Fire-protective textiles for cultural historic objects

Part 3 of the BraTeK project

RISE REPORT 2024:19

Ragni Fjellgaard Mikalsen
RISE Fire Research

Nina Kjølsen Jernæs
NIKU

Hanne Moltubakk Kempton
Hovedorganisasjonen KA

Fire-protective textiles for cultural historic objects (BraTeK project)

Ragni Fjellgaard Mikalsen (RISE Fire Research), Nina Kjølsen Jernæs (NIKU) and Hanne Moltubakk Kempton (Hovedorganisasjonen KA)

Summary

Fire-protective textiles for cultural historic objects (the BraTeK project), part 3

This report describes the experimental study in the BraTeK (Brannbeskyttende tekstiler for kulturhistoriske objekter) project part 3. A method for small-scale exposure of radiative heating followed by water exposure has been developed to imitate the scenario of a church fire with water extinguishing. Six textiles have been evaluated by their heat and water properties for fire-protection of cultural historic objects. The overall conclusion for each textile shows that two were ranked as good, three as intermediate and one as poor. The similarity of the two materials ranked as "good" is an aluminium layer on the exposed side. Combined with the results from BraTeK part 1 and 2 (NIKU reports), the conclusions from this report may support the owners' choice of fire-protective textiles.

Sammendrag

Brannbeskyttende tekstiler for kulturhistoriske objekter (BraTeK prosjektet), del 3

Denne rapporten beskriver den eksperimentelle studien i BraTeK (Brannbeskyttende tekstiler for kulturhistoriske objekter) prosjekets del 3. Det er utviklet en metode for småskala eksponering av strålevarme etterfulgt av vanneksponering for å imitere scenarioet med en kirkebrann som inkluderer slokking med vann. Seks tekstiler er evaluert med hensyn på deres varme- og vannbeskyttende egenskaper for beskyttelse av kulturhistoriske gjenstander. Den samlede konklusjonen for hvert tekstil viser at to ble rangert som gode, tre som middels og én som dårlig. Begge tekstilene som er rangert som gode har et aluminiumslag på eksponert side. Kombinert med resultatene fra BraTeK del 1 og 2 (NIKU-rapporter), kan konklusjonene fra denne rapporten støtte eiernes valg av brannverntekstiler.

Key words:
Fire, heritage, inventory, church, fire blanket, fire covers, protection, mitigation, experiment.
Brann, kulturminner, inventar, kirke, brannteppe, branntildekking, beskyttelse, innsats, eksperiment.

RISE Research Institutes of Sweden AB

RISE-report 2024:19
ISBN: 978-91-89896-22-2
Project number: 20590-3
Quality assurance: Anne Steen-Hansen
Funded by: The Directorate for Cultural Heritage in Norway (Riksantikvaren) and the Confederation of Churches and Nonprofits (Hovedorganisasjonen KA).
Cover image: Illustration of the use of fire-protective textile in a church, photo: Mona Hauglid.
Trondheim 2024

Innhold

1. Introduction

1.1. Background and literature

BraTeK part 1 was carried out in 2020, as a pre-project to map the status of fire-protective textiles for cultural historic objects. The results from the study is presented in NIKU report 143/2020 [1]. The main findings in part 1 of the study was a first survey of how fire-protective textiles might be a part of an overall safety picture, and how the textiles can be used. The survey was sent to personnel with responsibilities within fire advice, operations, security or collection management – related to museums and owners and managers of cultural and historical properties, including also voluntary organizations and larger state managers of historic buildings. A survey of their use in Norway, Sweden, Denmark, England and Scotland shows that very few organisations use fire-protective textiles as part of preventive routines at their historic buildings or for use in a value recovery effort. The undertaken literature study shows that there is little published information about the topic. Many of those we have been in contact with are positive to the potential of having fire-protective textiles to minimize damage from fire and water, and many want increased focus and knowledge in the area. Part 1 of the study concludes that there is a need for further work, and it should involve experiments with textiles that can give some answers on heat-insulating and water-repellent properties, as well as handling properties and material stability.

BraTeK part 2 was carried out in 2021, and included experiments to demonstrate the handling, insulation and water protective properties of the textiles, with assistance from three Norwegian fire services. The experimental results in terms of insulation and water protective were indicative due to the inherent uncertainties in the experimental set-up, but provided a basis for the laboratory experiments in part 3. The results and literature review from part 1 and 2 of the study are presented in NIKU report 109/2021 [2], and in a scientific article in the journal *Studies in Conservation* [3] and as a poster at the IAFSS 2023 conference [4]. The main findings in part 2 of the study can be summarised as follows: The goal was to survey the possibilities for using large format textiles to protect historic items from fire and/or water damage. The experiments were divided into three parts, focusing on manageability and handling properties, protection from heat and protection from water. The conclusion from the experiments indicates that three of the studied fire-protective textiles can indeed provide good protection and reduce the risk for damage on historical items if used by the fire brigade in an emergency. The report includes some advice for owners and managers of historic buildings who plan to buy fire-protective textiles for the purpose described.

BraTeK part 3 has been carried out in 2023 and the experimental method and results are presented in this report. The report also presents a discussion of the implications of the results for the manager's and owners' choice of fire-protective textiles in historic buildings, focusing on churches. The results are also relevant for historic building or cultural institutions such as museums or archives.

1.2. Objectives and hypotheses

The objective of BraTeK part 3 is to increase our knowledge about relevant textiles for fire-protective of cultural heritage objects. The undertaken experiments in part 2 in 2021 formed the basis for carrying out experiments on the textiles that came out best in terms of on-site protective and handling properties. The objective is to study the ability of each textile to protect against heat and water exposure. Based on the study, it should be possible to make recommendations for the owners and managers of heritage buildings and churches that want to buy covers to protect heritage objects from heat and water.

The following hypotheses are studied experimentally:

1. Differences in insulation properties can be demonstrated through measurement of temperatures on the unexposed side of the textiles, with a significant difference in the measured temperature increase and stabilization temperature on the unexposed side.
2. Higher heat stress will damage the fire-protective textiles more than lower heat stress, to an extent that is visually observable after the exposure.
3. It is possible to distinguish between different fire-protective textiles in their water protective properties, with a significant difference in the amount of water penetrating through the textile after the heat exposure with the given experimental procedure.

1.3. Scenario

The scenario in this study is a fire in a church room in which there is one or more cultural historic objects that are too large, heavy, or for other reasons cannot be removed during the fire. To save them from being damaged by the fire, and by the extinguishing efforts, the object is to be covered by a fire-protective textile, as illustrated in Figure 1-1 and Figure 1-2. The textile should be taken out of its packaging, unfolded and placed on top of the object by the fire service. The textile will after this be left in place until the fire is extinguished. The fire in the scenario is at some distance from the object, so the object is exposed only to heat and not direct flame contact. The textile should first protect the cultural historic object from heat, and then from water coming either from an installed water-based suppression system, or from extinguishing efforts by the fire and rescue service.

Figure 1-1 Illustration of the use of fire-protective textile to protect a small (top) and a large (bottom) object in a church. The photo is taken in Øyestad medieval church with fire officers from the Østre Agder fire service. Smoke is added digitally. Photo: Mona Hauglid.

1.4. Limitations

For each scenario and material three repetitions were made. Increasing the number of repetitions would have given a lower uncertainly of the results.

Fire exposure by radiation (heat) is considered in this study, and the textiles are not exposed to direct flame contact.

The method for documentation of water protective properties is not based on a standardized test method, but is designed for this purpose. The repeatability and reproducibility of the method is therefore not documented.

1.5. Ethical aspects

For BraTeK part 3 there is no collection of personal sensitive information, there is no health exposure of personnel or other ethical aspects that need to be considered.

The suppliers were chosen based on evaluation of results from part 2 of this study. Additionally, there was one material that was ranked as poor/failed in part 2 for unknown reasons, and the supplier was invited to be a part of the laboratory experiments. All suppliers got the same information on beforehand and were invited to choose the material that could show the best performance.

1.6. Project group

The project group consisted of representatives from The Norwegian Institute for Cultural Heritage Research (NIKU, Nina Kjølsen Jernæs), the Norwegian Association for Church Employers (Hovedorganisasjonen KA, Hanne Moltubakk Kempton) and RISE Fire Research (Ragni Fjellgaard Mikalsen, Morten Daffinrud and Anne Steen-Hansen). There was no reference group in part 3 of the project.

1.7. Funding

BraTeK part 1 was funded by the Directorate for Cultural Heritage in Norway (Riksantikvaren).

BraTeK part 2 was funded by the Norwegian Association for Church Employers (Hovedorganisasjonen KA), Knif Insurance (Knif Forsikring), the Directorate for Cultural Heritage in Norway and in Sweden (Riksantikvaren og Riksantikvarieämbetet).

BraTeK part 3 is funded by the the Norwegian Association for Church Employers (Hovedorganisasjonen KA) and the Directorate for Cultural Heritage in Norway (Riksantikvaren).

2. Methods and materials

In this section, the materials and method used in this study are described. The background for the choice of method and development of the final experimental procedure are described in Appendix A. The experimental method imitates the scenario of a church fire (heat exposure) followed by extinguishing efforts (water exposure) described in section 1.3.

2.1. Material

Six types of textiles were included in this part of the study. Three of the textiles (number 2, 3 and 4) are identical as textiles used in BraTeK part 2, see NIKU report 109/2021 [2]. They were chosen based on good handling, heat and water protective properties in the large-scale demonstrations, as described in the report. For the products that were sub-optimal in part 2, the suppliers were contacted and given the option to provide other textiles. One supplier (number 5) made a modified textile for use in the current study, and one supplier chose to use another of their already existing product types (number 1). In addition, a welding protection textile from a commercially available supplier was included (number 6), based on promising results in the pre-study (see Appendix A).

Table 2-1 Overview of the six fire-protective textiles in this study.

Material number	1	2	3	4	5	6
Supplier	Bridgehill	Vitrea	Hiltex	Dale Intertec	Insulcon	TESS/ Industri-spesialisten
Product name by supplier	Heat Block Fire Sail	Svetsduk EGF550 S2-60	Preox-Para-Aramid fabric	Paratec Extreme HT S4	Insulcloth 600 SP FR 1xSC Black	Sveiseduk GW650AL
Area density, measured (g/m^2)	506	528	342	669	973	635
Area density, from supplier (g/m^2)	430	550	350	565	770	650*
Thickness, measured (mm)	0.639	0.419	0.530	0.425	0.945	0.642
Thickness, from supplier (mm)	0.500	0.430	0.540	0.400	0.700	Not given

Material number	**1**	**2**	**3**	**4**	**5**	**6**
Material type (s), as given by the supplier	100% Quartz with 450 gsm combined with reflecting alufoil	E-glas, silicone coating	Preox + Para-aramid + aluminium foil	HT fibre blend containing glass, silicone coating	Silika glass	Silver aluminium fiberglass
Exposed side description	Aluminium	Semi-dark grey	Aluminium/ shimmer	Light grey	Black	Aluminium
Unexposed side description	Shimmer light grey	Semi-dark grey	Grey/green	Light grey	Light grey	Off-white
Figure showing photos of material	Figure 3-5	Figure 3-6	Figure 3-7	Figure 3-8	Figure 3-9	Figure 3-10

* Assumed based on material name.

2.2. Experimental set-up for heat exposure

The experimental set-up for heat exposure is based on the ISO 5660 cone calorimeter method [5]. The textile was placed in a specimen holder, backed with refractory fibre blanket insulation (thickness ca. 50 mm, nominal density 65 kg/m^3). An encapsulated thermocouple type K (0.5 mm thickness) was placed below the textile on top of the insulation, with the measurement position of the thermocouple touching the unexposed side of the textile (Figure 2-1). The specimen holder was placed horizontally under a radiative heat exposure of 20 kW/m^2 or 30 kW/m^2 for 10 minutes, after which the specimen was removed from the heat. The temperature on the unexposed side of the textile was recorded every second using an Agilent data acquisition unit. The ambient temperature in the room was between 19.1-20.6 °C.

During heat exposure, visual observations were recorded of any smoke formation or flaming ignition (examples in Figure 2-2). Notice that a material may have both smoke and flaming, as a material may first emit smoke, before the smoke gases (pyrolyzates) ignite into a flaming fire.

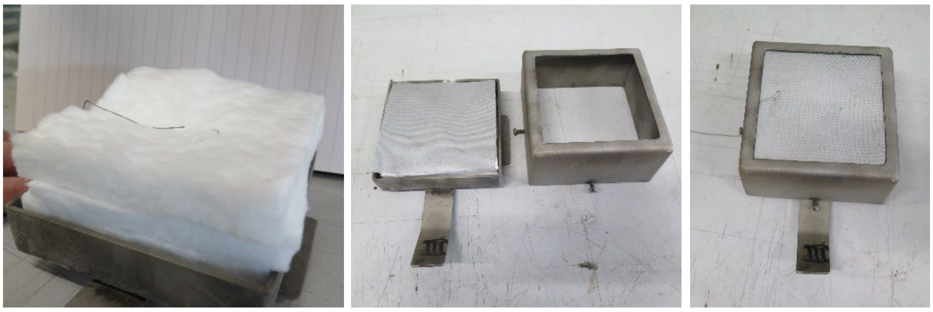

Figure 2-1 Specimen holder according to ISO 5660 with refractory fibre blanket insulation and thermocouple pointing upward towards the unexposed side of the textile (left), specimen holder with textile placed on top of the thermocouple (centre) and with the top cap in place (right).

Figure 2-2 During heat exposure, visual observations of smoke (left) and of flaming (right) were recorded.

2.3. Experimental set-up and procedure for water exposure

After heat exposure, the textile was placed onto a bent sieve, and a stainless-steel ring was placed firmly on top of the textile, giving the textile a concave shape. The orientation was the same in the heat and water exposure, with the side facing upwards being the heat exposed side.

A syringe (20 mL) filled with room temperature (18-25 °C) water was positioned 15 cm above the textile using a rack. Below the sieve was a bowl with a scale under, to document any water dripping into the bowl.

At 1 minute after heat exposure, the water was dripped onto the textile during 10 seconds. Visual observations were made during 5 minutes of any formation of droplets on the unexposed side of the textile. Finally, the textile was scratched firmly on side facing upwards using a 2 mm thick metal wire. Visual observations were made of any holes in the textile formed by the scratching, or of any formation of droplets on the unexposed side of the textile.

After this, the textile was removed from the sieve, observed visually, photographed and inspected using a B-350 Optica microscope, using 4x resolution.

Figure 2-3 The water exposure procedure: the textile was placed on a sieve, held in place with a metal ring, with the heat exposed side facing upwards. First adding of water (left), then waiting 5 minutes and observing any water penetration (centre), and finally scratching on the side facing upwards (right).

Figure 2-4 Visual observations of damage to the textile were made and photographed using a camera (1x zoom) and using a microscope (4x) with camera.

2.4. Handling

An ad-hoc handling demonstration was performed for one of the textiles, since this material was not included in part 1 and 2 of the study. The textile was unfolded, placed over a small (0.5 meter high) and an intermediate size (1 meter high) object, and the handling properties was qualitatively evaluated.

3. Results from main experimental study

In September 2023, the main part of this experimental study was performed. For each of the six textiles, three repetitions were made at each of the two heat exposure levels (20 kW/m^2 and 30 kW/m^2). In total, 36 experiments were performed, 18 at each heat exposure level.

3.1. Temperature results

In this section, the temperature data from the heat exposure is presented. A representative, example series for one material is shown in Figure 3-1, with the temperature profile for each of three repetitions, as well as the average temperature shown. The temperature average is calculated and shown for each second. Starting at ambient temperature, the temperatures increase, towards a temperature at which it stabilizes (hereby called *stabilization temperature*) and is more or less constant till the end of the experiment. For some experiments, the temperature never stabilizes at a constant temperature, but reaches a stage when the *increase* is slower than at the start. The spread in the data between repetitions is smallest in the start, and periodically up to ~40 °C difference between the lowest and the highest measurement. This is important to notice when comparing different materials, as an apparent difference may only be coincidental, if the temperature differences are not too large.

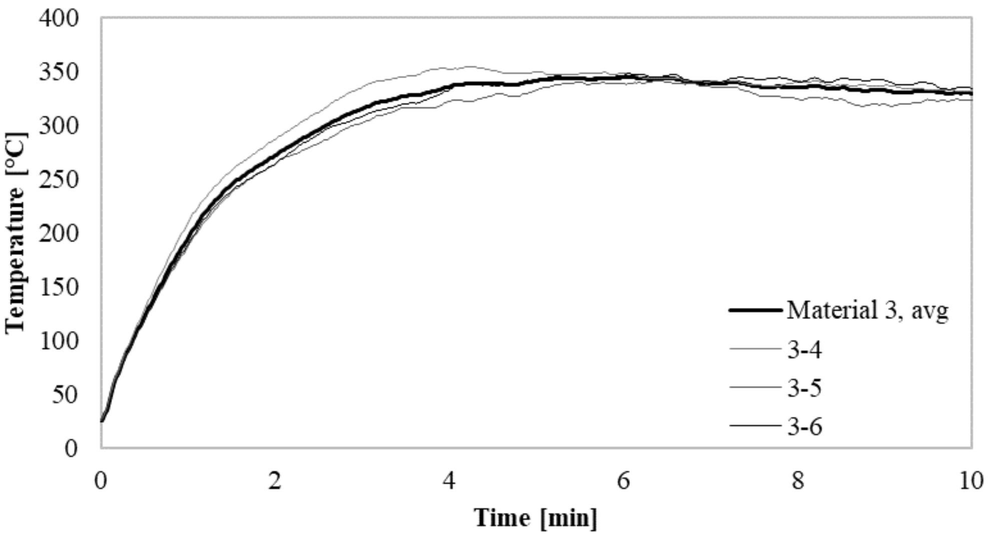

Figure 3-1 Temperature as function of time for an example series, three repetitions and the average of these, for material 3 at 30 kW/m^2.

The average temperature as function of time for each material is presented in Figure 3-2. Both heat exposure levels show similar temperature trends. The highest heat exposure gives highest temperatures on the unexposed side, as expected. The results indicate that the textiles may be divided into three groups. Material 1 and 6 have the slowest temperature increase and reaches the lowest temperatures (~130/190 °C for respectively 20 kW/m^2 and 30 kW/m^2) on the unexposed side, and no smoke observed. These are also the two materials with an aluminium layer on the exposed side. Material 3 has an aluminium/shimmer-material on the exposed side, which was somewhat different in appearance than material 1 and 6. Material 3 has an intermediate temperature increase and stabilization temperatures (~260/330 °C). This material had the largest difference between the two exposure levels, in that it had no smoke emission and limited textile damage (see section 1.14) at 20 kW/m^2, and smoke emission and more extensive textile damage at 30 kW/m^2. Material 2, 4 and 5 have the most rapid temperature increase and stabilizes at the highest temperatures (~420-450/515 °C) on the unexposed side, and all had smoke emission at both heat exposure levels.

Only one material obtained flaming ignition. Material 5 had flaming ignition for all three repetitions at the highest heat exposure level. This is reflected in the measured temperatures, peaking significantly higher than those with no flaming, with peak temperature on the unexposed side of the textile of 681 °C, 671 °C and 662 °C for the three repetitions.

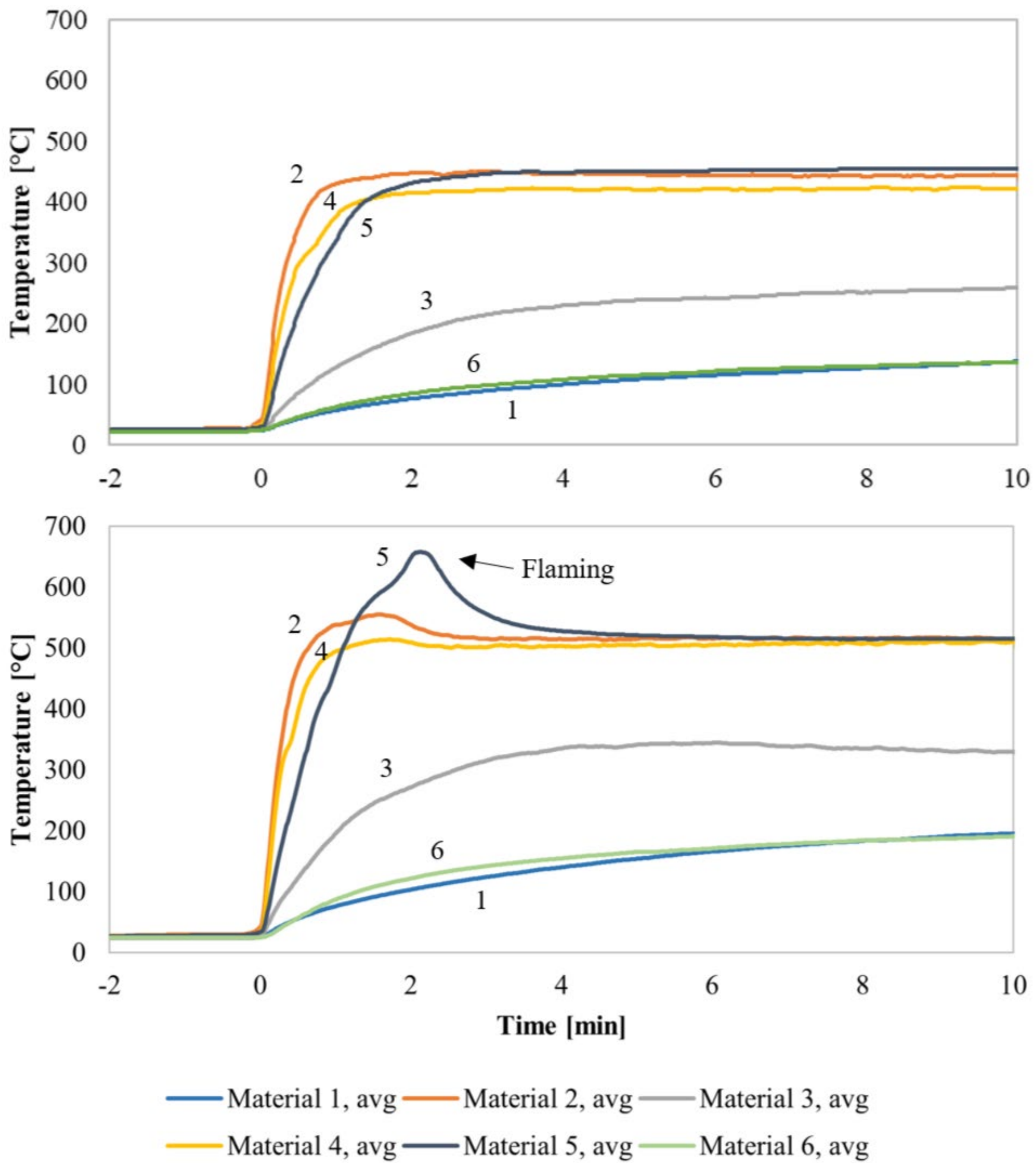

Figure 3-2 Temperature as function of time, for material number 1-6, given as temperature averages of three repetitions every second, for heat exposure 20 kW/m^2 (top graph) and 30 kW/m^2 (bottom graph).

The temperature average at 1, 2, 5 and 10 minutes is presented in Figure 3-4, also showing the standard deviation between the three repetitions. The relatively small standard deviations, means that the apparent differences between the three groups of materials from Figure 3-2 described above most likely are real differences.

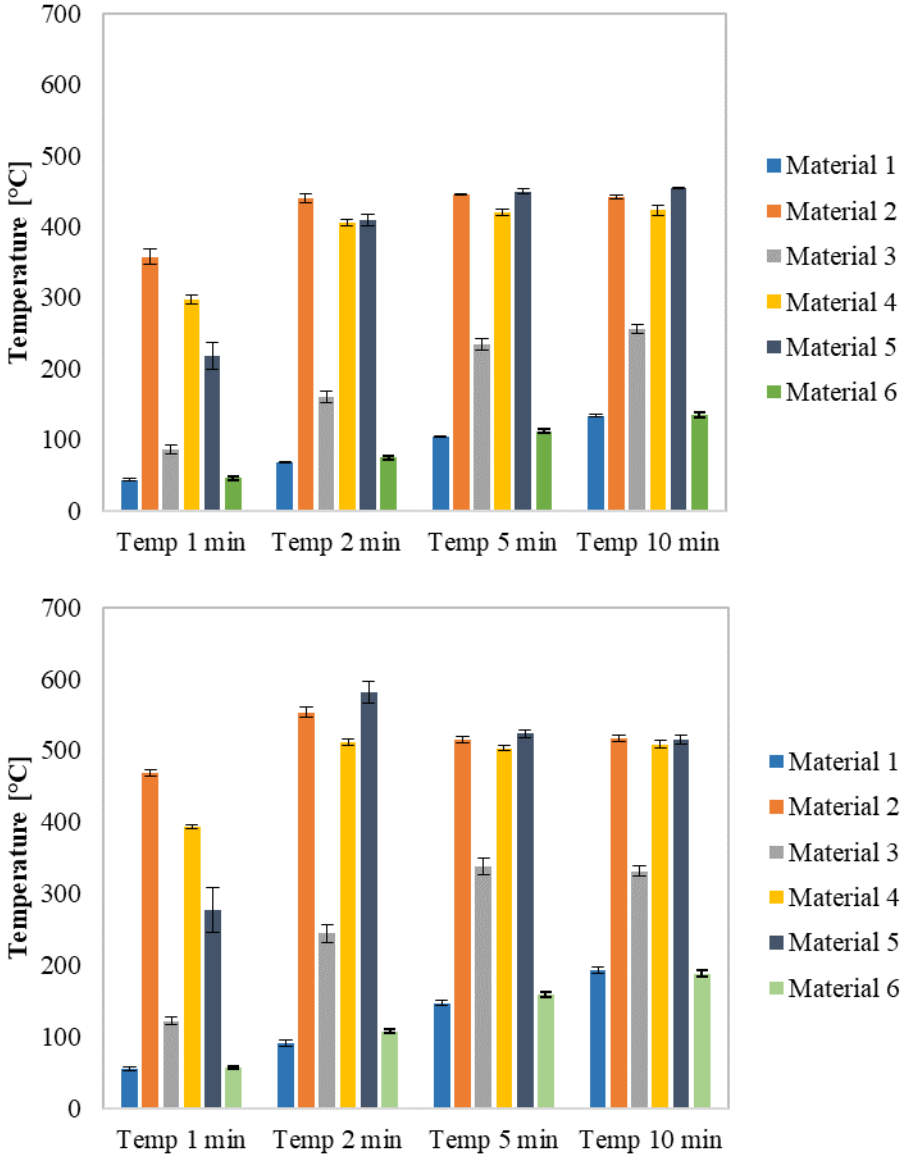

Figure 3-3 Temperature averages and standard deviations between the three repetitions for each material at 1, 2, 5 and 10 minutes, for heat exposure 20 kW/m^2 (top graph) and 30 kW/m^2 (bottom graph).

High temperature development combined with smoke or flaming gives a poor overall score for heat exposure, and opposite for low temperatures and no smoke or flaming. The results from the heat exposure for each textile is summarized in section 1.16. Each textile is given a score 1-3 depending on whether or not smoke or flaming were observed during the heat exposure. The overall trend of the temperature development on the unexposed side is also considered in the final conclusions for each textile, presented in Table 4-1.

3.2. Water penetration results

In this section, the results from the water exposure are presented. Each textile is given a score 1-3 for water penetration properties, with running water or large droplets on the unexposed side giving the poorest score. For most textiles, there was no water penetration during the water exposure. There were only two cases of water penetration in the study.

For material 1, at 20 kW/m^2, one of three repetitions had moisture on the unexposed side of the textile. The water had made the threading moist, and there was tangible moisture formation on the unexposed side. The main reason for the water penetration was that the surface layer of aluminium was fragile, combined with poorer water protection properties of the material below the aluminium. In the cases of material 1 where the top layer was intact, there was no water penetration, but if the fragile top layer was damaged (here by scratching), there was moisture formation on the unexposed side. This gave material 1 an intermediate score for water damage at this heat exposure level. Notice that the other textile with aluminium surface (material 6), did not show the same fragility.

For material 5, at 30 kW/m^2, all three repetitions had large droplet formation on the unexposed side of the textile (Figure 3-4). This gave material 2 a poor score for water damage at this heat exposure level. Material 5's poor water protection properties correspond with the observed damages to the textile (details in section 1.14), with observable damage to the textile allowing water to penetrate.

The results for the water penetration through each textile is summarized in section 1.16. Any penetration of water would be unfortunate for the cultural historic object below the textile, and this was emphasised in the final conclusions for each textile, presented in Table 4-1.

Figure 3-4 Example of droplet formation on the unexposed side of the textile, for material 5 after heat exposure of 30 kW/m^2. The observation was made while the textile was lying in the set-up, and lifted up here only for this illustration photo.

3.3. Damage to textile results

Damage to the textile was divided into three categories: colour change on the exposed side, colour change on the unexposed side and change in the texture of the textile, either observed manually or in the microscope. In general, the highest heat exposure level gave most damage to the textiles, as expected. Photos of the six textiles before and after the experiments are shown in Figure 3-5 to Figure 3-10. Evaluation of the damage to each textile is given in the figure captions. The evaluation is based on visual inspection of each textile, including scratching of the textile and observations in the microscope. Example microscope photos are shown in Figure 3-12 and Figure 3-13. The results from the observations of damages to the textiles are summarized in section 1.16. Colour changes on the exposed and unexposed side were noted for information, but only damages that caused water penetration had an impact on the final conclusions for each textile, presented in Table 4-1.

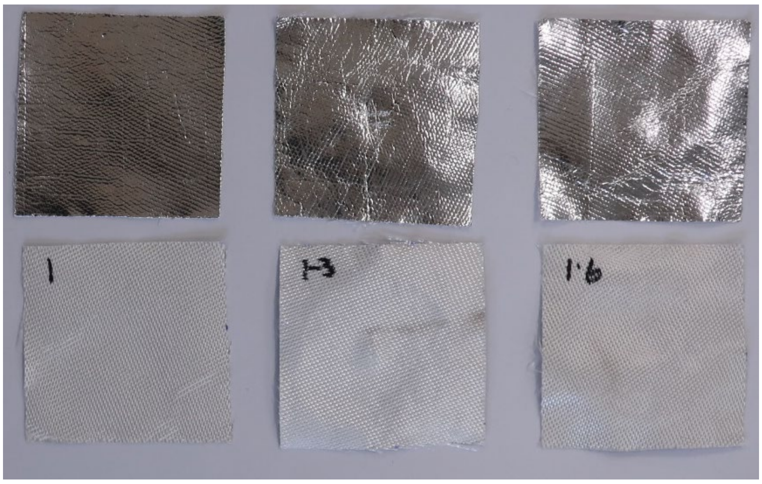

Figure 3-5 Material 1, exposed side (top) and unexposed side (bottom). Before (left), after 20 kW/m^2 heat exposure (centre) and after 30 kW/m^2 heat exposure (right). Evaluation: No colour change on the exposed or unexposed side, and no visible change in texture.

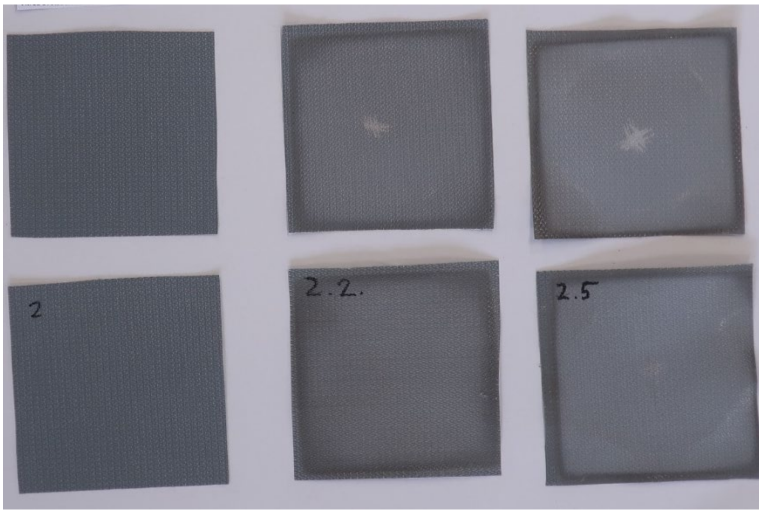

Figure 3-6 Material 2, exposed side (top) and unexposed side (bottom). Before (left), after 20 kW/m^2 heat exposure (centre) and after 30 kW/m^2 heat exposure (right). Evaluation: Colour change on the exposed and unexposed side, and some change in texture for both heat exposure levels (cracked, loose flakes, brittle coating, some fibres pulled up during scratching).

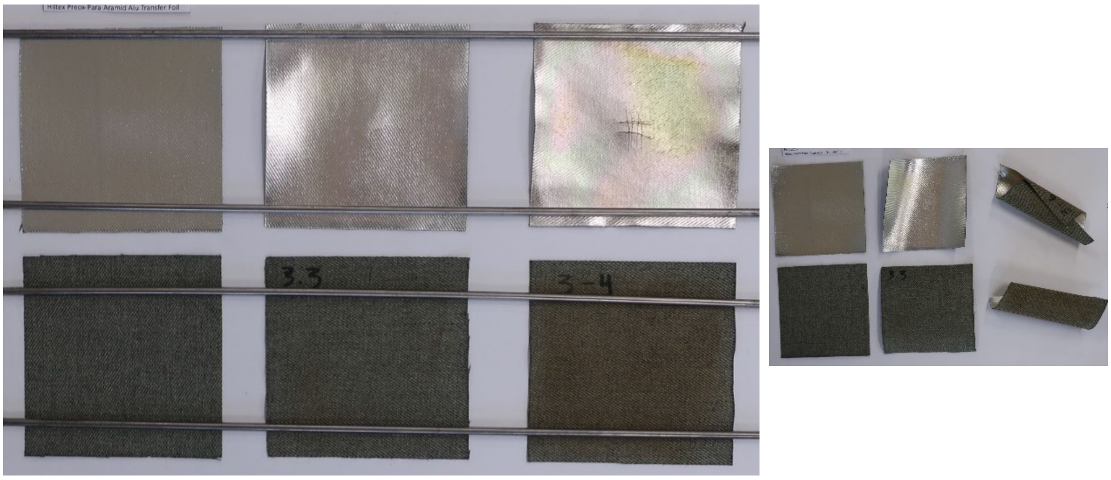

Figure 3-7 Material 3, exposed side (top) and unexposed side (bottom). Before (left), after 20 kW/m^2 heat exposure (centre) and after 30 kW/m^2 heat exposure (right). The metal rods are there to keep the textile flat, the small image shows how the textile looks with no support. The difference between the two heat exposure levels was also observed in the temperature development (section 1.12). Evaluation: Colour change on the exposed and unexposed side. No visible change in texture at the lowest heat exposure, and some change in texture at the highest heat exposure (the specimen curls up).

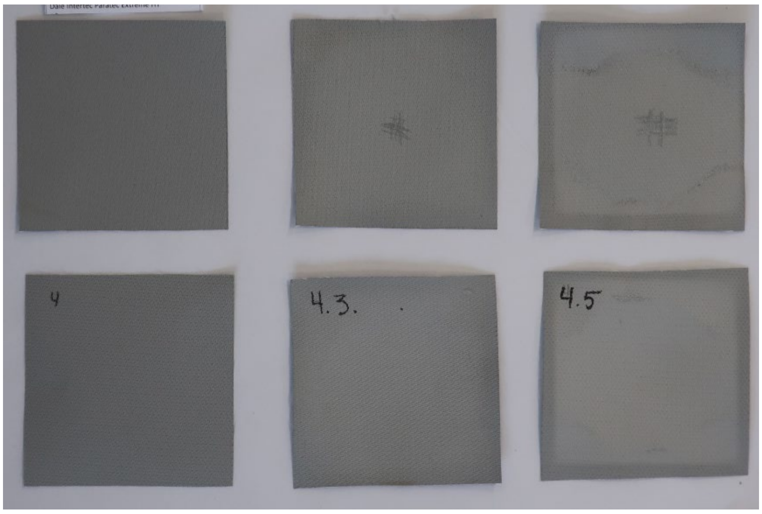

Figure 3-8 Material 4, exposed side (top) and unexposed side (bottom). Before (left), after 20 kW/m^2 heat exposure (centre) and after 30 kW/m^2 heat exposure (right). Evaluation: No colour change on the exposed and unexposed side for the lowest exposure, and colour change on the exposed and unexposed side for the highest. Some change in texture at both heat exposure levels (brittle, chipped and scratches easily).

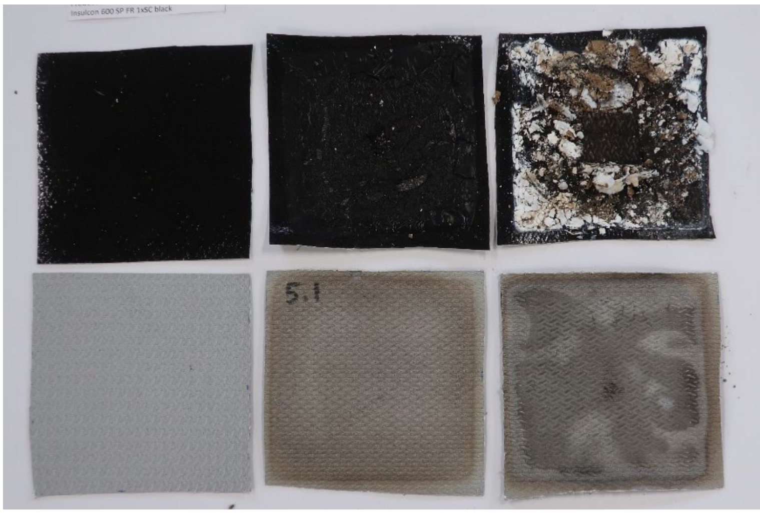

Figure 3-9 Material 5, exposed side (top) and unexposed side (bottom). Before (left), after 20 kW/m^2 heat exposure (centre) and after 30 kW/m^2 heat exposure (right). Evaluation: Colour change and charred on exposed side for both heat exposures, colour change on the unexposed side for both heat exposures. Large change in texture for both heat exposure levels (charred/burnt).

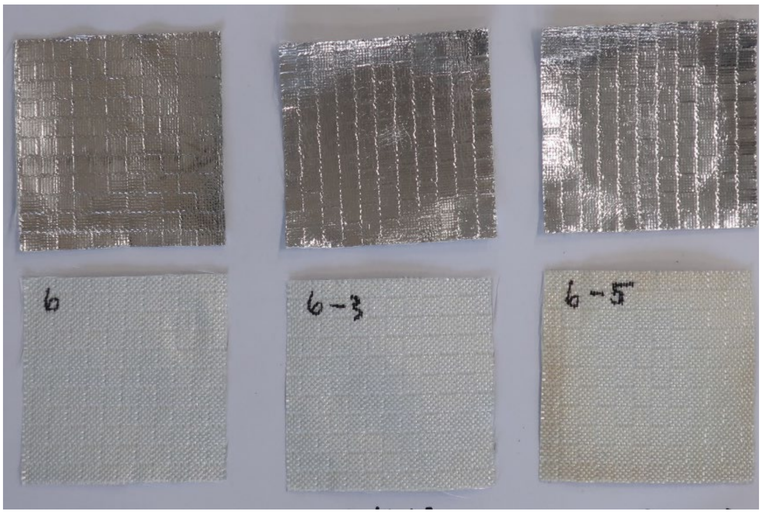

Figure 3-10 Material 6, exposed side (top) and unexposed side (bottom). Before (left), after 20 kW/m^2 heat exposure (centre) and after 30 kW/m^2 heat exposure (right). Evaluation: No colour change on the exposed side for both heat exposure levels, no colour change on the unexposed side at for the lowest exposure, and colour change on the unexposed side for the highest. No visible change in texture for both heat exposure levels.

Material 5 was the only textile where damage to the underlaying refractory fibre blanket insulation was observed (Figure 3-11). The insulation was discoloured in a depth of several centimetres. This was observed after flaming fire at the highest heat exposure level (30 kW/m^2), as may be expected. But notably, this was also observed after no flaming fire at the lowest heat exposure level (20 kW/m^2). Despite having similar temperature trends as material 2 and 4 for 20 kW/m^2, material 5 therefore differs from these two with this strong indication of poorer insulation properties.

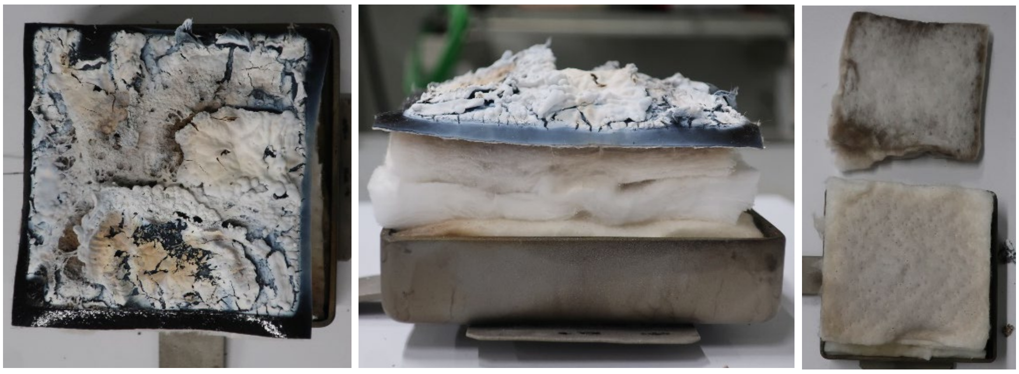

Figure 3-11 Detail photos of material 5 after 30 kW/m^2 heat exposure (left, centre). The surface of the material is charred or burnt, has changed colour, swelled up and become brittle. Detail photo of the insulation below the textile (right), showing the discolouring of the top layer insulation (top) and the following layer underneath (bottom).

Figure 3-12 Example photo (left) of cracking in the textile surface (material 2, after 30 kW/m^2). Example photo (right) of chipped textile (material 4 after 30 kW/m^2). Photos taken using the microscope (magnification 4x).

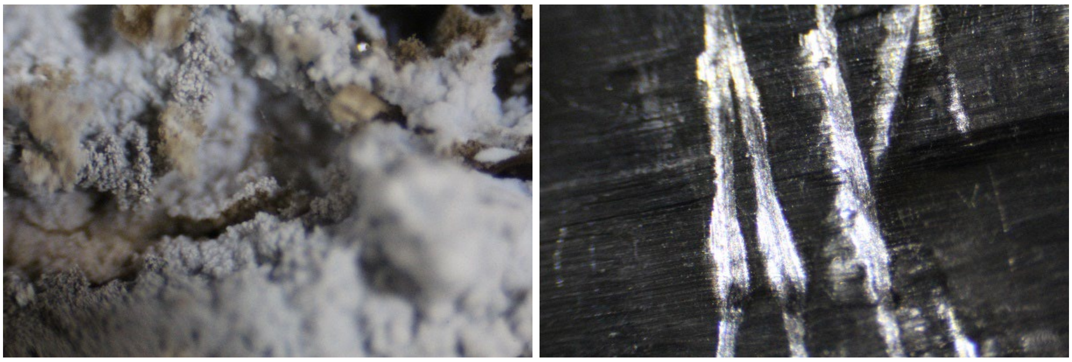

Figure 3-13 Example photo (left) of charred or burnt area of the textile surface (material 5, after 30 kW/m^2). Example photo (right) of the surface of the textile in the area that has been scratched (material 6, after 30 kW/m^2). Photos taken using the microscope (magnification 4x).

3.4. Handling results

The handling properties of materials 1-5 are described in NIKU report 109/2021 [2], and a summary is given here. The textiles in the handling-study were different in weight, thickness, and stiffness. The heaviest textile was not always the most rigid, it also depends on the type of material. None of the studied products were perceived as too stiff to handle. The study showed that the slightly stiffer textiles were easier to use for covering a large and tall object, since they did not so easily get caught up on edges. It was also easy to adjust them after covering, and the stiffness gave more space between textile and object, and thus also more air that insulates and could contribute to less damage, regardless of the textile's material properties. Some key results:

- Large formats of up to 4x4 meters are manageable, but the placing of the cover seems to affect the result of possible damages.
- The studied products could be easily handled by two people.
- It is better if the textile is too big than too small, and it is a good idea to order a textile cover for one of the larger objects of high priority. Then the same fabric can also be used for smaller items if needed.

- Regardless of weight (of three different materials), it was possible to cover the tall object quickly (within 15-20 sec.).
- Stiffness in the textile was positive since it enabled position adjusting after covering.
- Challenges could arise if the first positioning was not sufficient, since it was more difficult to get the textile off the object than to throw it over.
- The study showed that a covering can be carried out by two people in an emergency situation, but it is crucial that one of them has knowledge of the purpose. It was not deemed necessary to be familiar with techniques for appropriate throwing/covering.

For material 6 in the 2023-study (part 3), which was added afterwards, an ad-hoc handling demonstration was made (Figure 3-14). The textile area used was 1 x 2 meters, which is smaller than what was used for the handling property evaluation for the other textiles in 2021. The results from this evaluation showed that this textile was quite rigid compared with some of the other textiles from the 2021 handling-study. A certain stiffness in the material could be considered as positive (as was demonstrated in the 2021 study), but only to a certain extent. Material 6 did not fall easily over the object, which means that it may be a challenge to use in practise. It was, however, possible to wrap around an object and once in place it was sturdy, but because of the stiffness it left open areas for possible smoke and soot to get underneath. This indicates the need for fastening systems if similar stiff material should be considered.

Figure 3-14 Photos from the study of handling properties of the welding protection textile, with throwing and wrapping around a small object (0.5 m high, left/centre) and an intermediate sized object (1 m high, right).

3.5. Summary of results

For each of five key parameters, each textile is given a score from 1 (good) to 3 (poor), see Table 3-1. Table 3-2 and Table 3-3 show the scores for each material exposed to 20 kW/m^2 and 30 kW/m^2 respectively.

Table 3-1 Five key parameters for evaluation of the textiles, with description of how the results are given scores 1-3, where 3 is the poorest.

Score	Observation during heating	Colour change exposed side	Colour change unexposed side	Texture change	Water penetration
1	None	None	None	None	None
2	Smoke	Colour changed	Colour changed	Some (surface tension, cracking, crumbling)	Moist unexposed side
3	Flame	Color changed & charred	Color changed & charred	Melted, charred, burnt	Drop formation unexposed side or falling droplets

Table 3-2: Performance of the six textiles at 20 kW/m^2 for each of the five key parameters.

Material number	Observation during heating	Colour change exposed side	Colour change unexpose d side	Texture change	Water penetration	Sum of scores at 20 kW/m^2
1	1	1	1	1	2	6
2	2	2	2	2	1	9
3	1	2	2	1	1	7
4	2	1	1	2	1	7
5	2	3	2	3	1	11
6	1	1	1	1	1	5

Table 3-3: Performance of the six textiles at 30 kW/m^2 for each of the five key parameters.

Material number	Observation during heating	Colour change exposed side	Colour change unexposed side	Texture change	Water penetration	Sum of scores at 30 kW/m^2
1	1	1	1	1	1	5
2	2	2	2	2	1	9
3	2	2	2	2	1	9
4	2	2	2	2	1	9
5	3	3	2	3	3	14
6	1	1	2	1	1	6

4. Discussion

4.1. Evaluation of results

All results for each textile were evaluated and each textile was ranked as good, intermediate or poor. The final conclusions for each textile are presented in Table 4-1 with a comment describing the background of the conclusions.

Table 4-1 Final conclusions for each textile, based on all results in the study.

Material number	Conclusion	Comment
1	Good, but fragile	Low temperature development, good overall score on visual observations, but no water resistance in the underlying textile below the aluminium. If the surface layer of thin aluminium foil is damaged, water may penetrate and reach the object below.
2	Intermediate performance	High temperatures on the unexposed side. There was visible damage to the textile, but there was no water penetration. Similar to material 4.
3	Intermediate performance	Intermediate temperature on the unexposed side. Overall intermediate score on changes in colour and texture, but there was no water penetration. The observed bending of the textile upon high heat exposure could indicate that the protection of the object below may be affected.
4	Intermediate performance	High temperatures on the unexposed side. There was visible damage to the textile, but there was no water penetration. Similar to material 2.
5	Poor	High temperatures on the unexposed side. Charring of the material and colour change of insulation below for the lowest heat exposure, but there was no water penetration. Flaming fire and colour change of insulation below for the highest heat exposure, water penetration was observed (water droplet formation on unexposed side). Combined, the material was concluded to be poor. These results give an unacceptable performance.
6	Good, but rigid	Low temperature development, good overall score on changes of colour and texture. The main challenge is rigid handling properties and only 1 meter width. Wider products would have to be made for the end-use, and limited use because of material stiffness.

4.2. Hypotheses

Hypothesis 1: Differences in insulation properties can be demonstrated through measurement of temperatures on the unexposed side of the textiles, with a significant difference in the measured temperature increase and stabilization temperature on the unexposed side.

Conclusion: Yes. There was a significant difference in the temperature increase and stabilization temperature on the unexposed side between the textiles, with several hundred degrees differentiating between highest from the lowest stabilization temperature. The temperature on the unexposed side gives an indication of the insulation properties of the textiles, and by extent, an indication of how much damage may be expected to the cultural historic object below. The chosen method made it possible to evaluate the insulation properties during heat exposure. Hypothesis strengthened.

--

Hypothesis 2: Higher heat stress will damage the fire-protective textiles more than lower heat stress, to an extent that is visually observable after the exposure.

Conclusion: Partly. For some of the textiles there was a difference between the damage to textiles exposed to the highest heat exposure level (30 kW/m^2) versus the lower (20 kW/m^2). Textiles exposed to the lowest level (10 kW/m^2) in the pre-study showed no visually observable damage. Hypothesis partly strengthened.

--

Hypothesis 3: It is possible to distinguish between different fire-protective textiles in their water protection properties, with a significant difference in the amount of water penetrating through the textile after the heat exposure with the given experimental procedure.

Conclusion: Partly. There was water penetration only for two of six materials, and only for some conditions. The chosen experimental procedure is most likely not optimal for the purpose, and other methods should be considered in future studies. Hypothesis neither falsified nor strengthened.

4.3. Discussion of expected damage to cultural historic objects

The results from this study may be used for recommendations for heritage owners on which fire-protective textiles they should choose for their specific end-use. In all, it is important to consider risks, challenges and possible mounting or covering options before choosing a material for a specific case.

When a fire-protective textile is used to cover a cultural historic object during a fire in a church, historic building or a cultural institution such as museum or archive, it must protect the object from heat from the fire. If the object under the textile becomes too hot, it may be damaged. In addition to the heating, it would be very destructive for the object if the fire-protective textile in fact contributed to the fire exposure, by starting burning. This was the case one of the textiles, which was evaluated as poor.

Following the heat exposure, the textile could be exposed to water, either from an installed suppression system or from manual firefighting efforts. Even if the textile is damaged by the fire exposure, it still needs to keep the water out, since some fragile cultural historic objects may be damaged by water. Five of six textiles showed some colour or texture change due to the heat exposure but only two textiles were damaged to a degree where it resulted in water penetration, one of which was more severe than the other, with drop formation unexposed side. We would recommend choosing a textile that protects from fire, and also keeps the water out.

Different cultural historical objects will respond to temperature and water exposure differently. For example, a sculpture made of wood will behave differently than a paper-based artwork or an oil painting on canvas. The measured temperatures in this study may be compared with ignition temperatures for different materials, depending on the end-use. Here, chapter 14 in the "Ignition Handbook" by Babrauskas [6] gives ignition data for many different materials (e.g., wood, thin white paper, paint and textiles), most of which are dependent on how the fire is started (ignition method) and other factors. This is a good starting point for making material-specific evaluations for specific cultural historic objects.

During the experiments, smoke was observed coming from the materials during heat exposure, for 3 of 6 materials at the lowest exposure and for 4 of 6 materials at the highest exposure. Smoke is a mix of gases and aerosols, including particles and air [7]. The question could then be raised, on whether this smoke or offgassing could be harmful to the objects below. This would depend on two key factors, namely the 1) type of smoke, and 2) the amount of smoke.

1) In this study, the type of smoke was not analyzed, but it is known from literature that in general, fires smoke may consist of a wide range of gases (see e.g. chapter 62 on Combustion Toxicity in the SFPE Handbook [8]). Literature on damage on cultural objects and art from air pollutants suggests [9] that air pollutants may cause damage including corrosion, tarnishing, discoloration, soiling, embrittlement, reduced tensile strength and fading. The pollutants include sulphur oxides, hydrogen sulphide, acidic gases, alkaline aerosols, nitrogen oxides, ozone (see details in Table 2 in [9]). Many of these are known gases produced also in fires. Therefore, it may be assumed that if a cultural heritage object is exposed to fire smoke, the smoke *may* cause damage to the object.

2) The amount of smoke, or the *total smoke production* or *smoke production rate* for a given material is dependent on the type and amount of material burning. A 2x2 meter blanket of the textiles used in this study weighs in the range of ~1-4kg. The majority of this is materials which is not expected to contribute significantly to the fire, such as fiberglass and aluminium. Combustible materials that would contribute to the fire could include e.g. surface coatings. If we estimate that such materials are 10% of the total weight of the textile, there is 400 grams of material available for contributing to smoke production. Assuming that the textile catches fire and all of the coating is consumed by the fire, this gives a maximum of approximately 2.5 cubic

meters of smoke[1]. To put this into perspective, we also need to estimate the smoke production from the fire in the room. In the given scenario with heat exposure of 20 kW/m^2 and 30 kW/m^2, there would be a large fire in for example the main church room or a fire close to the object. The smoke from this fire could enter under the textile, since the covering of the object is not air-tight (as was seen in the handling part of this study). A large fire in a church room could be e.g. a large part of a wooden wall or 50 wooden chairs burning. If we assume that the average wooden church chair weighs 10 kg[2], this means that there is ~500 kg wood burning, giving a maximum of approximately 3000 cubic meters of smoke. This amount of smoke would partly fill up the church room in a small church (e.g. 100 m^2 floor area and 6 meters ceiling height, volume of room being 6000 m^3). With about 1000 times more potential smoke volume from inventory burning compared with the textile burning, the smoke from the textile is relatively limited, and should not be the main concern. To summarize, during the given scenario with a fire in the church room, if there is smoke damage to the object, this would most likely be caused by the large fire in the room, and not offgassing or smoke from the textile itself. Offgassing during other scenarios, such as long-term storage, is not considered here (see future work).

[1] Smoke production amount was estimated as follows: The fuels (textile coating and wooden chairs) were assumed to be hydrocarbons, using the molecular weight of only carbon for simplicity. Further, it was assumed that smoke density was the same as air density. Complete combustion was assumed, with one mole of CO_2 and two moles of H_2O produced for each mole of carbon burnt. Ideal gas law was then used to find the volume of smoke gas produced, assuming room temperature and ambient conditions.
[2] According to Yale's furniture weight approximations, a *chair, office, stationary* weighs 17 lbs (~7.7 kg). https://your.yale.edu/work-yale/campus-services/eli-surplus-exchange/furniture-weight-approximations

5. Conclusions

Six textiles have been evaluated by their heat and water properties for protection of cultural historic objects from fires and water damage. The overall conclusion for each textile shows that two were ranked as good, three as intermediate and one as poor. The similarity of the two materials ranked as "good" is an aluminium layer on the exposed side. Combined with the results from BraTeK parts 1 and 2 (NIKU reports), the conclusions from this report may support the church owners' choice of fire-protective textiles.

6. Further work

An interesting continuation of this study would be to combine part 2 and part 3 in a larger scale laboratory study. This would give fewer unknowns or variables than in part 2, but still facilitate the study of handling, geometry, distance, direct contact between textile and object etc., in addition to heat and water exposure.

A fire scenario not considered in this study is burning objects falling onto the fire-protective textile, once placed on the object. This would give conductive heat transmission in the direct contact point between textile and burning object, in addition to flame contact and radiation exposure. The scenario would be relevant for example in older brick and stone churches with wooden roof constructions, in a scenario where the inner walls and facades are intact but the combustible roof collapses into the church room.

Some textiles showed emission of smoke during heat exposure, but in only one case the gases started burning (flaming fire). This study did not involve the use of sparks or flaming fire exposure, which could have contributed to ignition of any combustible gases in the smoke. A study of the gas composition would give more insight into which gases are emitted from the textiles during heat exposure, and whether or not these are likely to contribute to the fire. A fire-protective textile should ideally not contribute to the fire.

Gas-composition would also be of interest not only during heat exposure, but also during long-term storage. For museum applications textiles may be used for permanent coverage of objects, and here it would be interesting to document the long term off-gassing also with no heat exposure, in addition to shelf life in general (aging of the products), and reuse of the products.

For long-term storage, ageing of textiles could potentially change their fire-protective properties, e.g. if textiles become brittle, cracked or otherwise deteriorated. This would be interesting to study in future work.

It is important to point out that there are numerous materials on the market that are not part of this study, which might be suitable for protecting art and heritage objects. After initiating this study, new products have entered the market. As an example, there is a product made especially for protecting art, called "Otego" textile[3]. It would be relevant to study this material in the light of the undertaken experiments. This material is much thinner than the studied materials in BraTeK, which could give different handling properties.

[3] Otego texile: Aluminized cover for protection of works of art and valuable objects (otegotextile.com)

7. References

[1] N. Kjølsen Jærnes, ‘Brannbeskyttende tekstiler for å minimere skader på kulturhistoriske gjenstander. Forprosjekt.’, Norsk Institutt for Kulturminneforskning (NIKU), Oslo, NIKU Oppdragsrapport 143/2020, 2020.

[2] N. K. Jernæs, ‘Brannbeskyttende tekstiler. Testing for bruk på kulturhistorisk materiale. Revidert 2022.’, Norsk Institutt for Kulturminneforskning (NIKU), Oslo, Norway, NIKU rapport 109/2021, Spring. 2022.

[3] N. K. Jernæs and R. Fjellgaard Mikalsen, ‘In the Heat of the Moment: Testing Fire-Protective Covers for Mitigating Damage to Large Historic Inventories’, *Studies in Conservation*, pp. 1–12.

[4] N. Kjølsen Jærnes, H. M. Kempton, and R. F. Mikalsen, ‘Testing fire-protective textiles to minimize damage to historic items from fire and water’, in *Poster session at the 14th International Symposium on Fire Safety Science IAFSS2023*, Tsukuba, Japan, 2023.

[5] ISO, ‘ISO 5660-1:2015 Reaction-to-fire tests - Heat release, smoke production and mass loss rate - Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement)’. International Organization for Standardization, 2015.

[6] V. Babrauskas, *Ignition handbook: principles and applications to fire safety engineering, fire investigation, risk management and forensic science*, 2 (pdf version). Issaquah, WA: Fire Science Publishers, 2014.

[7] ‘Kollegiet for brannfaglig terminologi’, 2024. [Online]. Available: http://www.kbt.no.

[8] D. A. Purser, ‘Combustion Toxicity’, in *SFPE Handbook of Fire Protection Engineering*, 5th ed., vol. 1, M. J. Hurley et al, Ed. New York: Springer, 2016, pp. 2207–2307, Chapter 62.

[9] N. S. Baer and P. N. Banks, ‘Indoor air pollution: effects on cultural and historical materials’, *The International Journal of Museum Management and Curatorship*, pp. 9–20, 1985.

[10] ‘ISO 9705-1:2016. Reaction to fire tests - Room corner test for wall and ceiling lining products - Part 1: Test method for a small room configuration’. International Organization for Standardization, Geneva, Switzerland, 2016.

[11] M. Beshir, Y. Wang, F. Centeno, R. Hadden, S. Welch, and D. Rush, ‘Semi-empirical model for estimating the heat release rate required for flashover in compartments with thermally-thin boundaries and ultra-fast fires’, *Fire Safety Journal*, vol. 120, p. 103124, Mar. 2021.

[12] T. E. Waterman, ‘Room flashover—Criteria and synthesis’, *Fire Technology*, vol. 4, no. 1, pp. 25–31, Feb. 1968.

Appendix A: Pre-study, Development of Method

In June 2023, a pre-study was performed with the aim of developing an experimental method for the small-scale experiments to imitate the scenario of a church fire with water extinguishing presented in section 1.3. This chapter presents the background for the chosen experimental set-up, choices made related to the experimental method, as well as the results from the experiments in the pre-study and changes made for the final experimental set-up based on these results.

7.1. A1 Heat exposure: Choice of method

Choice of heat exposure duration for pre-study: Based on part 1 and part 2 of the project and in discussions in the project group, the scenario presented in section 1.3 was chosen. In this scenario, there is no set limitation to the duration of the fire. However, any fire that is very short, for example only a minute or two, would most likely not give a very severe fire exposure to an object nearby, since the fire would not have time to grow in size. On the other hand, any fire with a very long duration, for example several hours, would have to burn through a large amount of fuel to sustain, and would most likely also cause flashover in the room. This would mean that the cultural historic object would not survive the fire. In the pre-study, an intermediate exposure duration was therefore chosen, of 10 minutes, in addition to a slightly longer exposure of 30 minutes.

Choice of heat exposure method: Three different fire exposures were discussed in the project group and with the reference group:

- Direct flame contact: If the cultural historic object was exposed to direct flame contact, the fire would be very close to the object, and the chances of saving the object, even if protected with a fire-protective textile would be very small.
- Conductive heat exposure: If the cultural historic object was exposed to conductive heat transfer, this could represent e.g. a burning timber beam falling onto the object. In this scenario, the cultural historic object may have been severely damaged by the falling object, and the chances of saving the object are thus limited. While an interesting scenario for some cases, this was not seen as the most crucial scenario to study first.
- Radiative heat exposure: Representing a large fire, but at a distance. This would pose a threat to the object if unprotected, but a protective textile would possibly be able to save the object, given that the textile endures the radiative heat exposure from the fire. This was therefore the chosen fire exposure scenario.

With the chosen fire exposure being radiative heat exposure, it was decided to base the experiments on a standardized test set-up, to give a repeatable and reproduceable radiative heat exposure. The standardized cone calorimeter test method (ISO 5660 [5]) was chosen. Here, the test specimen is placed horizontally under a conically shaped radiative heater. In this standardized method, the heat exposure levels are well-known and possible to compare with different real-life scenarios.

Choice of heat exposure level for pre-study: In the pre-study, it was decided to use three different heat exposures to determine the best-suited heat exposure levels for the main experiments: 10 kW/m^2, 20 kW/m^2 and 30 kW/m^2. The first,10 kW/m^2, represent a fire scenario with a fire in the church room, but at a distance from the object. The other two, 20 kW/m^2 and 30 kW/m^2, represent a fire scenario with a larger fire or a fire closer to the object. These heat exposures represent conditions in the room close flashover conditions[4]. It was chosen not to use heat exposures above 30 kW/m^2, since any heat exposure higher than this would mean that the fire conditions in the room, in this case the church, would be beyond flashover conditions, meaning that the cultural historic object would not be possible to save. It was chosen not to use heat exposures below 10 kW/m^2, since any heat exposure lower than this would most likely not pose a large threat to the object at hand.

7.2. A2 Pre-study experimental campaign and instrumentation

In the pre-study, three heat irradiation levels and two exposure durations were used, see Table A1.

Three textiles from part 2 of the study were used in the pre-study, in addition to a welding protection textile. The textiles are anonymous here, since the purpose of the pre-study mainly was to test the experimental set-up.

A 0.5 mm encapsulated type K thermocouple was used to document the temperature development on the unexposed side of the textile. This was positioned to document the areas of the most severe heat exposure, that is, the areas where the textile is in direct contact with the cultural historic object, and there is direct heat conduction from textile to object, rather than an insulating air layer between. The thermocouple was connected to a Comark N9005 industrial thermometer from Impex and temperature readings were recorded manually a few times per experiment.

The cone calorimeter method is normally used to document the reaction to fire properties of a material, with time to ignition, smoke production (optical) and heat release rate (based on oxygen depletion and emission of CO and CO_2) as key results. In this study, we are merely utilizing the standardized radiative heating from the cone, with our key measurement being the temperature on the unexposed side of the textile. This is therefore more similar to a small-scale ad-hoc fire resistance test, rather than reaction to fire test. Measuring smoke production and heat release rate was therefore deemed as not necessary in this study.

[4] Using the room-corner test standard ISO 9705 [10], Beshir et.al. [11] describes flashover and post-flashover as follows: “The fully-developed fire stage is also usually referred to as the ‘post-flashover’ stage, where flashover was first defined and studied quantitatively by Waterman in 1968 [12], who defined it as conditional on a heat flux of 20 kW/m^2 on the floor.”

Table A1 Overview of the parameters in the pre-study, with heat exposure level and experimental duration time for the different textiles. All textiles were first exposed to heat, then to water.

Exposure level/time: *Textile*	**10 kW/m², 10 min**	**20 kW/m², 10 min**	**20 kW/m², 30 min**	**30 kW/m², 10 min**
Light grey	Test A	Test D	Test G	Test H
Dark grey	Test B	Test E		
Black	Test C	Test F		
Welding protection textile				Test I

7.3. A3 Results from heat exposure in pre-study

The temperature data points for each textile exposed to 10 kW/m^2 are presented in Figure A2 and for each textile exposed to 20 kW/m^2 in Figure A3. The results indicate that the *Light grey* textile has better insulation properties than the other two, based on that this has the slowest temperature increase at the start and the lowest temperature at which it stabilizes. The *Dark grey* and *Black* textiles were similar. With few datapoints per dataset, and no repetitions of each experiment, it is not possible to say whether it is coincidental that the stabilization temperatures for *Light grey* seems to be lower than the other two, so repetitions are needed in the main test series. Since the results between textiles were this similar, it was concluded that there is a need for repetition of experiments (as expected).

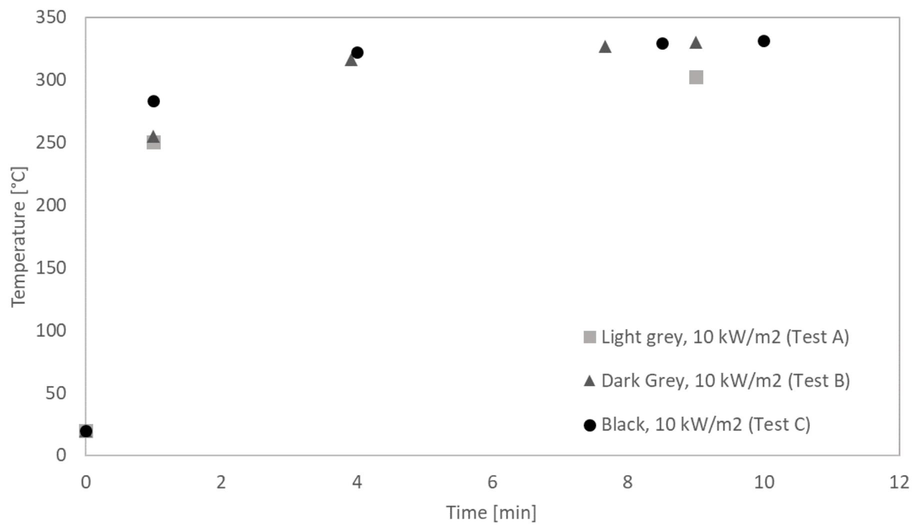

Figure A2 Temperature on the unexposed side of the three textiles as function of time for 10 kW/m^2 heat exposure. The temperature increased most rapidly during the first 2 minutes for Black. The temperatures stabilized towards the end, with stabilization temperatures of ~300 °C for Light grey, ~330 °C for Dark grey and ~330 °C for Black.

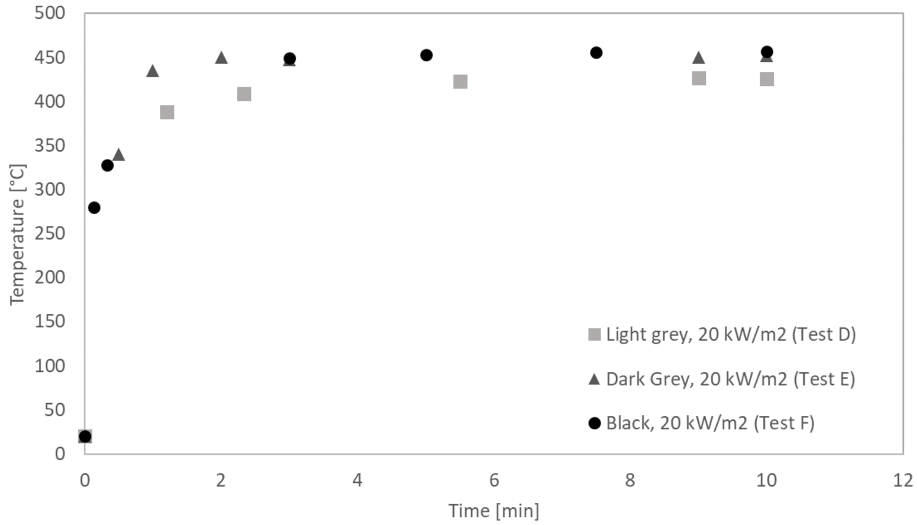

Figure A3 Temperature on the unexposed side of the three textiles as function of time for 20 kW/m^2 heat exposure. The temperature increased most rapidly during the first 2 minutes for Dark grey. The temperatures stabilized after approximately 4 minutes, with stabilization temperatures of ~425 °C for Light grey, ~450 °C for Dark grey and ~455 °C for Black.

For one textile, a series with the same heat exposure (20 kW/m^2) and two different experimental durations (10 and 30 minutes) was performed, see Figure A4. The temperatures increased significantly for the first 1-2 minutes, and after ~5 minutes the temperatures stabilized. Based on this, it was concluded that there is no need for a longer experimental duration than 10 minutes. The two experiments also indicate the repeatability using this experimental method, with a relatively small spread in the temperature data of up to 11 °C for the first 10 minutes. Based on this it was concluded that 3 repetitions per experimental condition for each material would be sufficient.

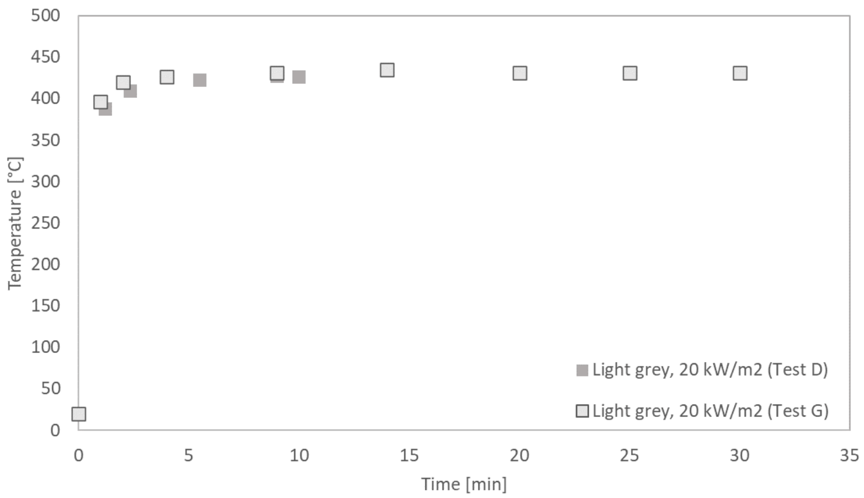

Figure A4 Temperature on the unexposed side as function of time for Light grey material with 10 min (Test D) vs 30 min (Test G) heat exposure of 20 kW/m^2. The spread in temperature data between the two single experiments was 0 °C at t=0, 8 °C at t ~1 min, 11 °C at t ~2 min and 4 °C at t ~9 min.

One of the textiles (*Light grey*) was also exposed to 30 kW/m^2 (*Light grey* in Figure A6) to check if there was any more damage to the textile after a higher heat stress. For the two lower heat exposures (10 kW/m^2 and 20 kW/m^2), it was not possible to observe any visual changes on the material surface, but for the highest heat exposure (30 kW/m^2), it *was* possible to see a change in the colour of the material, but no other damage was observed, see Figure A5. This highest exposure was only made for one textile to check whether the visible damage to the textile was possible to observe after the experiment, concluding that since there was *some* colour change, it would be beneficial for the study to include 30 kW/m^2 in the main experimental series.

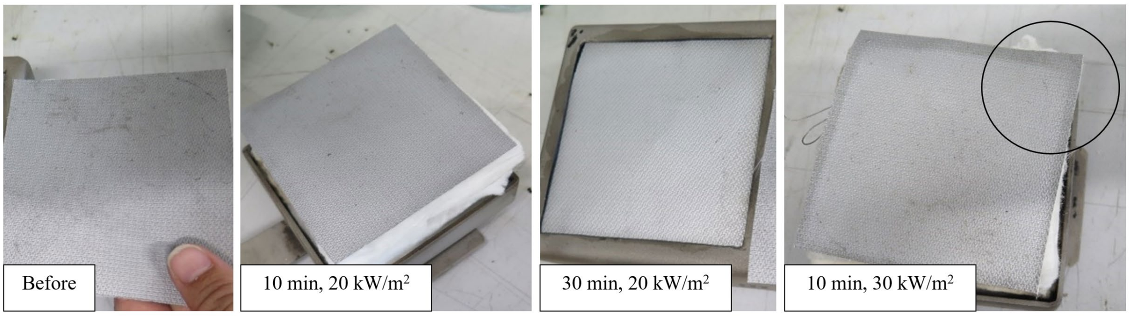

Figure A5 Light grey material. Left photo: Before, notice some dirt on the textile, from previous storage. Middle photos: After intermediate heat exposure of 20 kW/m^2 for 10 min (test D) and 30 min (test G, photo without frame missing, but visual inspection made), there was no visible change. Right photo: After high heat exposure of 30 kW/m^2 for 10 min (test H). Colour change in the centre compared with edge (see circled area), no other damage.

After these 8 experiments in the pre-study were complete, the project group discussed whether the similar temperature data trends observed between different textiles means that this method is not suitable to distinguish between different textiles. It was therefore decided to add a new material as a reference material to study if this would also give a similar temperature development. A commercially available welding protection textile was used for this purpose, since this has many of the same functionality requirements as fire-protective textiles/fire blankets. The welding protection textile was exposed to the highest heat exposure level of 30 kW/m^2 and the temperature data is shown compared with the *Light grey* textile in Figure A6. As can be seen, the insulation properties of the welding textile were better than for the *Light grey* textile, with temperatures stabilizing at 10 minutes almost 300 °C lower than *Light grey*. As for the *Light grey* textile, the welding material also had slight colour change after this high heat exposure (Figure A7), but on the unexposed side of the textile, rather than on the exposed side. Based on this it was concluded that this method *is* suitable for distinguishing between the temperature development of different textiles, and it was decided to keep this method for the main experimental series. In addition, it was concluded that a welding textile should be included in the main part of the study, based on its promising results in the pre-study. Including this new textile also means that its handling properties also was included in the main part of the study. All temperature data from the pre-study is shown in Figure A8.

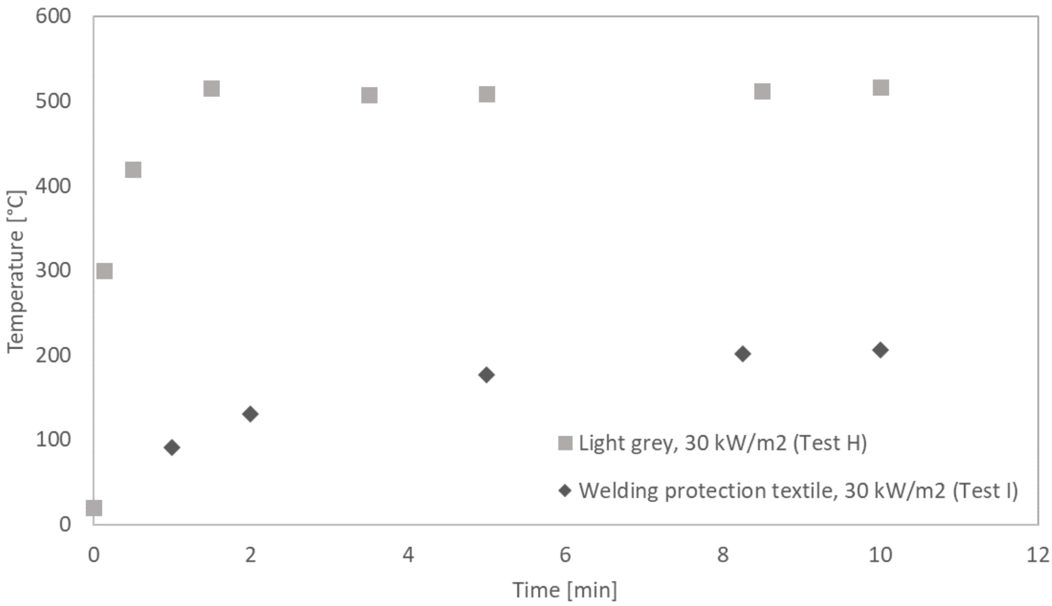

Figure A6 Temperature on the unexposed side as function of time for 30 kW/m^2 heat exposure, for Light grey textile and a Welding protection textile. The temperatures stabilized after approximately 2 minutes for Light grey, with stabilization temperature of ~515 °C. For the Welding protection textile, the temperature at ~8 minutes was 202 °C and at 10 minutes 206 °C, but still slowly increasing.

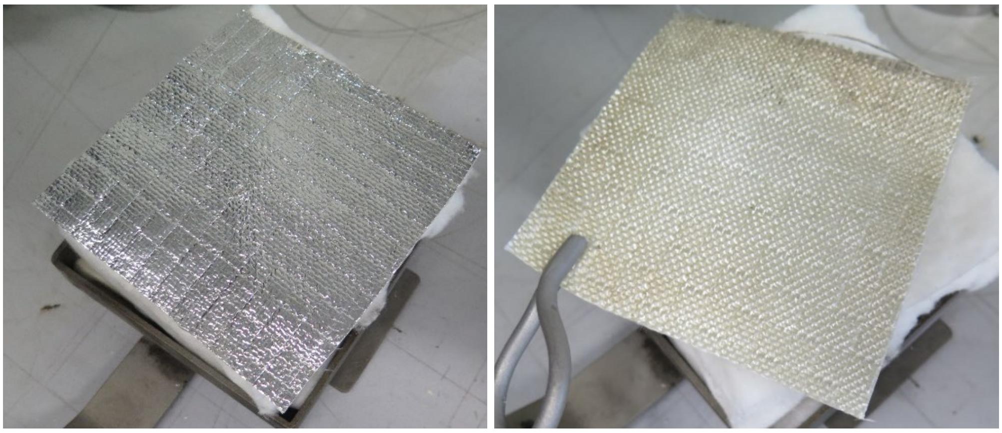

Figure A7 Welding protection textile after the experiment, no visual damage to the exposed side (left) and some colour change to slightly more off-white on the unexposed side (right).

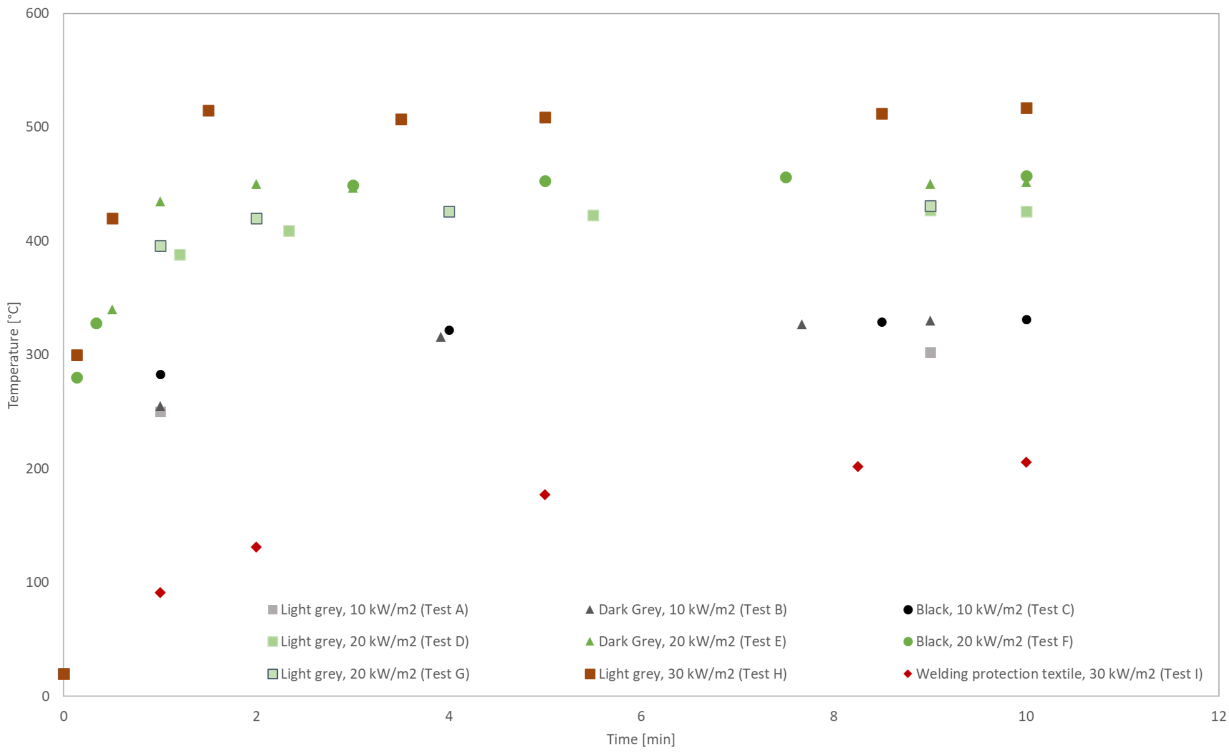

Figure A8 Temperature on the unexposed side as function of time for all textiles and heat exposures in the pre-study series. Lowest heat exposure of 10 kW/m^2 is greyscale, medium at 20 kW/m^2 is green-scale and highest at 30 kW/m^2 is red.

7.4. A4 Water exposure: Choice of method

As described in section 1.3, in the church fire scenario, the textile is first exposed to heat and then to water from suppression systems or extinguishing efforts. Therefore, after heat exposure, the method for water exposure should document any damage to the textile that would make water penetrate the textile.

A textile may behave differently if it is hot directly after the heat exposure, or if it is stored or transported before the water exposure. To ensure realism, it was therefore decided that the water exposure should take place as soon as possible after the heat exposure. Furthermore, ideally the water exposure should be representative of sporadic water "splashing", rather than constant water pressure.

Attempts at finding relevant standardized test methods were made, with a literature survey, online search and contact with organisations working specifically with testing of materials and water penetration, but without success. Some methods for documenting the water penetration through a textile were found, these methods are normally used e.g., for tents, tarpaulins or rain protection clothing. These were based on hydrostatic water pressure onto a textile, and therefore found to be not relevant for our scenario. The required size of the textile was also a challenge. Since our scenario requires heat exposure first, then water exposure, the textile size available for the water-part of the experiments is given by the heat exposure test method (ISO 5660 [5]), to

10 cm x 10 cm. The standardized methods found for water exposure required larger textile sizes than this.

Based on the lack of standardized water exposure methods, an ad-hoc method was developed and used, as follows: After the heat exposure, the textile was placed with exposed side facing up, in a bent sieve (Figure A9, see also Figure 2-3 for shape of sieve). A syringe (20 mL) filled with room temperature (18-25 °C) water was positioned 15 cm above the textile using a rack, and the water was dripped onto the textile during 10 seconds. A bowl with a scale below was placed below the sieve, to document any water penetrating through the textile and dripping into the bowl below.

The textiles were quite stiff, and dripping water onto it only lead to water run-off to the sides (left in Figure A9). A stainless-steel ring (75 mm outer diameter, 68 mm inner diameter, height 25 mm, weight 150 grams) was therefore positioned on top of the textile (Figure A10). When placed gently on top, the water escaped under the ring (centre in Figure A9). The final procedure used in the main experimental series therefore included firmly pushing the metal ring down onto the textile (right in Figure A9), giving the textile a concave shape, retaining the water within the ring and on top of the textile. Notice that the pushing caused some added mechanical stress onto the textile, that would not be represented in the church fire scenario.

First, 10 mL of water was used, but this only covered parts of the area within the ring. The amount of water used in the main experimental series was adjusted to 20 mL, sufficient to cover the area within the ring with a thin layer of water.

To imitate the chosen scenario as closely as possible, it was decided to initiate the water procedure as soon after completion of heat exposure as possible. In practice this means starting the water procedure at 1 minute after the heat exposure was finished. The syringe was emptied manually during 10 seconds, after which the water was left on the textile for 5 minutes. Visual inspections were made during the 5 minutes of any water droplet formation on the unexposed side of the textile. In the pre-study, no penetration of water was observed for any of the cases, meaning that the water resistance of the different textiles could not be differentiated using this method. It was therefore decided to add a final step to the procedure, with scratching of the textile. In the church fire scenario, the textiles may be exposed to some mechanical stress e.g., if it is pushed or moved during the firefighting efforts. The scratching imitates this, and could potentially provoke damage to some textiles, allowing for distinguishing between textiles. A metal wire (thickness 2 mm) with a semi-pointed end was used for the scratching (Figure A11).

Figure A9 Water exposure set-up modifications. Version 1 (left) with textile placed in sieve. Version 2 (center) with metal ring placed gently onto the textile. Version 3 (right) with metal ring placed firmly onto the textile.

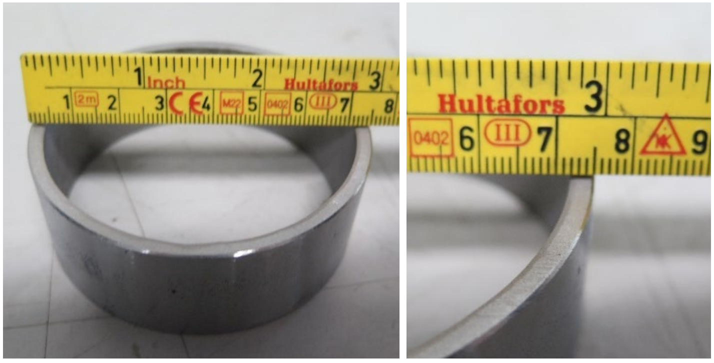

Figure A10 Stainless-steel ring placed onto the textile for the water exposure.

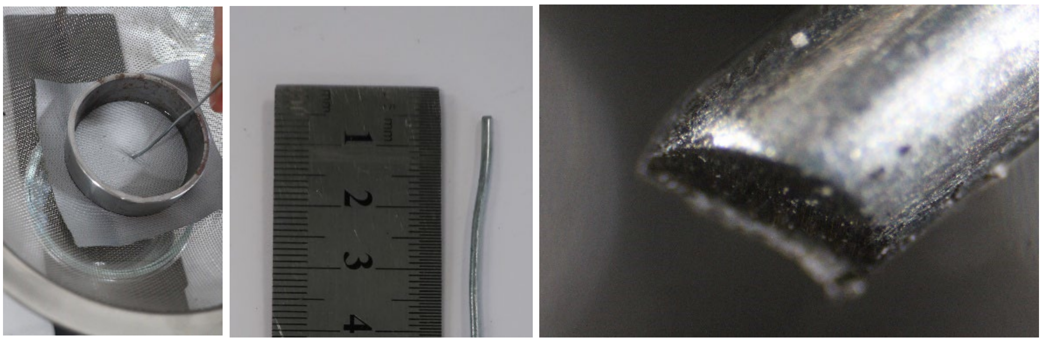

Figure A11 Scratching of the textile at the end of the water exposure, using a metal wire (left). Metal wire (centre) and microscope (4x) close-up view of the tip of the metal wire (right).

RISE – Research Institutes of Sweden
ri.se / info@ri.se / post@risefr.no / (+47) 464 18 000 / risefr.no
Postboks 4767 Torgården, 7465 Trondheim

RISE Fire Research
RISE Report: 2024:19
ISBN: 978-91-89896-22-2