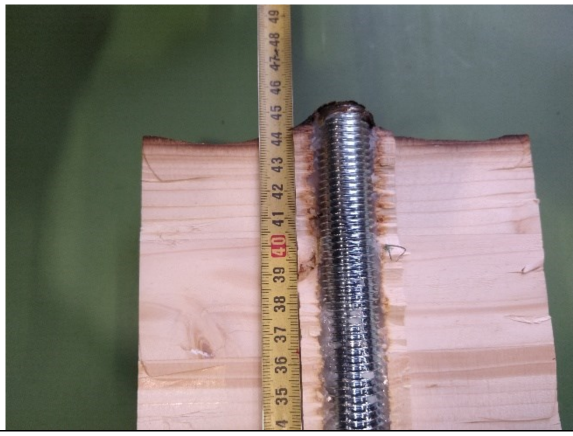
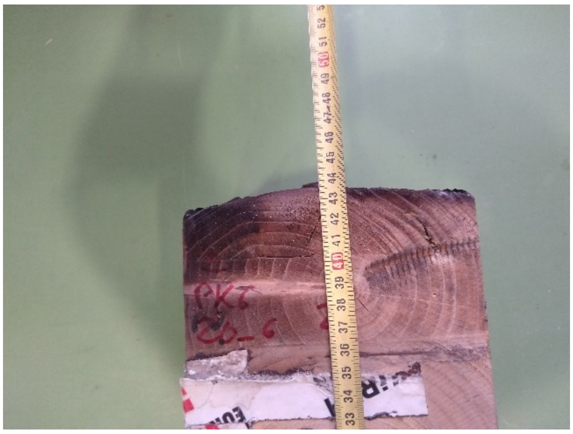
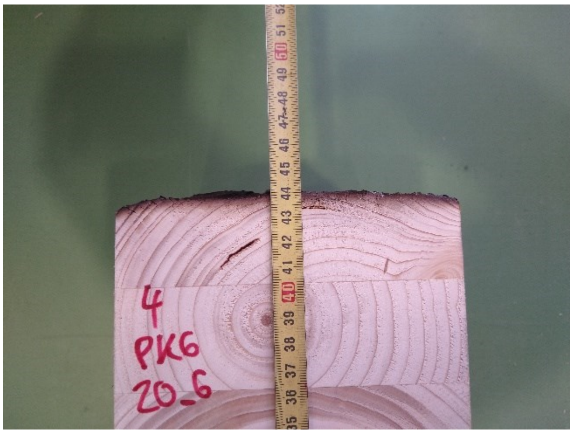
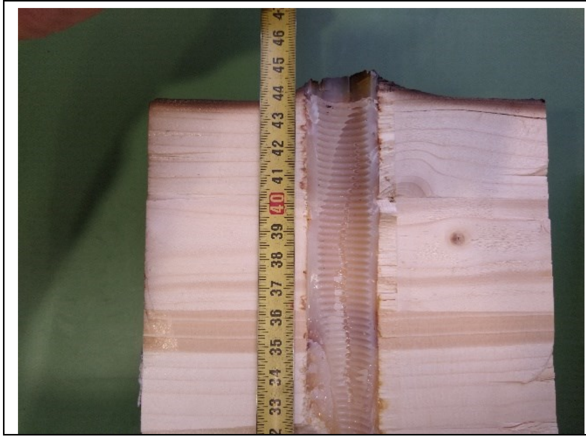
 1	 2
 3	 4
	

20_6

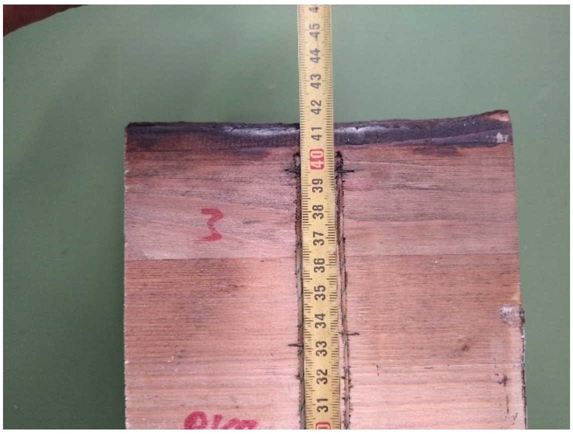
 1	 2
 3	 4
	

C.4.7 SP7

12_2

1

2



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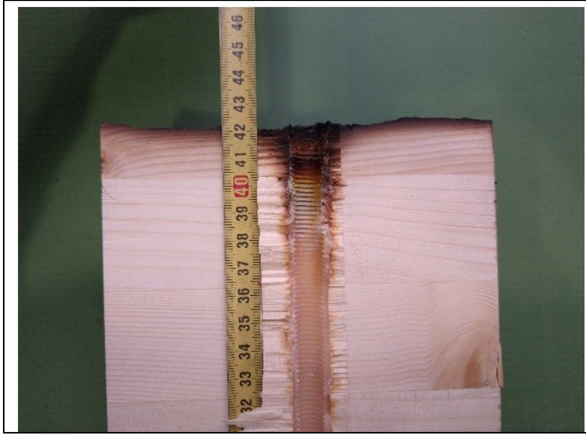
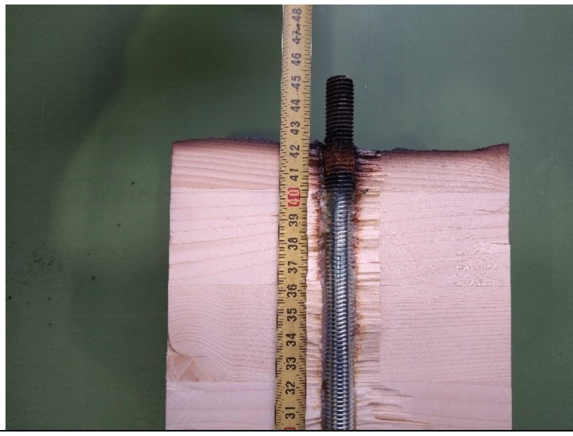
4





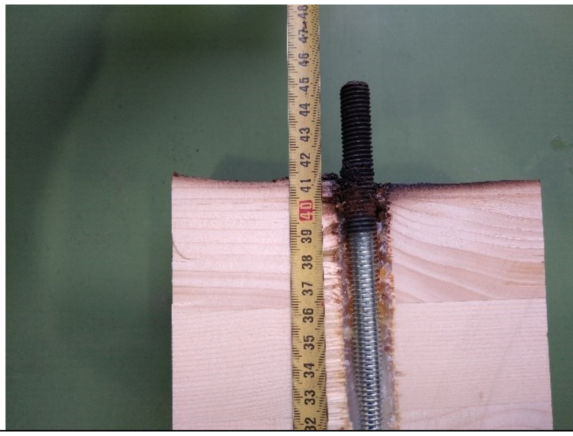
12_6

1

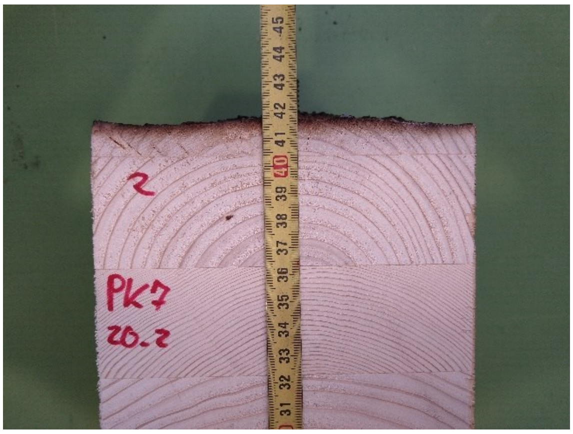
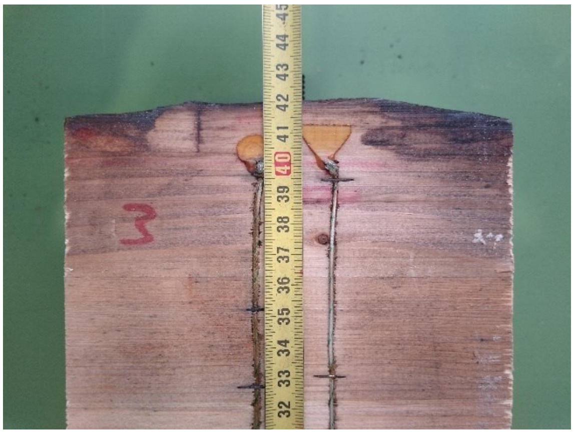
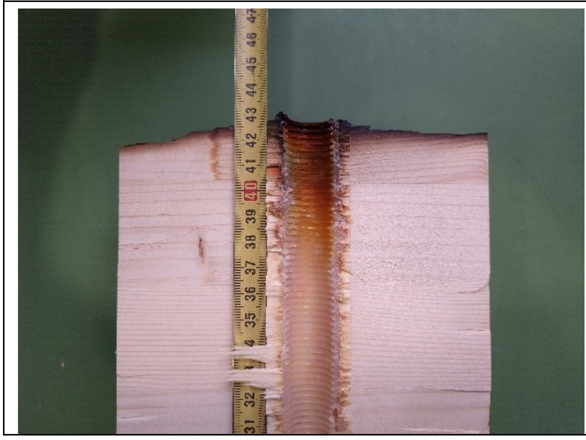
2

3

4



20_2

 1	 2
 3	 4
	

20_6

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2

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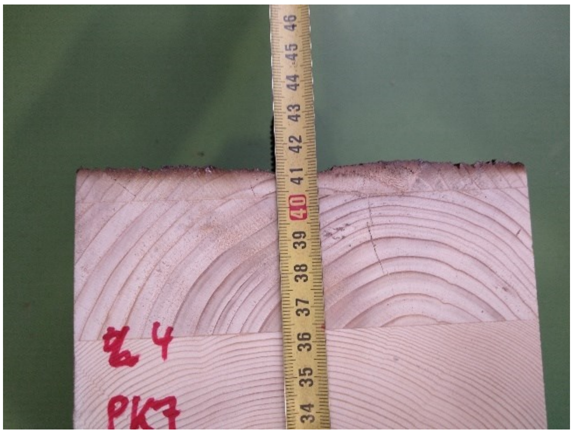

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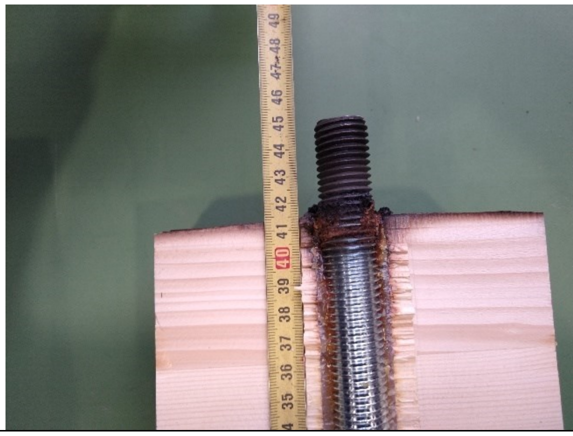
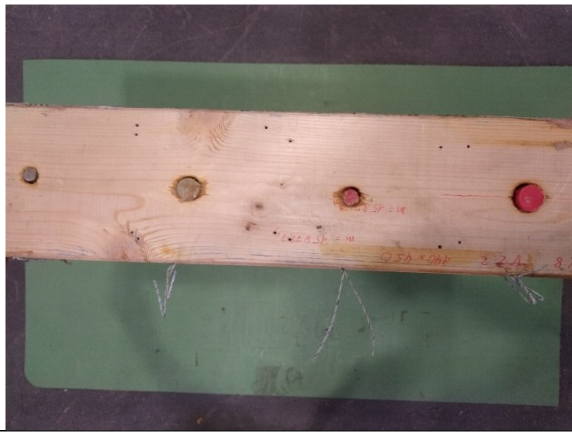


C.4.8 SP8



12_2

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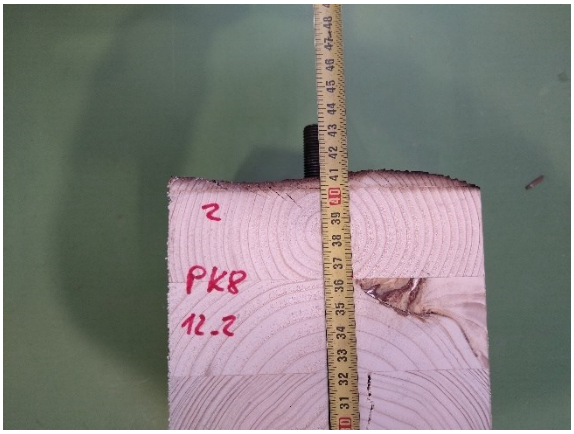

2

3

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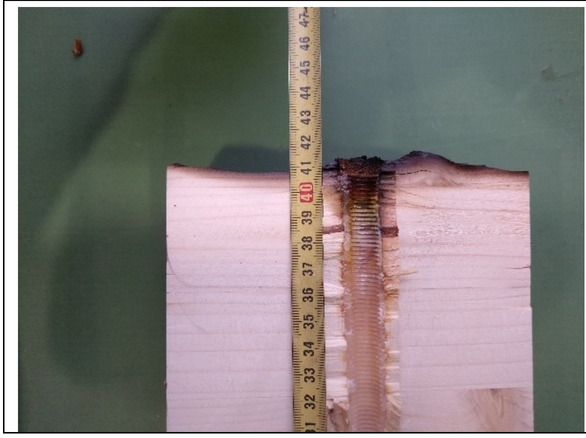
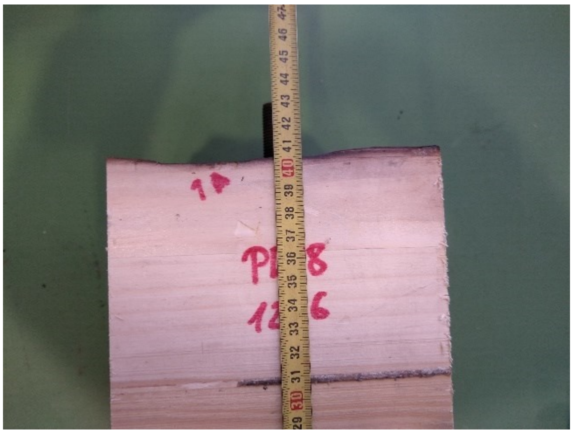


12_6



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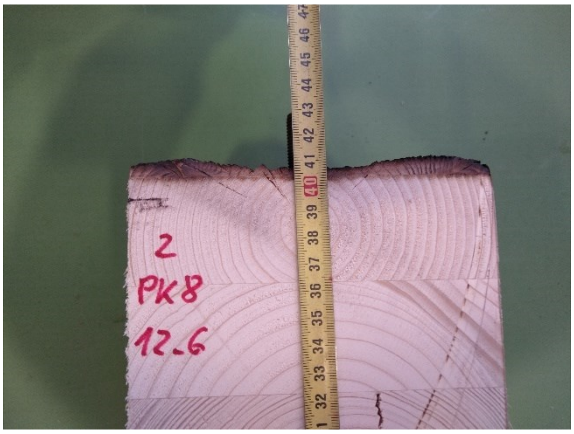

2

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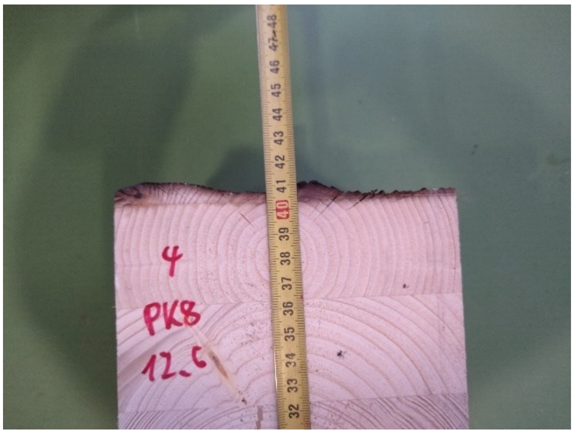

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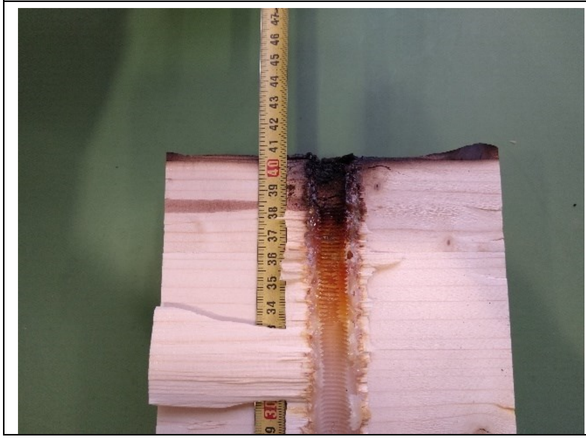

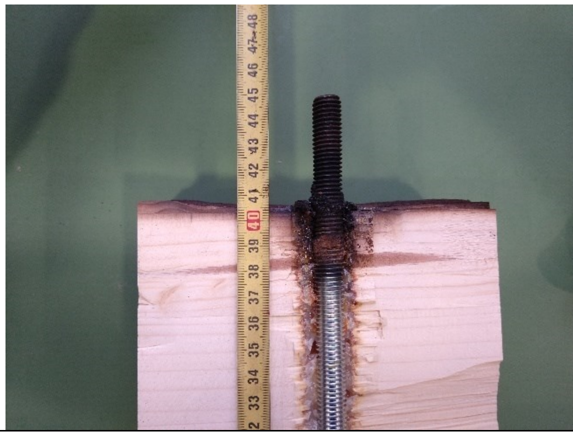

20_2

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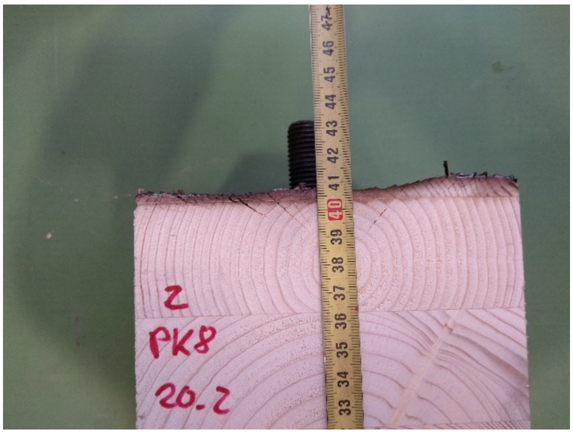
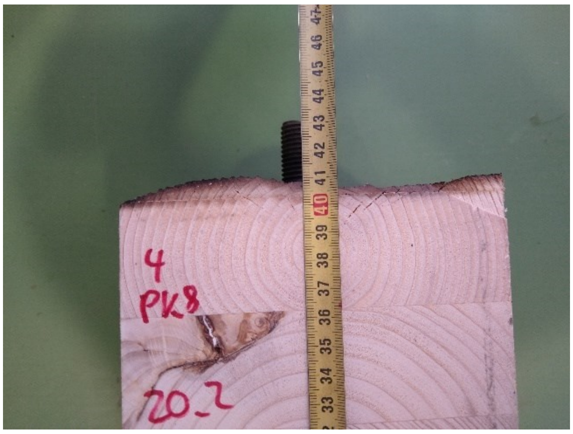


2

3



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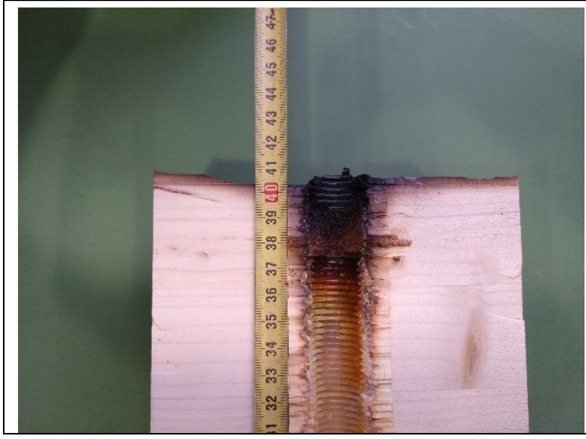
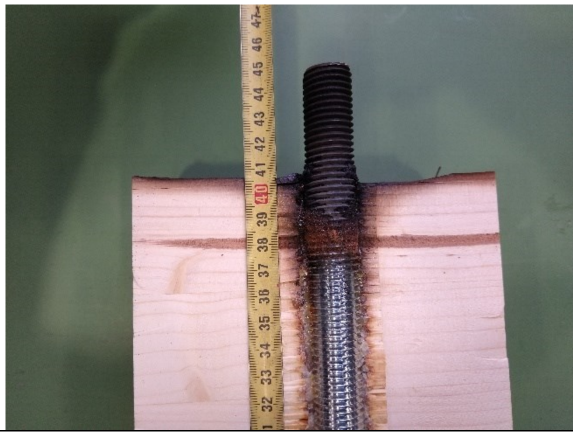
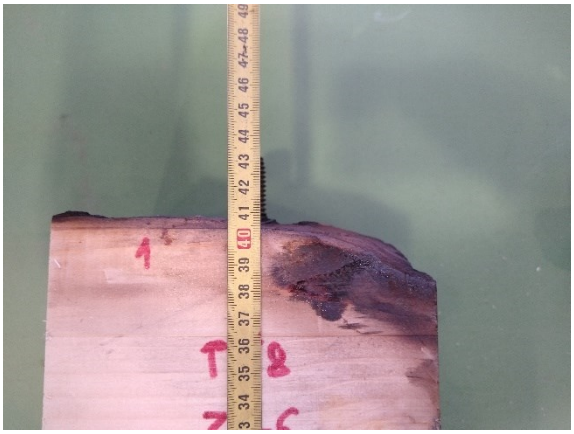




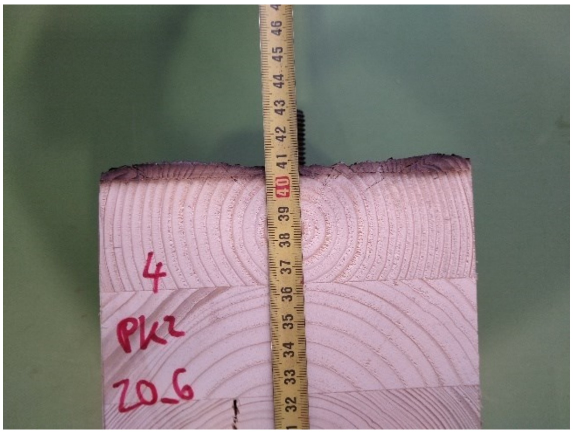
20_6



1

2

3



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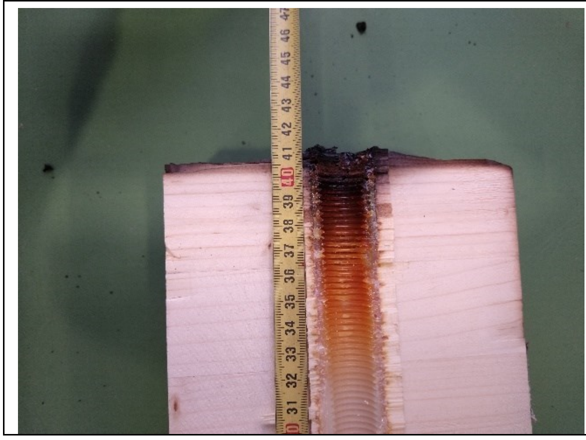

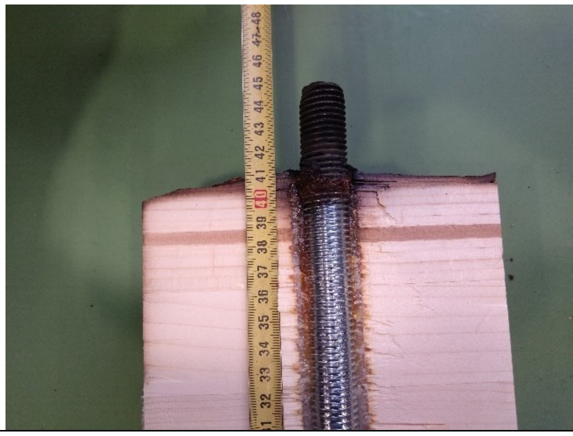

C.5 Temperature curves

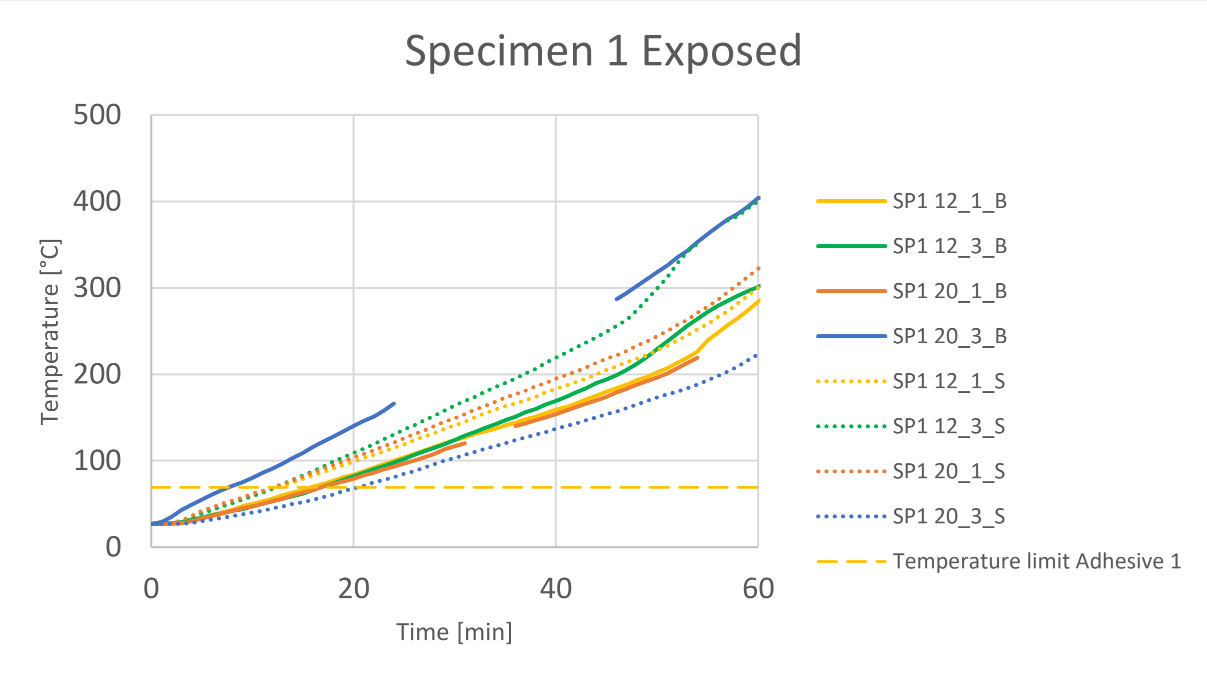

Figure 53: Temperature curves for specimen 1 of test series 2.2 on the side exposed to fire

Figure 54: Temperature curves for specimen 1 of test series 2.2 on the side unexposed to fire

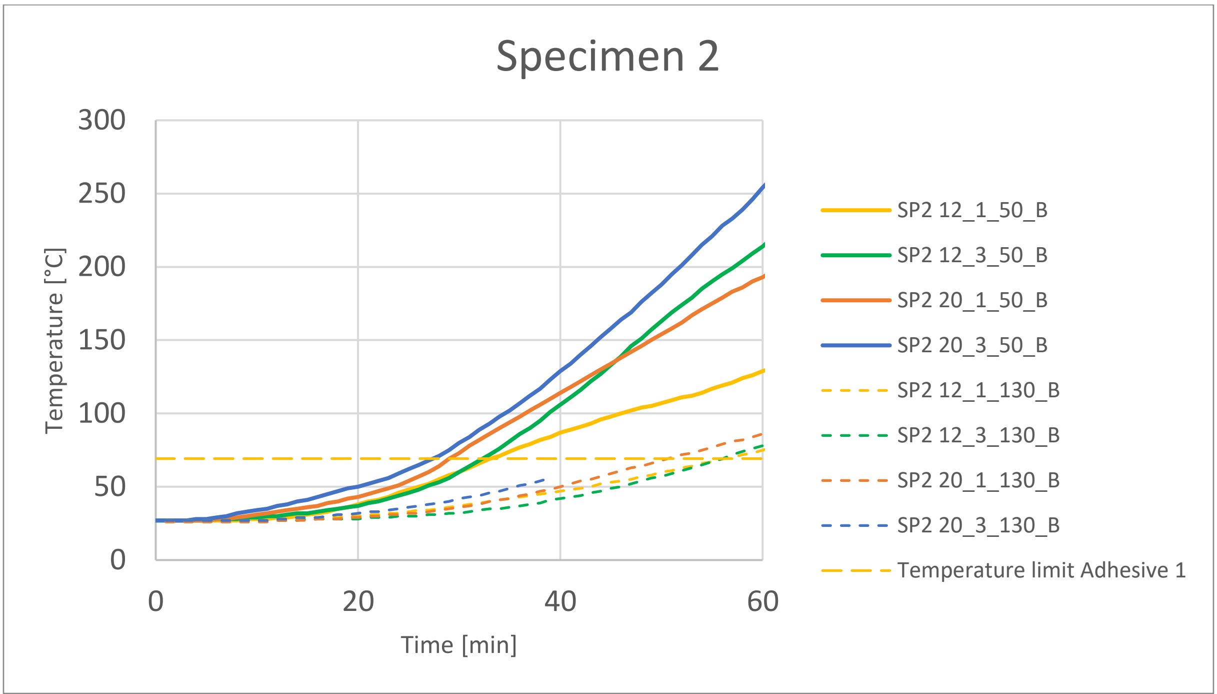

Figure 55: Temperature curves for specimen 2 of test series 2.2

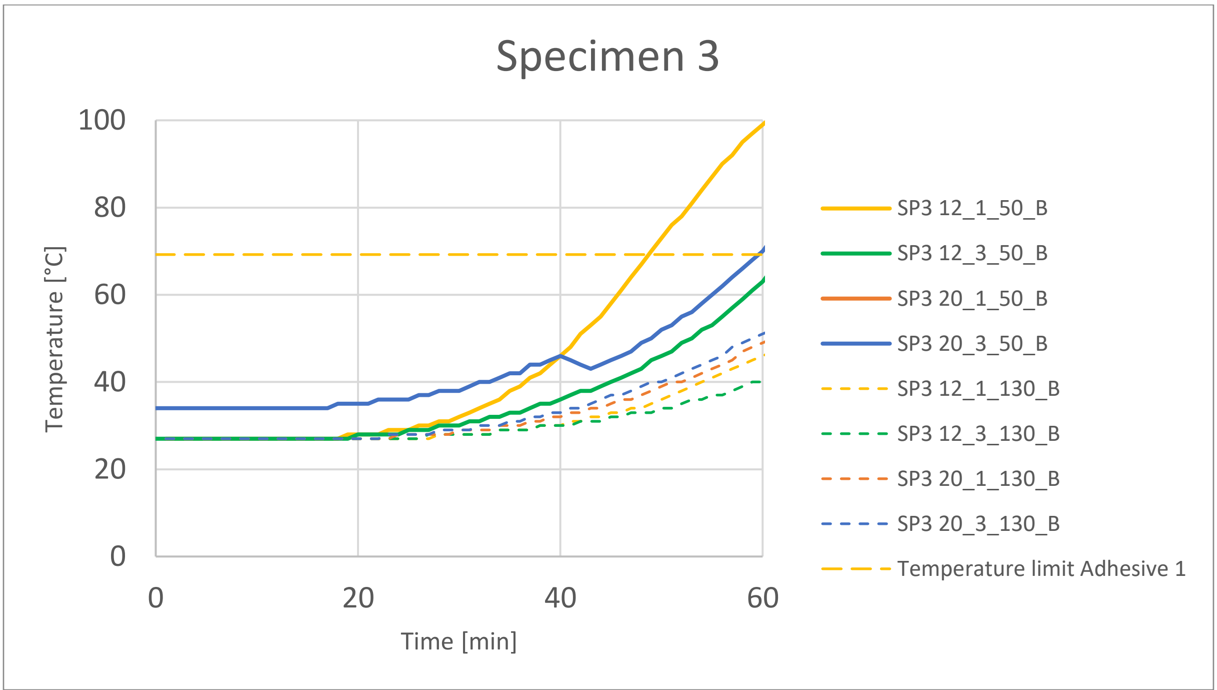

Figure 56: Temperature curves for specimen 3 of test series 2.2

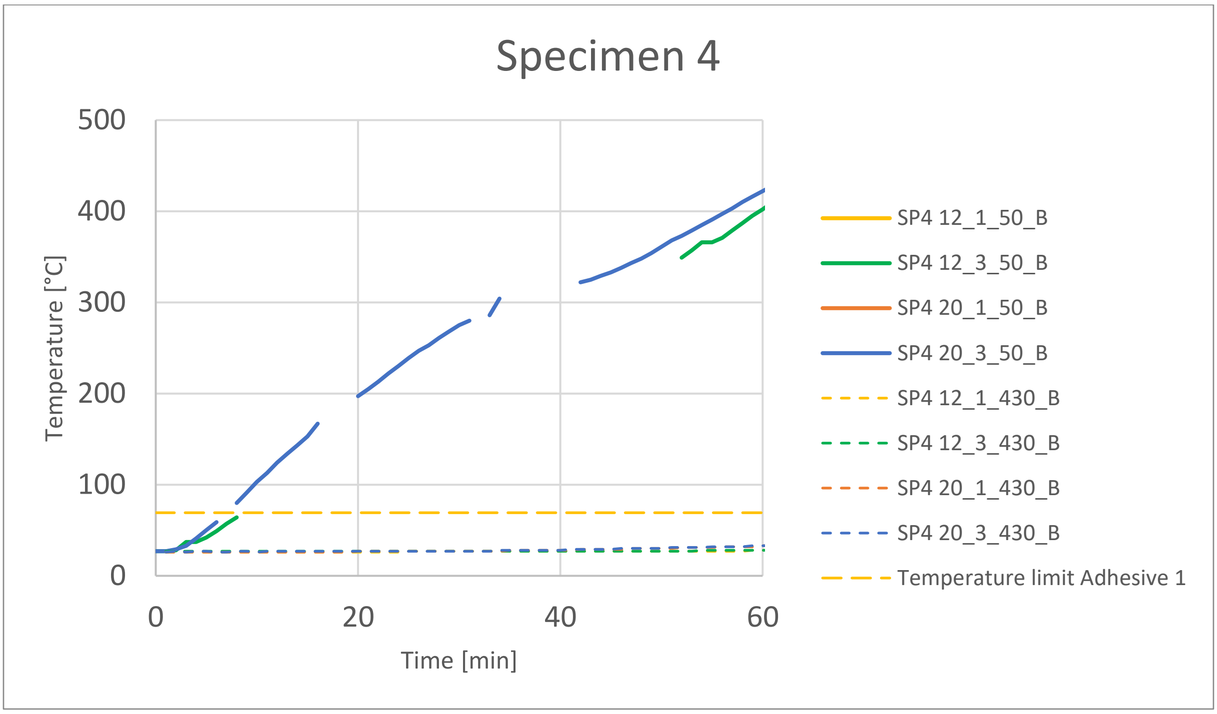

Figure 57: Temperature curves for specimen 4 of test series 2.2

Figure 58: Temperature curves for specimen 5 of test series 2.2

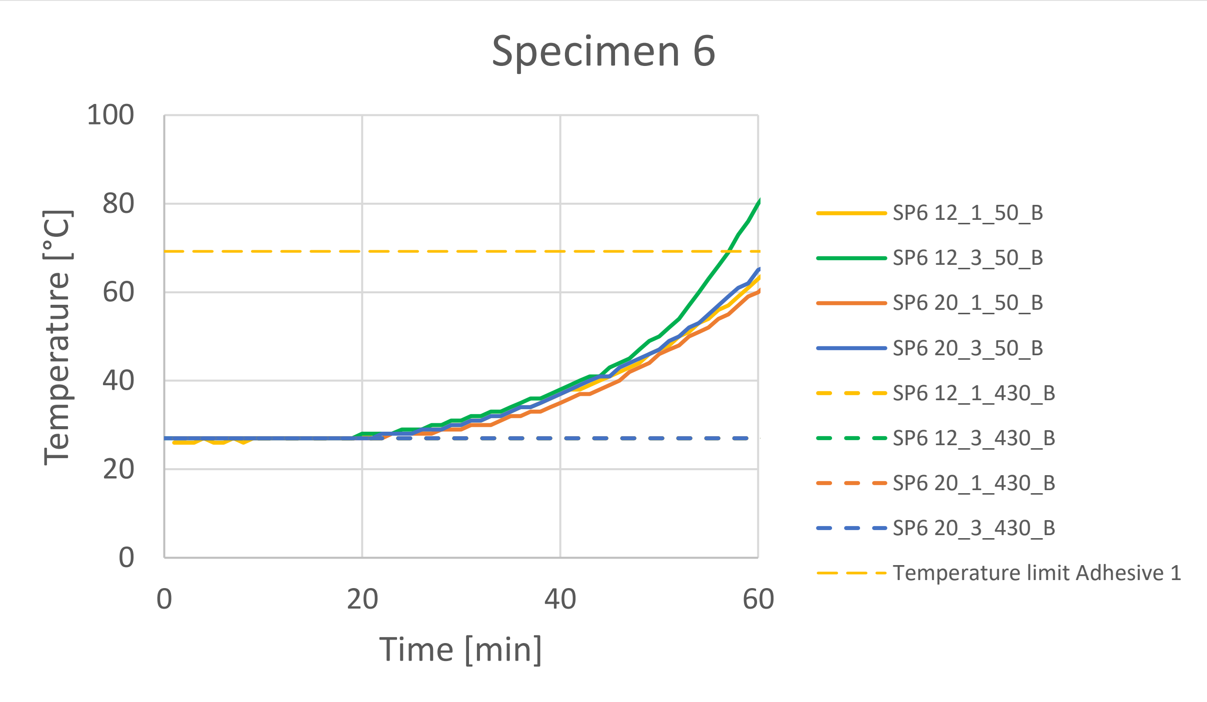

Figure 59: Temperature curves for specimen 6 of test series 2.2

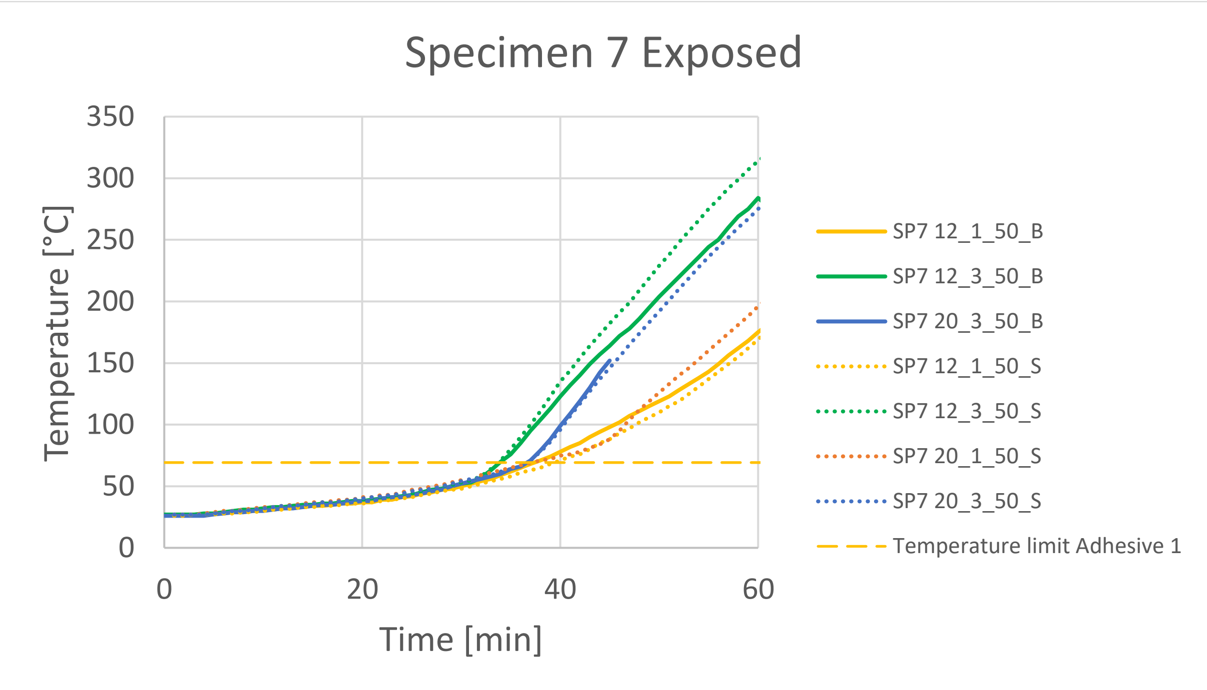

Figure 60: Temperature curves for specimen 7 of test series 2.2 on the side exposed to fire

Figure 61: Temperature curves for specimen 7 of test series 2.2 on the side unexposed to fire

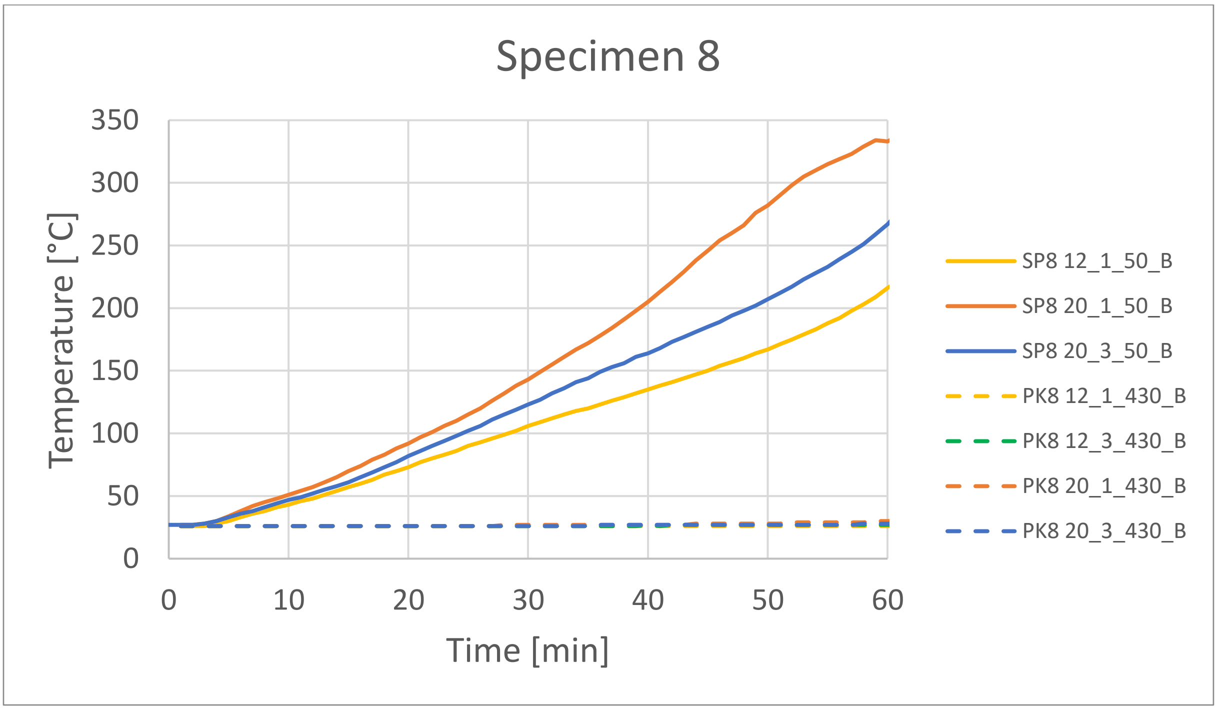

Figure 62: Temperature curves for specimen 8 of test series 2.2

C.6 Failure Thermocouple

Table 12: Failure and details of measuring points in test series 2.2

Test series 2.2			**Measuring Point**	
Specimen	Number	Board number	Partial failure	Failure
1	20_3_50_B	7	2	1
	20_3_130_B	8		
	20_3_50_S	9		
	20_3_130_S	10		
	12_3_50_B	11		
	12_3_130_B	12		
	12_3_50_S	13		
	12_3_130_S	14		
	20_1_50_B	15		
	20_1_130_B	16		
	20_1_50_S	17		
	20_1_130_S	18		
	12_1_50_B	19		
	12_1_130_B	20		
	12_1_50_S	21		
	12_1_130_S	22		
2	20_3_50_B	23	1	0
	20_3_130_B	24		
	12_3_50_B	25		
	12_3_130_B	26		
	20_1_50_B	27		
	20_1_130_B	28		
	12_1_50_B	29		
	12_1_130_B	30		
3	20_3_50_B	31	0	1
	20_3_130_B	32		
	12_3_50_B	33		
	12_3_130_B	34		
	20_1_50_B	35		
	20_1_130_B	36		
	12_1_50_B	37		
	12_1_130_B	38		
4	20_3_50_B	39	2	2
	20_3_430_B	40		
	12_3_50_B	41		
	12_3_430_B	42		
	20_1_50_B	43		
	20_1_430_B	44		
	12_1_50_B	45		

	12_1_430_B	46		
5	20_3_50_B	47	2	0
	20_3_430_B	48		
	12_3_50_B	49		
	12_3_430_B	50		
	20_1_50_B	51		
	20_1_430_B	52		
	12_1_50_B	53		
	12_1_430_B	54		
6	20_3_50_B	55	0	0
	20_3_430_B	56		
	12_3_50_B	57		
	12_3_430_B	58		
	20_1_50_B	59		
	20_1_430_B	60		
	12_1_50_B	61		
	12_1_430_B	62		
7	20_3_50_B	63	2	1
	20_3_430_B	64		
	20_3_50_S	65		
	20_3_430_S	66		
	12_3_50_B	67		
	12_3_430_B	68		
	12_3_50_S	69		
	12_3_430_S	70		
	20_1_50_B	71		
	20_1_430_B	72		
	20_1_50_S	73		
	20_1_430_S	74		
	12_1_50_B	75		
	12_1_430_B	76		
	12_1_50_S	77		
	12_1_430_S	78		
8	20_3_50_B	79	0	0
	20_3_430_B	80		
	12_3_50_B	81		
	12_3_430_B	82		
	20_1_50_B	83		
	20_1_430_B	84		
	12_1_50_B	85		
	12_1_430_B	86		
	Number	80	9	5
			0,1125	0,0625

D Test series 2.3

D.1 Glue date

Table 13: Gluing details in test series 2.3

Specimen	Glue date	Time
211	21.06.2021	12:00-12:10
212	21.06.2021	12:00-12:10
231	21.06.2021	12:00-12:10

D.2 Density

Table 14: Density in test series 2.3

SP number	Timber							Borehole		Rod	
	QS [mm]		Length [mm]	Side 1		Side 2					
				Mass [g]	Density [kg/m³]	Mass [g]	Density [kg/m³]	Diameter [mm]	Length [mm]	Diameter [mm]	Length [mm]
211	60	60	500	850,6	472,6	857,8	476,6	14	162	12	324
212	100	100	500	2169,4	433,9	2141	428,2	14	162	12	324
231	100	100	500	2116	423,2	2218	443,6	22	164	20	328

D.3 Failure Thermocouple

Table 15: Failure and details of measuring points in test series 2.3

Specimen	Number	Board number	Partial failure	Failure
211	A	1	1	1
	B	2		
212	A	3	0	0
	B	4		
231	A	5	0	0
	B	6		
	Number	6	1	1
			0,17	0,17