Bushfire Burnover Assessment of NanoChar™ Coated Powers Poles May 2013

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1. EXECUTIVE SUMMARY

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) were engaged by Pilbara Insulation PTY LTD to assess the suitability of passive fire protection treatments on timber power pole infrastructure in severe bushfire burnover conditions. The performance of NanoChar™ a fire retardant and fire resistance epoxy intumescent coating was evaluated utilising CSIRO's Full Scale Bushfire Flame Front Simulator in New South Wales.

The objective of the project was twofold, to explore the performance of NanoChar™ coating for hardwood poles and cross-arms as a protection mechanism in severe bushfire burnover conditions, and also to explore the effectiveness of the intumescent coating system in ensuring pole and cross-arm serviceability after exposure was assessed.

The test utilised four weathered retired power poles and cross-arm's sourced from commercial-industrial electrical contractor South Power. Pole species comprise, Spotted Gum with Copper Chrome Arsenic (CCA) treated sapwood, Iron Bark with CCA treated sapwood and untreated Blood Wood with no sapwood. Two poles and cross-arms where fully coated in NanoChar™, one partly coated pole with NanoChar™ with uncoated cross-arm and one uncoated pole and cross-arm.

The fire test conditions replicated the three stages of severe bushfire burnover conditions being; pre-fire front radiant heat, flame immersion and post fire front radiant heat, the total fire duration was 49 minutes. The specimens were exposed to high heat fluxes and flame immersion conditions exceeding the fire test methods of the Australian Standard (AS) 1530.8.1 and the Energy Network Association (ENA) Pole Fire Test method for simulating the exposure of the base of power poles [14].

NanoChar™ coated poles and cross-arms were effectively protected by the insulating protective char formation that develops on the surface of the intumescent coating only when exposed to extreme heat. The timber substrate of the coated timber did not show any evidence of charring. Further the NanoChar™ coating remained attached to the timber substrate; post fire test examination of the cross sectioned timber showed the adhesion of the NanoChar™ was not compromised by the exposure. The coated poles and cross-arms remained serviceable with sufficient un-reacted NanoChar™ coating depth remaining post-test to resist further bushfire burnover conditions of the same magnitude.

In contrast the uncoated specimens were severely burnt and unserviceable. The Spotted Gum CCA pole burnt to completion, the Blood Wood pole with no sapwood sustained significant charring and self- extinguished following the exposure with the exception of the pole cross-arm interface which continued to smoulder.

The effectiveness and efficiency of NanoChar™ as a fire resistant treatment for hardwood poles and cross-arms in severe bushfire burnover conditions is conclusive.

2. INTRODUCTION

The CSIRO was engaged by Pilbara Insulation to test the performance of NanoChar™ coated power poles for worst case bushfire burnover conditions using CSIRO's Bushfire Flame Front Simulator at the NSW Rural Fire Service Eurobodalla Training Centre near Mogo, NSW (see Figure 1). The facility has been extensively used [1-9] to test fire trucks, cars, power poles, fencing and water tanks for radiant head and flame exposure due to a bushfire.

Four poles were used in the test. Two were coated and two left uncoated for comparison. The poles were exposed to a combination of radiant heat and flame immersion that matched a credible worst case bushfire flame front exposure as if the poles were built adjacent to high fuel load forest. The radiant heat build-up simulates the slowest credible build up which provides the maximum amount of preheating of the power poles prior to flame immersion. The flame immersion phase involved a flame body that reached approximately 1200^{o}K (927^{o}C) and immersed the poles for a minimum period of 110 seconds.

The poles were instrumented with thermocouples to record the air, coating and timber temperature at various locations on the poles.

The coating used was:

NanoChar™ epoxy based intumescent fire protection as described in http://www.advancedepoxycoatings.com/nanochartechnicalbulletin22109.pdf

The test was conducted on 15th April 2013.

Figure 1 CSIRO's bushfire flame front simulator at the NSW Rural Fire Service Eurobodalla Training Centre at Mogo NSW.

3. TEST POLES

3.1 Description

Four second hand hardwood power poles in good condition were provided by South Power for testing.

They were selected to:

- reflect the typical condition of weathered poles in use
- provide a reasonable surface condition on which to apply the coating

The four poles used are shown in Figure 2.

A description of the timber is also provided in Table 1.

The poles were approximately 250mm in diameter and approximately 7.5m in length (net after ends had been removed).

Each pole was installed with a hardwood cross-arm that had been in use for some time so that the surface was weathered. The cross-arms installed on the coated poles were also coated. The cross-arms used are shown in Figure 3. In this figure the cross-arms (from top to bottom) were matched to the following poles 2, 1, 4 and 3 given in Table 1.

Table 1 Timber description

Pole	Surface	Timber	End Section
1 Treated	CCA Treated Sapwood	Spotted Gum Hardwood with CCA Treated Sapwood	
2 Coated 1	NanoChar™ Coated over CCA Treated Sapwood	Spotted Gum Hardwood with CCA Treated Sapwood	
3 Untreated	Heartwood	Blood Wood Hardwood supplied without sapwood	
4 Coated 2	NanoChar™ Coating over CCA Treated Sapwood	Iron Bark Hardwood with CCA Treated Sapwood	

Figure 2 Poles as installed

Figure 3 Cross bars

3.2 Conditioning

The poles as supplied were already in a seasoned condition as they had been in service. However, prior to installation the poles and the cross-arms were conditioned in a heated shipping container (see Figure 4 & 5) for one week at >40^{o}C to reduce any surface moisture content. A check of the moisture content using a moisture meter showed the timber to be in a well seasoned state. To control the moisture content the uncoated poles were wrapped in plastic after conditioning and installation (see Figure 6). This was removed just prior to testing. Samples were taken from the power prior to testing and assessed for their moisture content using a gravimetric method. Samples were between 12-12.7% Moisture Content. Note: Lower moisture content levels may be reached in actual worst case bushfire conditions, these lower moisture contents are likely to have caused more extensive combustion of the unprotected poles but are not likely to significantly influence the coated pole performance.

Figure 4 Insulated Container used for conditioning poles and cross-arms

Figure 5 Poles in insulated conditioning container, surface thermocouple installation

Figure 6 Uncoated poles wrapped in plastic after removal from the container

3.3 Application of Coating

The coating was applied by Pilbara Insulation two days prior to positioning the poles on the test pad. This was to allow enough time for the coating to cure. The application of the coating is shown in Figure 7**.**

Figure 7 Application of coating

The thickness of the coating varied between 4-10mm with an average of approximately 6-7mm (see Figure 8). In commercial application the coating would be more uniform and applied with a target thickness of 4-6mm.

Figure 8 Coating thickness

For ease of coating, the ends of the poles were left bare to allow the poles to be turned over. Prior to installation the ends were cut off (see Figure 9) and coating was applied to the top. The bottom was left uncoated as it was to be installed 1.4m into the ground. For comparison a 1 m section of the untreated pole (pole 3) was coated (see Figure 9) approximately 2 -3m above the installed ground level.

Figure 9 Bare ends of poles removed

3.4 Weathering

Power poles were considered to be effectively weathered as they were all at the end of their life as a commissioned pole. Weather of the pole after coating with NanoChar™ prior to fire testing was consider to be not necessary are previous test certification has demonstrated that NanoChar™ does not suffer from significant degradation of its fire protective properties after weathering. Documents provided (10, 11) detail that NanoChar™ has a Norsok M-501(12) compliance for fire protective coatings. The Norsok M-501 standard requires extensive weather including UV exposure followed by a fire insulation assessment to a hydrocarbon furnace curve. The weather requirements are in accordance with ISO 20340 for Norsok M-501 compliance of offshore fire protection coating systems and appears to be substantially more severe than ASTM D2898 (13) accelerated weather standard. Compliance is achieved if there is less than 10% variation in fire insulation performance between weather and unweathered specimens. Hence it was considered not necessary to pre-weather these specimens prior to the bushfire burnover assessment as it was consider that the weathering would have had a negligible effect on the coating fire performance.

3.5 Installation of Poles

The poles were installed to a depth of approximately 1.4m using a boring attachment to an excavator (see Figure 10). Each pole was located adjacent (~0.5m offset) to a grid burner (at 2m spacing) to provide uniform exposure. The installed poles are shown in Figure 2. The cross-arms were orientated as in use (perpendicular to the line of the poles).

Figure 10 Boring of holes in test pad, each pole adjacent to a burner

4. INSTRUMENTATION

4.1 Thermocouples

The thermocouples used were 1.5mm diameter, Type K, Mineral Insulated Metal Sheath (MIMS) with stainless steel (AISI 310) sheath, magnesium oxide powder insulation, ungrounded tips and PVC leads as shown in Figure 11. These are suitable for temperature up to approximately 1050^{o}C. These were chosen for the following reasons:

- they have been successfully used in previous tests
- along its length the probe is protected against the high temperatures (1050^{o}C) that were likely to be experienced
- where surface temperature was required the thermocouple could be held by screws and bent to give a positive contact to the surface as shown in Figure 12.

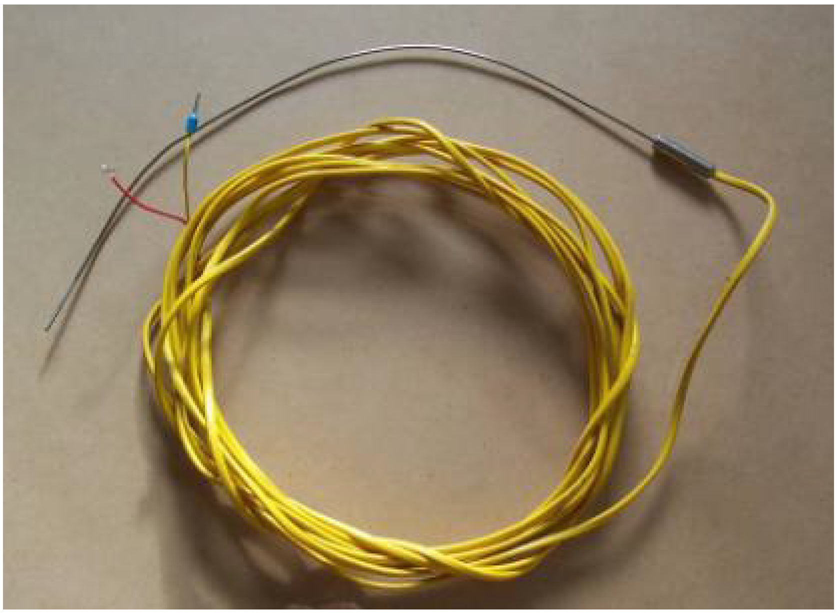


Figure 11 Typical thermocouple

(Type 'K', MIMS, 1.5 mm diameter, stainless steel sheath with PVC lead. Probe shown is 300 mm long but probes up to 8 m were used)

(top: thermocouple installed prior to coating, bottom: thermocouple installed to measure coating surface and air temperature)

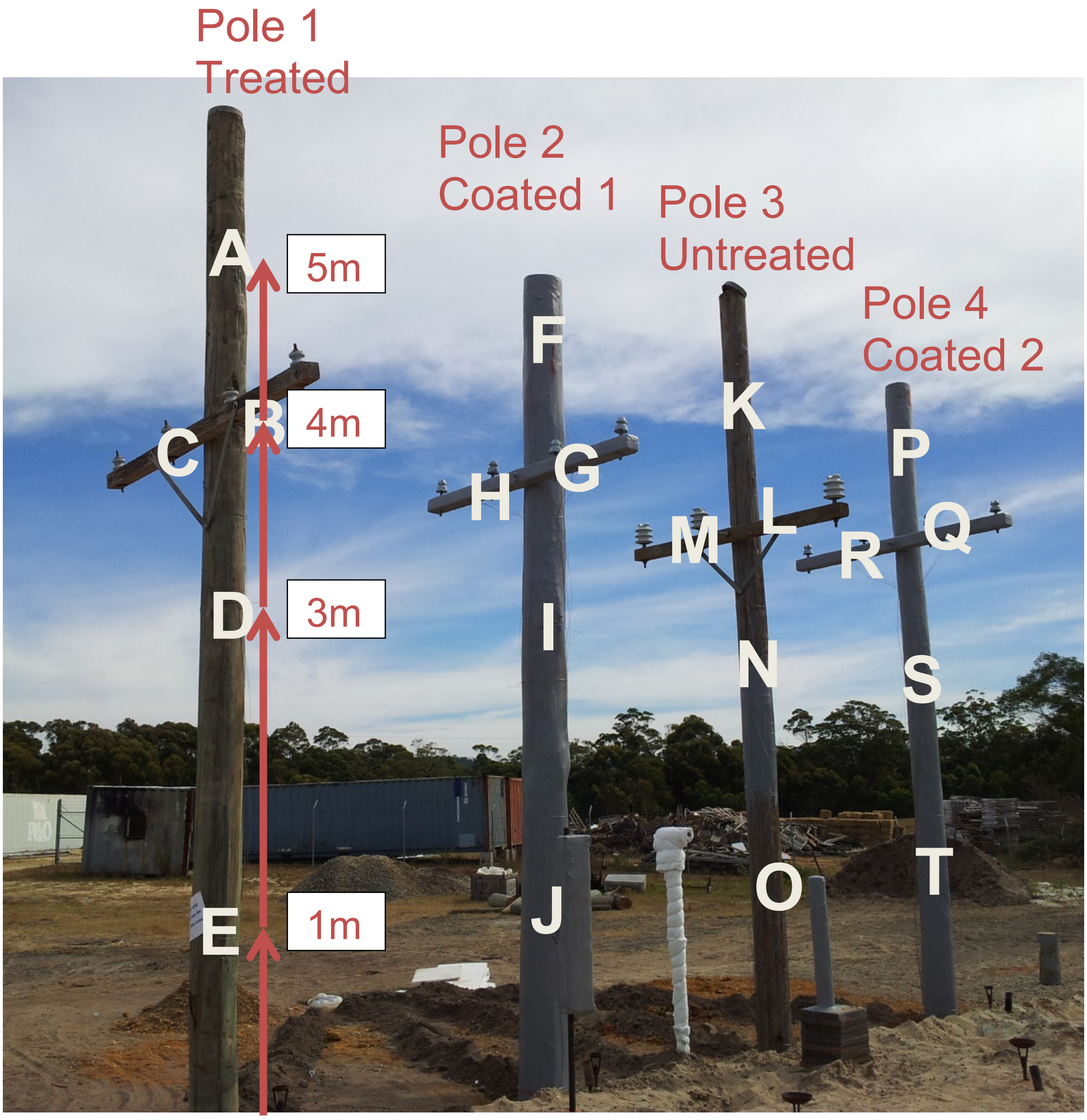
Figure 12 Typical thermocouple installation

Thermocouples were installed:

- at 1, 3 and 5m heights above ground level on the front face of the pole facing the burner grid
- on the underside of the cross bars at two locations, 0.5m offset on each side of the pole

On the coated poles, thermocouples were installed against the timber surface prior to coating to provide a temperature measurement under the coating. Thermocouples used to measure air temperature extend out form the surface by 150mm as shown in Figure 12.

The locations of all the thermocouples are shown in Figure 13.



Height (m)	Location	Temperature	Location	Temperature
5	A	Timber Surface, Air	K	Timber Surface, Air
4	B	Timber Surface	L	Timber Surface
4	C	Timber Surface	M	Timber Surface
3	D	Timber Surface, Air	N	Timber Surface, Air
1	E	Timber Surface, Air	O	Timber Surface, Air
5	F	Coating Surface, Timber Surface, Air	P	Coating Surface, Timber Surface, Air
4	G		Q	
4	H		R	
3	I		S	
1	J		T	

Figure 13 Location of thermocouples

4.2 Radiant heat measurement

A single radiometer (see Figure 14) was positioned at the centre of the poles between poles 2 and 3 to measure the applied radiant heat from the grid of gas burners. The details of the radiometer used are given below. This radiometer was constantly water cooled throughout the experiment.

Manufacturer:	Medtherm Corporation
Model No.:	64-10SB-18
Sensor Type:	Water cooled Schmidt-Boelter
Emissivity:	0.94
Range:	0 - 100 kW/m^2

Figure 14 Radiometer wrapped in heat resistant blanket

4.3 Data Logging

The thermocouples and radiometer were logged at 5-second intervals via a Datataker 505 data logger with an expansion module. Wireless communications were used to transfer the data in real time back to a laptop in the control room. The data logger and wireless modem were placed in a pit in the ground and covered with insulation and soil. A 12V pump powered by a battery was used to circulate the water to the radiometers through silicone tubing from a container inside the pit (see Figure 15).

Figure 15 Instrumentation pit prior to being covered with insulation blanket and soil

5. BURNOVER EXPOSURE

The bushfire flame front simulator allows the test specimen to be exposed to a range of bushfire conditions. For the pole test, the specified exposure requirement was full flame immersion in a worst case real bushfire, and was based on the thermodynamic assumptions contained in AS 3959-2009 [9]. The exposure exceeds the recently published ABCB Performance Standard for Private Bushfire Shelters.

By having a grid of burners and controlling the flow of liquid propane to the burners, the simulator can apply a radiant heat profile and flame immersion to the poles. A sensors (radiometers) level with the face of the poles was used to monitor the level of radiant heat being applied, enabling feedback and adjustment of burner settings. A detailed description of the simulator is presented later.

The worst case burnover exposure is as used in past worst case burnover exposures for housing located against the forest with no clearance MacIndoe[8], Leonard[9].

A plot of the target exposure applied to the poles is presented in Figure 16.

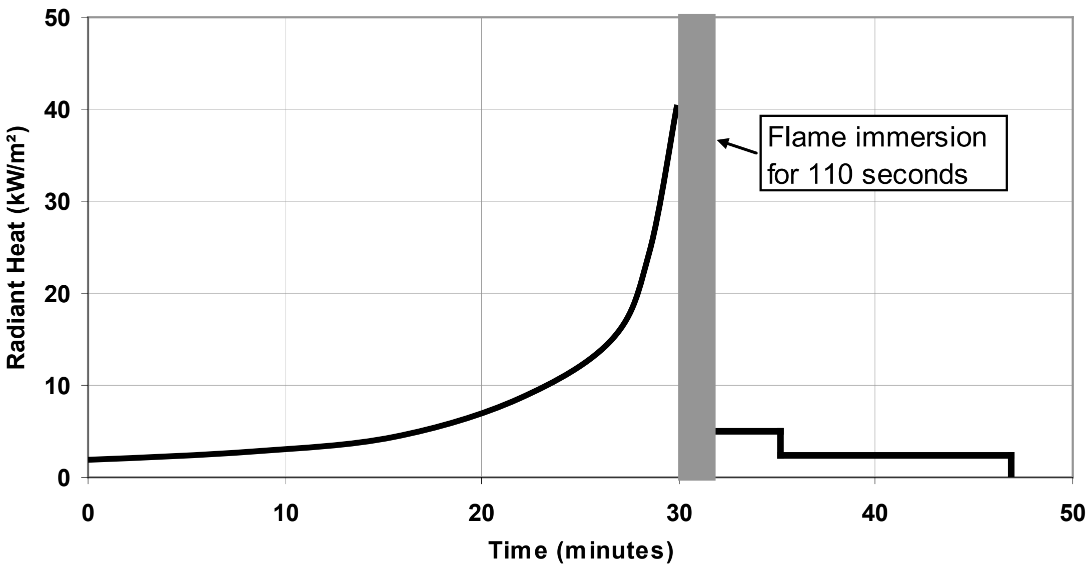


Figure 16 Radiant heat profile

The profile has three stages:

- Pre-fire front radiant heat
- Flame immersion
- Post-fire front radiant heat

The pre and post fire front radiant heat is provided by a single row of burners set on the ground 5m from the front of the poles as shown in Figure 17. The timing of the test is matched to the weather conditions to ensure the heated air from the burners is blowing towards the poles.

Figure 17 Poles during the radiant heat exposure phase

The flame immersion stage uses a grid of burners immediately adjacent to the poles as shown in Figure 18. Following this phase there is a post flame front radiant heat phase using the same burners as the pre-fire front radiant heat phase as shown in Figure 19.

Figure 18 Poles during the flame immersion phase

Figure 19 Post fire front radiant heat

6. FLAME FRONT SIMULATOR

6.1 Liquid Propane Supply

Liquid propane is stored in an 8000-litre tank permanently installed at the RFS Eurobodalla Training Centre at Mogo, NSW. The tank is pressurised by regulated nitrogen to ensure propane arrives at the burner heads in liquid phase. Safety features fitted to the supply include over-pressure valves and overflow valves.

The supply pressure is regulated at 780kPa to avoid fluctuations associated with changing ambient conditions. This supply pressure is typical of the vapour pressure of propane at moderate ambient conditions. If the vapour pressure rises beyond the regulated supply pressure due to solar heating, venting to atmosphere cools the tank and its contents. A pneumatically operated vent valve is fitted to the tank for this purpose.

The pressurised propane is then piped to the simulator grid in a buried 75 mm internal diameter pipe, a distance of approximately 30 metres. The large diameter keeps pressure drops to a minimum. The pipe diameter and supply pressure are a practical compromise between keeping supply pressures moderate and avoiding the problem of two-phase flow.

Two-phase flow occurs if the pressure of propane falls below the vapour pressure at the current temperature of the liquid. A drop in pressure is unavoidable as liquid flows downstream in a pipe. Local low-pressure zones on the inside of sharp corners can also cause local points of vaporisation. In the gas phase, the total mass of propane that will flow at a given pressure is greatly reduced. The sudden reduction in flow reduces the pressure differential and flow returns to liquid – the cycle is repeated as a rapid pulsation with net flow rates much reduced. Two-phase flow is also caused if hot spots develop due to insufficiently insulated pipes near the burner heads or even exposure to the sun. To reduce this possibility, clean sand is heaped over all pipe runs. The problem of two-phase flow is that it causes reduced power output at the burners.

6.2 Burner gas flow control

The main supply line delivers liquid propane to a series of valves which are operated from a control panel in a nearby building. A safety cut-off button is installed on the control panel that will shut the main valve cutting supply to all stages simultaneously.

6.3 Grid layout

Figure 20 shows the grid layout. The clusters of burners in the foreground (shown in blue) are used to control the radiant heat applied to the face of the poles. They consist of a row of 4 groups of 3 burners positioned approximately 5 m from the front of the poles. Each of the three burners in the group has a selected jet size. By utilising a combination of the 3 burners the radiant heat on the wall can be adjusted.

The main burners consist of a grid (shown in red) of 6 by 3 burners spaced approximately 2 m and 1.5 m apart respectively. The first row of the main burners is positioned approximately 0.5 m from the front of the poles. For the flame immersion phase all the burners are turned on.

Figure 20 Grid layout

6.4 Burners

Burner nozzles used are mounted on 150 mm vertical stems off the manifolds. This allows the manifolds to be covered with sand to a depth of 50 to 100 mm for heat insulation see Figure 21. Brass jets, appropriately sized for each test, can be quickly screwed in as needed. For the purpose of flame shaping, each burner has a convex-down deflector approximately 150 mm in diameter mounted 150 mm above the jet. For this experiment the burner nozzles delivered at approximately 16 MW/m of fire line, which is the upper limit of the grid supply network.

The burners are ignited by pilot flames that are lit prior to the start of the test.

Figure 21 main grid burners at full flow

6.5 Audio visual recording

Both still and audio visual records of the test were made. Video cameras from a number of positions were used during the test. Photos were taken during the construction to record the details of construction and the positions of the thermocouples. Photos were also taken during the day of the test to record the conditions before, during and after the test.

7. EXPERIMENTAL PROCEDURE

7.1 Poles orientation

The pole orientation is selected to ensure the burners will produce the correct flame/heat impact on the poles. The poles are orientated with the front facing the North-East which is the dominate wind direction during summer at Mogo. The testing is only scheduled when a high confidence of a steady 2-6 m/s NE wind is forecast. Each pole is positioned adjacent to a main burner giving a pole spacing of approximately 2m and an offset from the burner of 0.5m as shown in Figure 22.

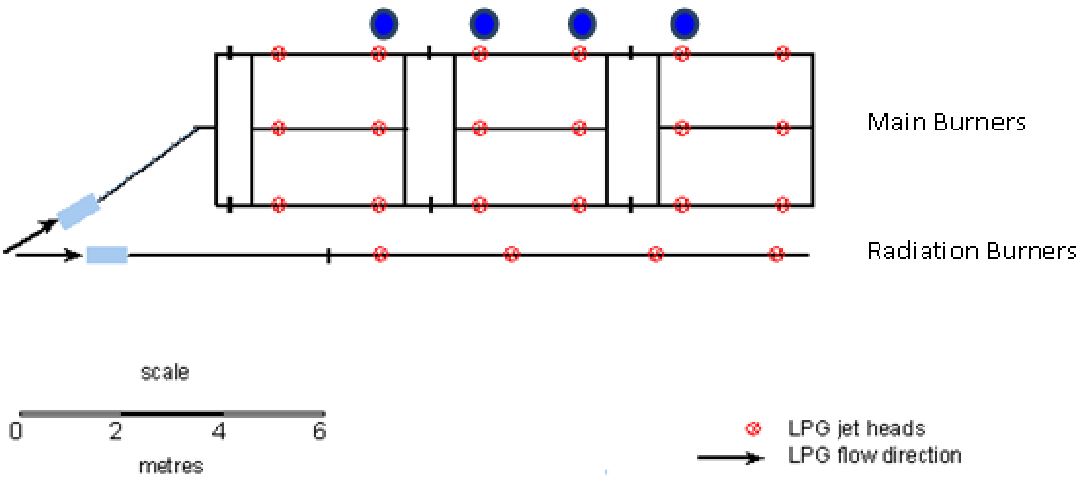


Figure 22 Poles orientation

7.2 Procedure on test day

On the day of the test a briefing was held to provide background information, an overview of the test and the OH&S requirements. This included where visitors could view the test, how to synchronise electronic devices such as cameras and how/what announcements would be made.

The test followed a predetermined timetable. The countdown included scheduled enforcements of safety zones in the region of the simulator and donning of safety apparel.

All personnel responsible for poles instrumentation were required to clear the grid 10 minutes prior to start of test. When instrumentation staff had cleared the grid it was handed over to the simulator controller. From this time on, only the simulator controller and the person he had nominated to light the pilot burners were permitted on the grid.

7.3 Simulation sequence

Ten minutes prior to the test, the simulator grid was primed with liquid propane. Five minutes prior, the pilot burners were ignited. At the nominated time the test was commenced and time zeroed.

The typical sequence of the simulation is given below:

- *Radiant Heat*. Commences at time t=0. Duration and radiant heat intensity follows the profile given in Figure 16. A schedule is used to determine the timing of operation of the individual radiation burners (shown in
- Figure 22). Each group of burners has 3 jet sizes which when used individually or in combination allow various radiant heat levels to be applied to the poles. The burners are manually operated from the control room with feedback from the radiometers on the poles used to fine tune the procedure. The result is a stepwise approximation of the profile required.
- *Flame Immersion.* At approximately 30 minutes into the test the flame immersion phase commences. This involves the activation of the main burners (shown in Figure 18). Six seconds before scheduled immersion, the dump valve is activated and main valve opened to allow rapid priming to burner jets. The dump valve is closed at the scheduled immersion time and, on visual confirmation of the main grid achieving full power, a secondary timer is started. Once the nominated duration of immersion is achieved on the secondary timer, a call is made to the simulator controller to reactivate the dump valve and close the main valve. At this stage the main grid is rapidly depowered. (The flame immersion for this test was scheduled to last 1.8 minutes.)
- *Radiant Heat*. Once the flame immersion phase has finished the radiation burners are again used to provide the post-flame immersion radiant heat profile show in Figure 19. Once this has been completed the grid is deactivated.

Note. The valve must be adjusted to allow for radiation fluctuations as flame angle responds to the ambient wind. There is considerable overshoot and undershoot, so for a precise record of the achieved radiation build up it is necessary to refer to the recorded values rather than the target values.

8. RESULTS AND DISCUSSION

8.1 Wind speed and direction

The wind speed during the test varied between 2-6m/s. This was slightly higher than desirable for the test as a lighter wind (2-4 m/s) would have allowed a higher average flame height. Sufficient flame, radiation and convective heat immersion was achieved at the cross-arm level to cause expected failure of untreated cross-arms and poles. The wind direction varied between North and North-East. Winds persisted through the night into the next day at 0.5- 2m/s in this direction.

8.2 Radiant heat on the front of the poles

- The radiant heat on the front of the poles was measured using the radiometer shown in Figure 14. The readings have been plotted in

Figure 23 with the flame immersion interval shown in orange. The plot differs slightly from the designed profile given in Figure 16 due to the stronger than expected wind affecting the flame impact on the poles. The result was:

- The initial radiation level was higher, $10kW/m^2$ instead of $3kW/m^2$
- The main burners (flame immersion) stage was increased from 110s to 150s to compensate for the reduced flame height.

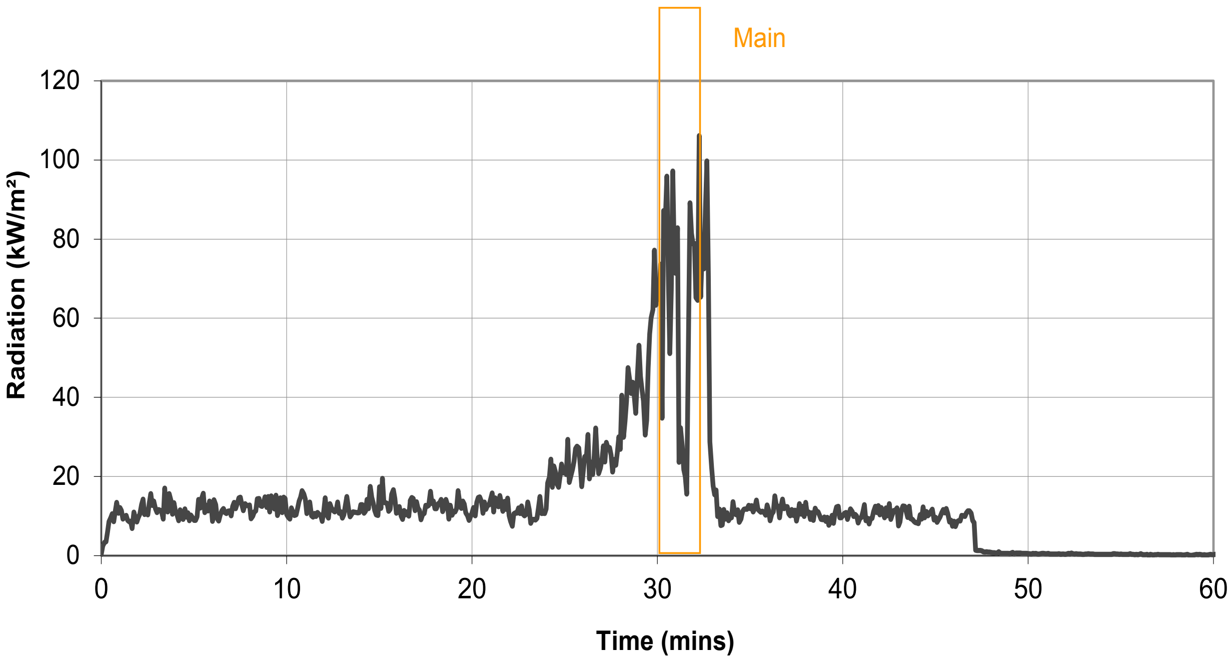
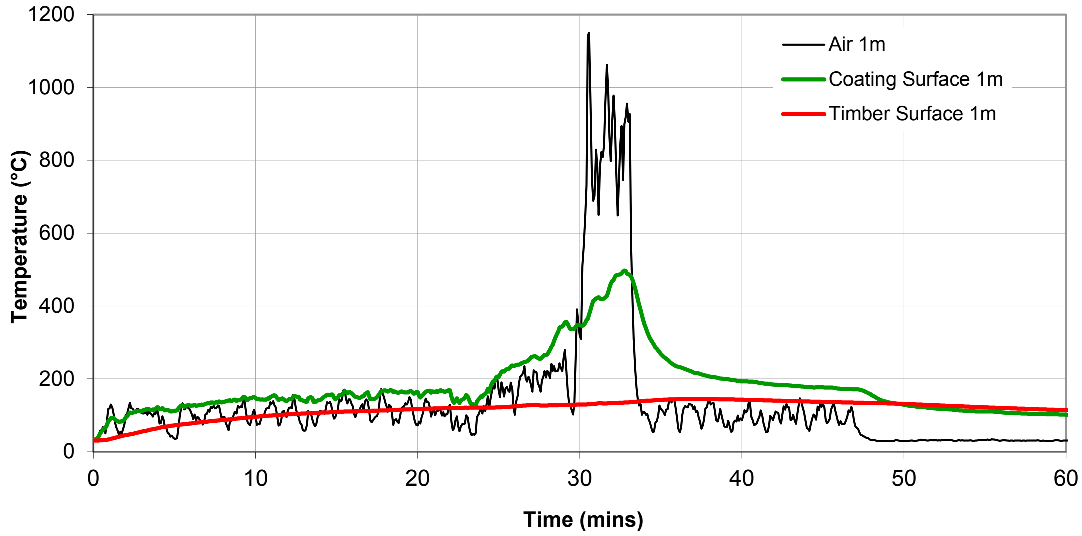


Figure 23 Radiant heat applied to the front of the poles

8.3 Temperature Measurement

- A detailed set of temperature profiles are provided in Appendix A. This section highlights a few of the key temperature profile locations that typify pole behaviour. The temperature measurements 1 meter is the highest thermal load on the poles the temperature at this point is summarised as follows:
- Figure 24, For coated pole
- Figure 25, For Uncoated poles



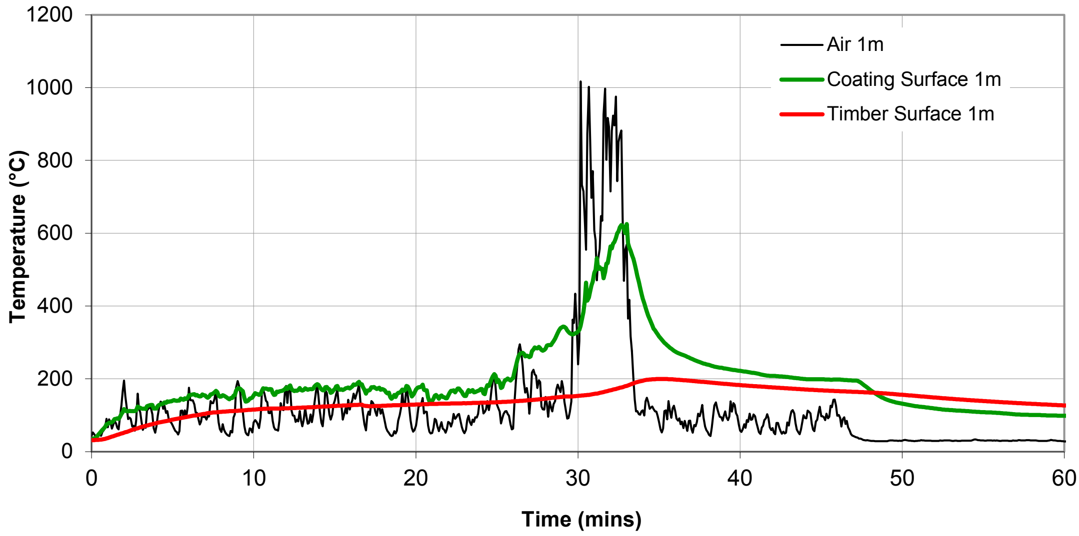
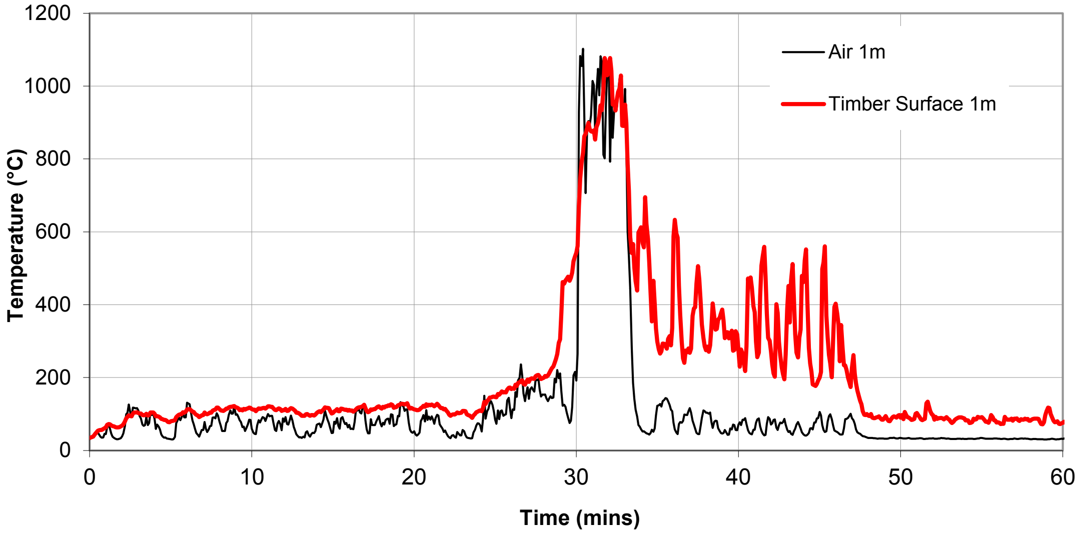


Figure 24 Coated Pole temperature profiles at 1m, Coated 1 top, Coated 2 Bottom



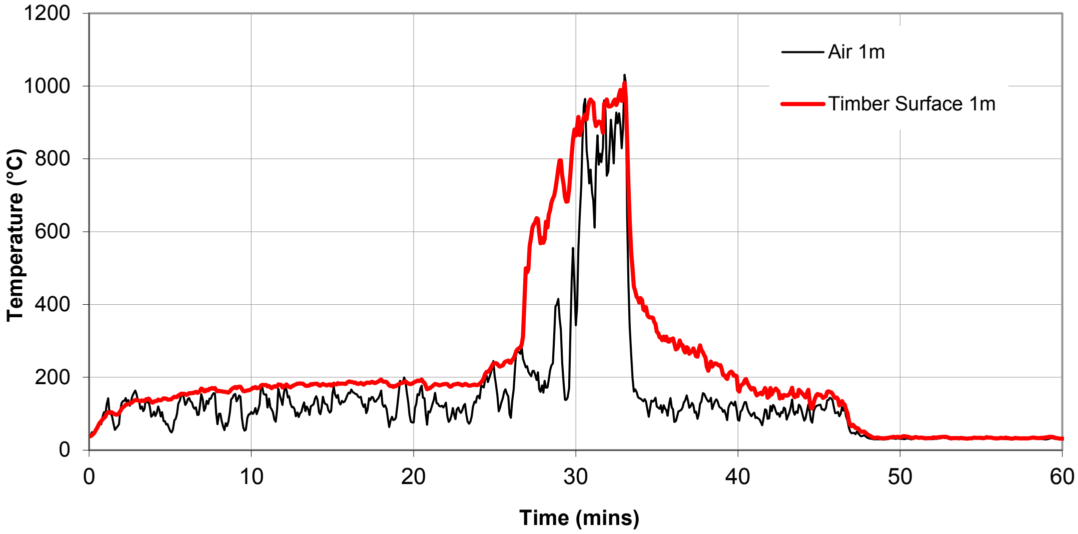


Figure 25 Untreated Poles temperature at 1m, Spotted Gum with Sap wood at the top, Blood wood without Sapwood at the bottom

All poles received a similar thermal exposure as seen in both figures following the black line for external air exposure. The timber surface temperature for treated poles remained below 200 °C which peaked briefly after the end of the main flame front passed. Both timber poles showed surface temperatures higher then air temperature following the main fire front due to ongoing combustion of the timber surface. The uncoated spotted gum pole with sap wood was still higher than air temperature after the 60mintue test due to ongoing combustion while the uncoated Blood Wood pole ceased to burn at 47 minutes when the external radiation ceased.

Visual Assessment

8.3.1 Directly after the test

Photos of the poles after the test are shown in Figure 26.
The following points are noted:

- Pole 1 (treated) continued to smoulder and burn post test well into the following day at which point there was no structural timber left standing, see Figure 26.
- Combustion of pole 3 ceased shortly after radiation ceased except for a small region of pole immediately adjacent to the cross-arm where ingoing smouldering of pole and cross air continued.
- Combustion of the coated poles was not evident when the main flame immersion phase was complete

Figure 26 Poles after test note ongoing smoke emission for pole 1 on left.

- The cross-arms on the uncoated poles are significantly burnt at the joint with the pole and continue to smoulder.
- The cross-arms on the coated poles had no evidence of weakening at cross-arm joint.

Figure 27 cross-arm smouldering at pole interface for uncoated poles, pole 1 left, pole 3 right

8.3.2 17 hours after the test

Photos of the poles 17 hours after the test are shown in Figure 28, Figure 29 and Figure 30.

The following points are noted:

- Most of Pole 1 (treated) has burnt away with only the top and the base remaining. Continues to smoulder, see Figure 28 and Figure 29.
- The coated poles are in the same condition as after the test with only surface charring of the coating of the poles and cross-arms. The charring on the coated cross-arm is shown in Figure 32 showing how the pole to cross-arm interface has no significant charring.
- Pole 3 (untreated) is in a similar condition to after the test with outer surface charring except that the area around the cross-arm attachment had continued to smoulder and ceased at some stage during the night. The extent of the cross-arm damage is shown in Figure 31.

Figure 28 Poles 17 hours after the test

Figure 29 Pole 1 and 2 17hrs after test

Figure 30 Pole 3 and 4 17hrs after test

Figure 31 Cross-arm on Pole 3 (untreated) 17 hrs after test

Figure 32 Coated cross-arm after the test

8.3.3 Cross section through poles

Photos of cross-sections through one of the coated poles (pole 2) are shown in Figure 33. The following points are noted:

- The expanded char thickness at 1m above the ground was 10-20mm thick (see Figure 34 & Figure 34). This equates to 1-2mm of converted coating.
- The pole ground interface showed not specific modes of coating failure, see Figure 35.
- Observations at 2m are similar to 1m.
- At 3m above the ground the char depth is <10mm or less than 1mm of converted coating
- At 4 m above the ground there was no significant charring.
- There is a significant minimum depth of coating remaining (between 3-8mm) on the coated poles (see Figure 35) providing enough protection for at least two more exposures of the same magnitude even if the protective char was removed prior subsequent exposures.
- The timber substrate showed no evidence of charring under the epoxy coating.

Figure 33 Cross-section through pole 2 (coated 1)

(clockwise from top left: 1m, 3m, 5m, 4m sections)

Figure 34 Char depth on coated pole at approximately 1m above the ground

Figure 35 Coated poles being withdrawn from soil

9. CONCLUSIONS

The pole received a worst case bushfire burnover assuming that the pole was completely surrounded by dense forest with no clearance with the assumption that combustible heavy fuel elements such as logs were not resting against the power poles to provide a long term low level flame immersion. The burnover is a combination of worst case time/radiation exposure followed by a worst case flame immersion phase and a heavy fuels burnout phase consistent with an absence of direct heavy fuel contact. The unprotected poles failed in ways consistent with those lost in severe bushfire exposure events while the NanoChar™ coated poles remained structurally sound and serviceable. The following detailed conclusions are provided:

- The performance of the uncoated poles varied. The spotted gum poles with CCA treated sapwood pole were still smouldering after the 47 minute exposure profile and the cross-arm was severely burnt and unserviceable. After a further 17 hours this pole was almost completely burnt away with only the top and base of the pole remaining. The untreated ironbark hardwood pole which had no sapwood present had surface charring but did not burn to collapse. However the cross-arm was severely burnt and would not have been serviceable, the cross-arm pole interface was a point of significant combustion with loss of more than half of the cross-arms thickness.
- The NanoChar™ coated hardwood poles performed well, with only surface charring of the protective coating and no evidence of charring of the timber substrate. The poles and cross-arms remained serviceable and still had sufficient coating depth to resist at least two more heat exposures of the same magnitude. The coating effectively insulates the timber maintaining the timber subsurface of the pole at 1m above the ground to less than 200 ^{o}C throughout the test exposure while external conditions reached 920 ^{o}C.
- A minimum of 2mm of coating appears to be sufficient to protect the timber from burning.
- The coating was effective at providing protection at critical locations such as where the timber cross-arm joins to the pole and on the underside of the cross-arm which experienced a higher heat load compared to the face of the pole at the same height.

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11. Exova Report Number 320109 - Indicative fire test utilising a hydrocarbon temperature/time relationship on four coated steel panels.

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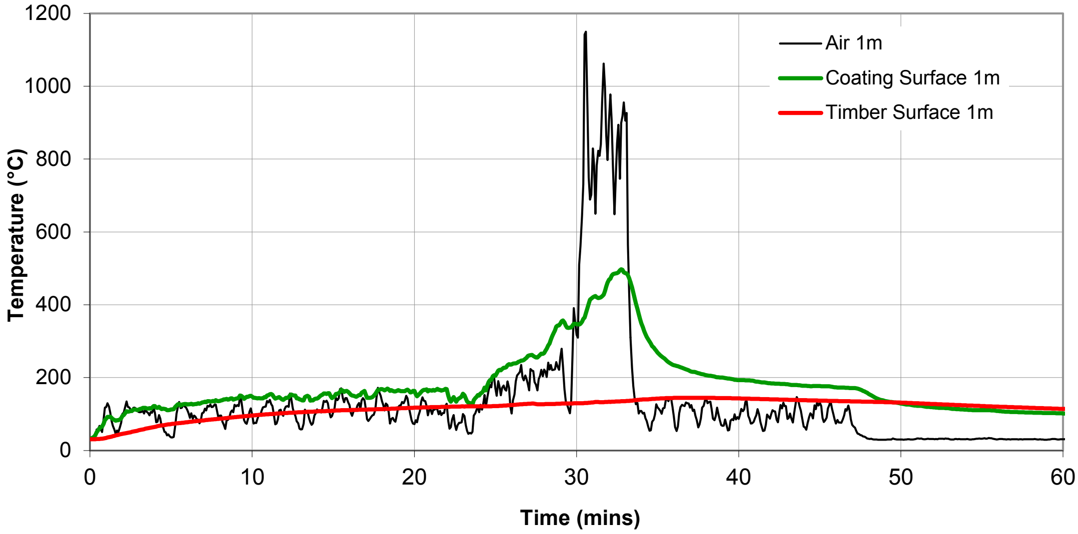
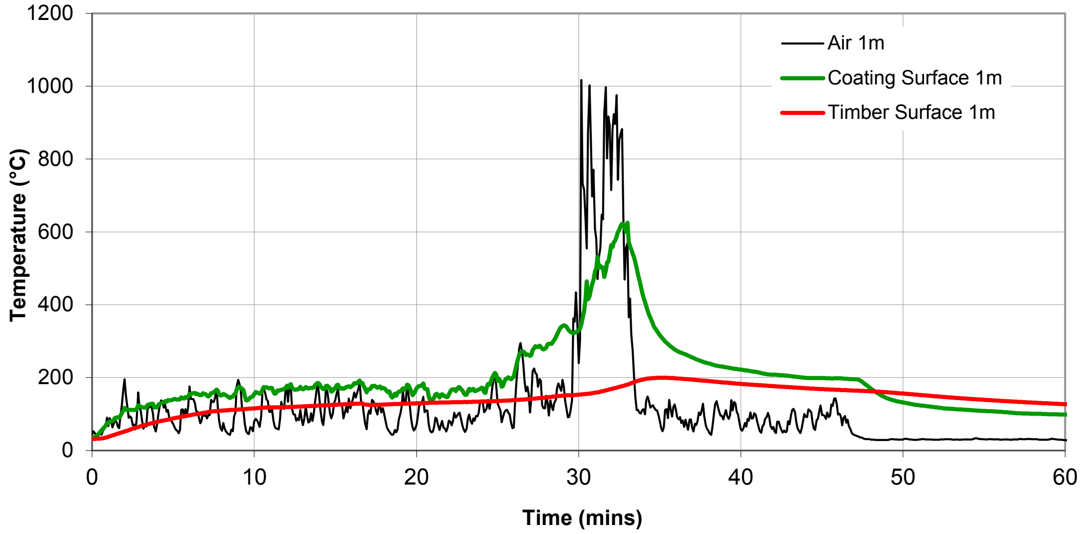
13. ASTM D2898 – 10 Standard Practice for Accelerated Weathering of Fire-Retardant-Treated Wood for Fire Testing, http://www.astm.org/Standards/D2898.htm

14. Gardner. W. D, & White. J. A, Assessing the ability of a large-scale fire test to predict the performance of wood poles exposed to severe bushfires and the ability of fire retardant treatments to reduce the loss of wood poles exposed to severe bushfires.

APPENDIX A, TEMPERATURE PLOTS

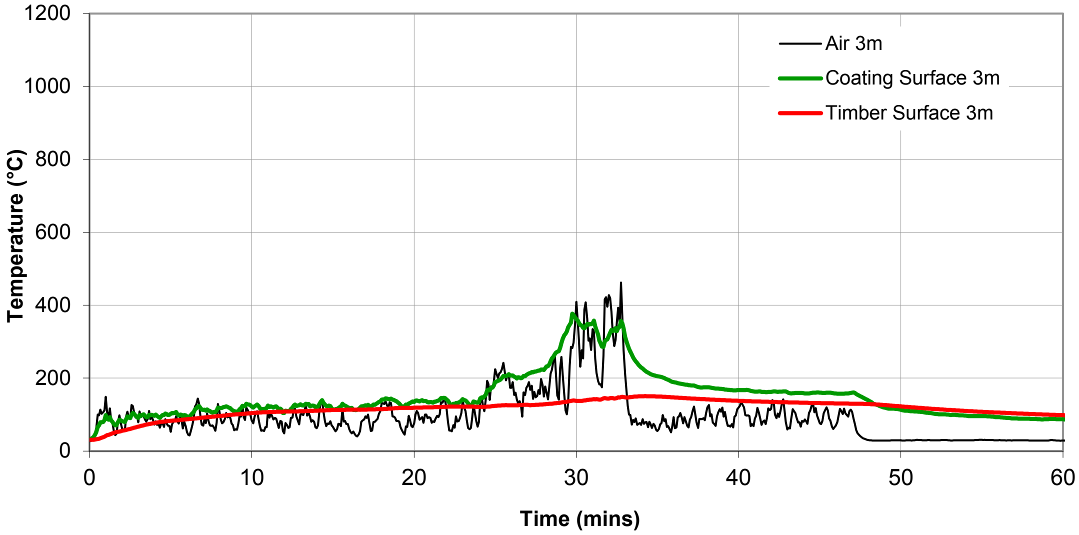


(a) Coated 1



(b) Coated 2

Figure 36 Temperatures at 1m height on coated poles



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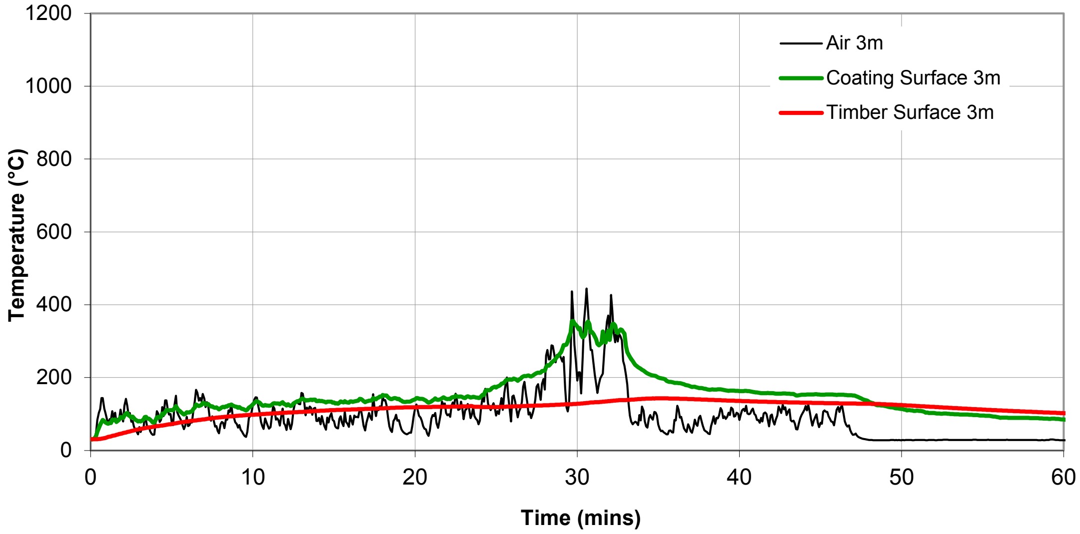
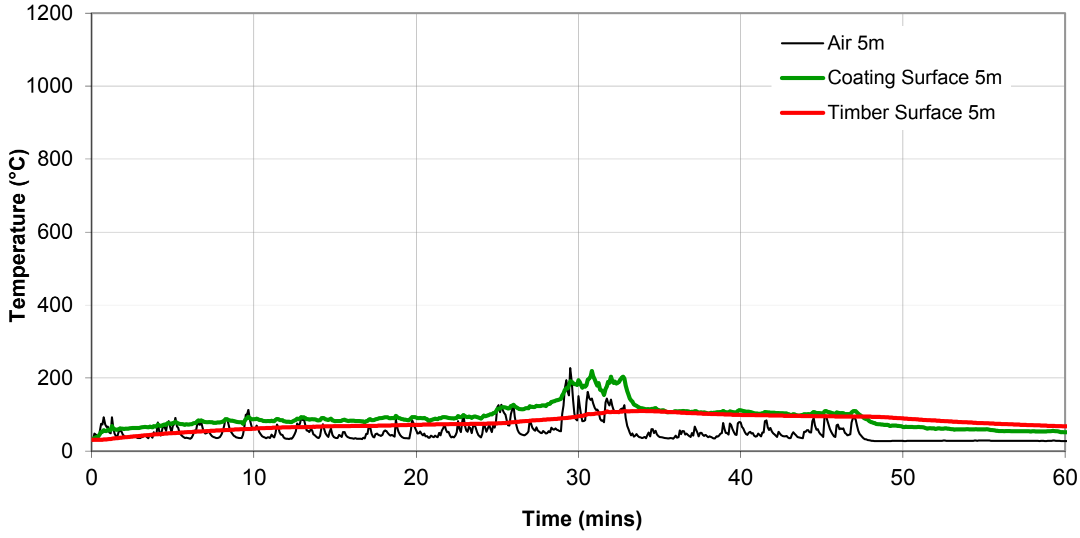
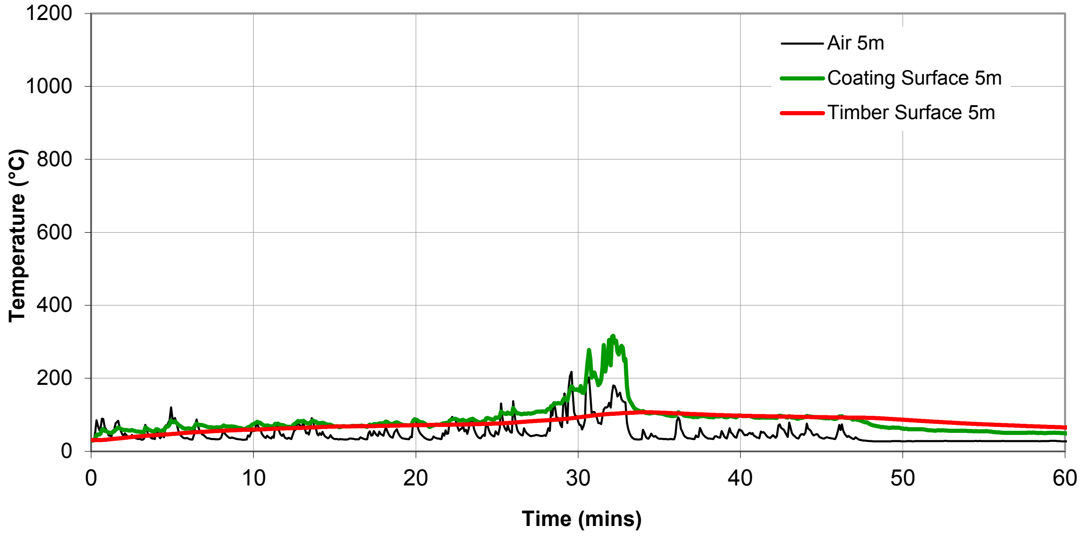


(c) Coated 2

Figure 37 Temperatures at 3m height on coated poles



(a) Coated 1



(a) Coated 2

Figure 38 Temperatures at 5m height on coated poles

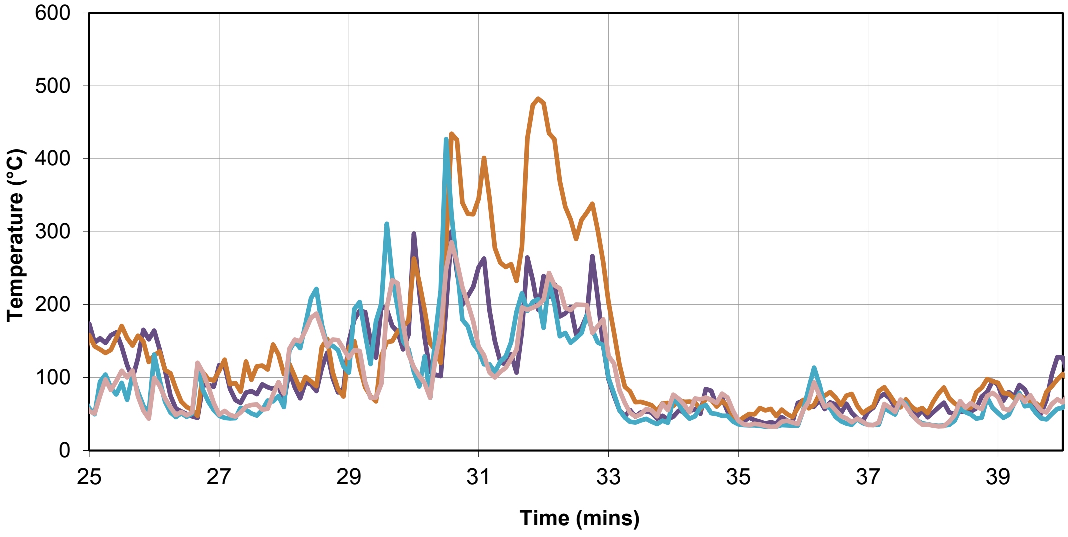


Figure 39 Air temperatures on coated cross-arms during main flame immersion phase

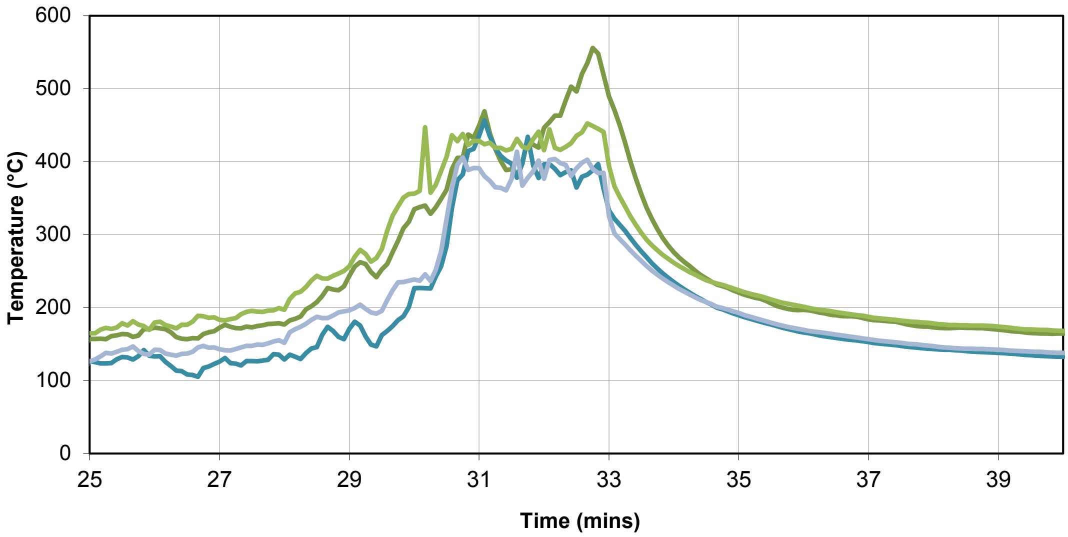


Figure 40 Coating surface temperatures on coated cross-arms

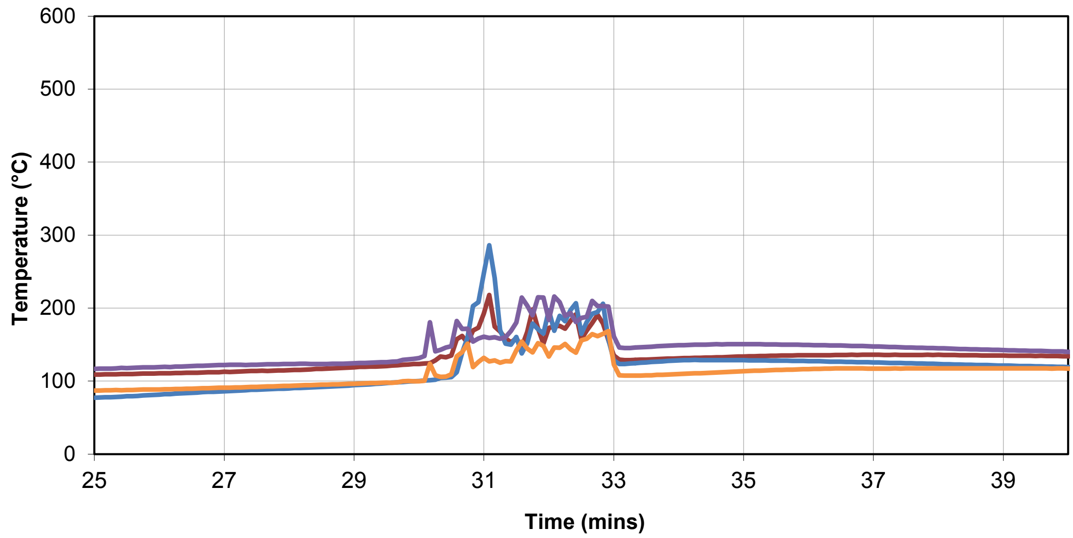
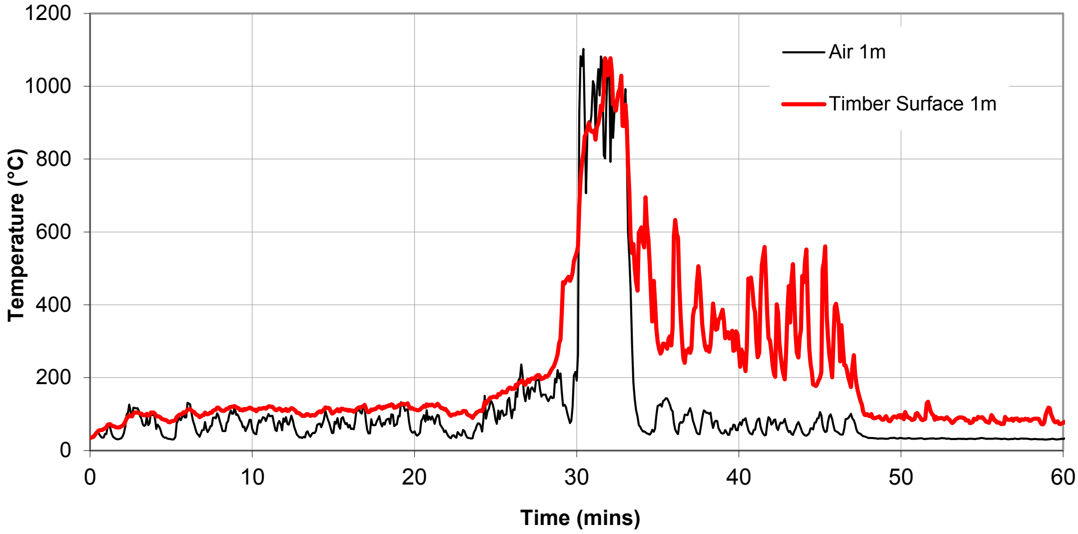
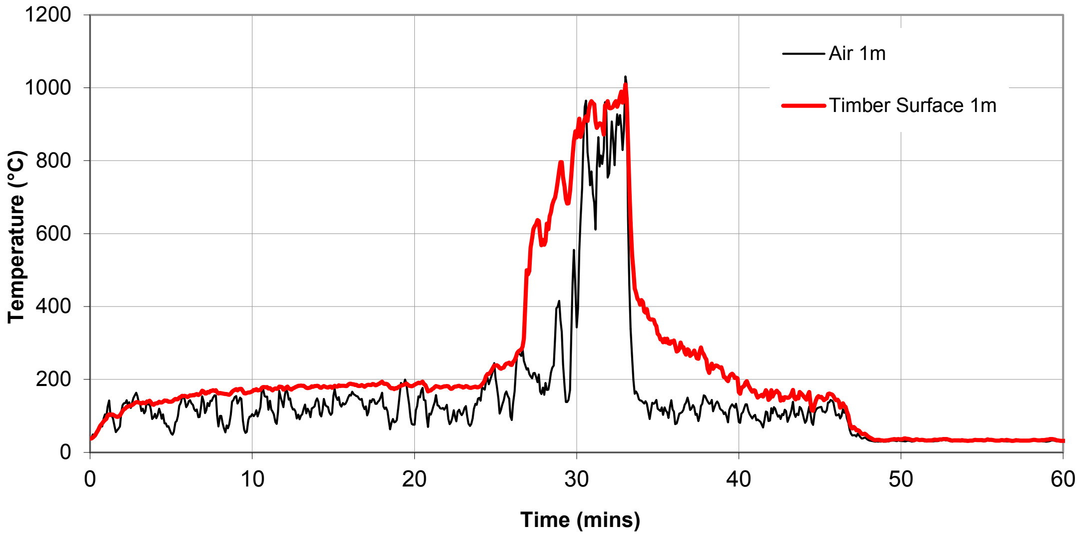


Figure 41 Timber surface temperatures beneath coating on coated cross-arms

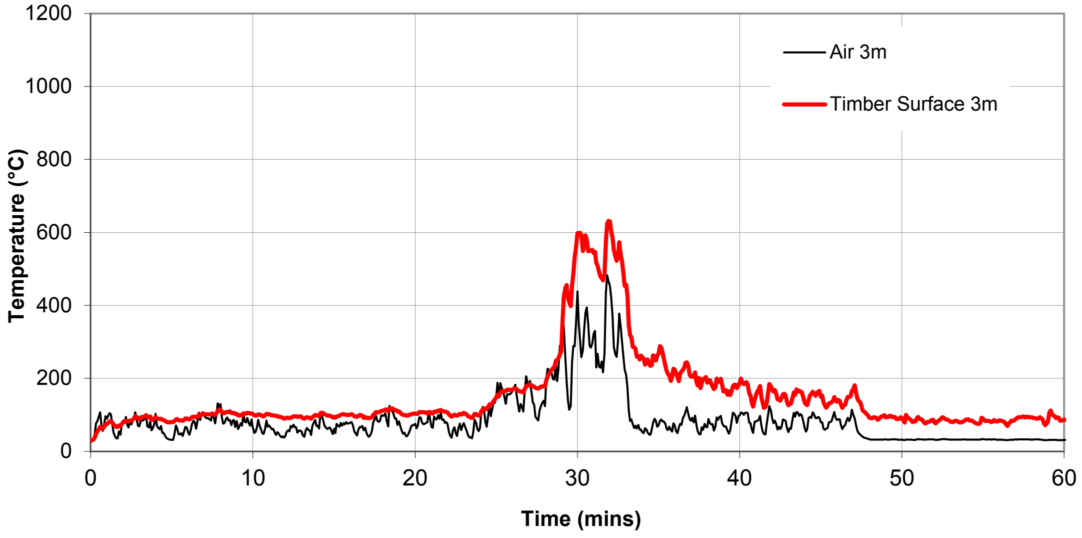


(a) Treated Spotted Gum (pole 1)

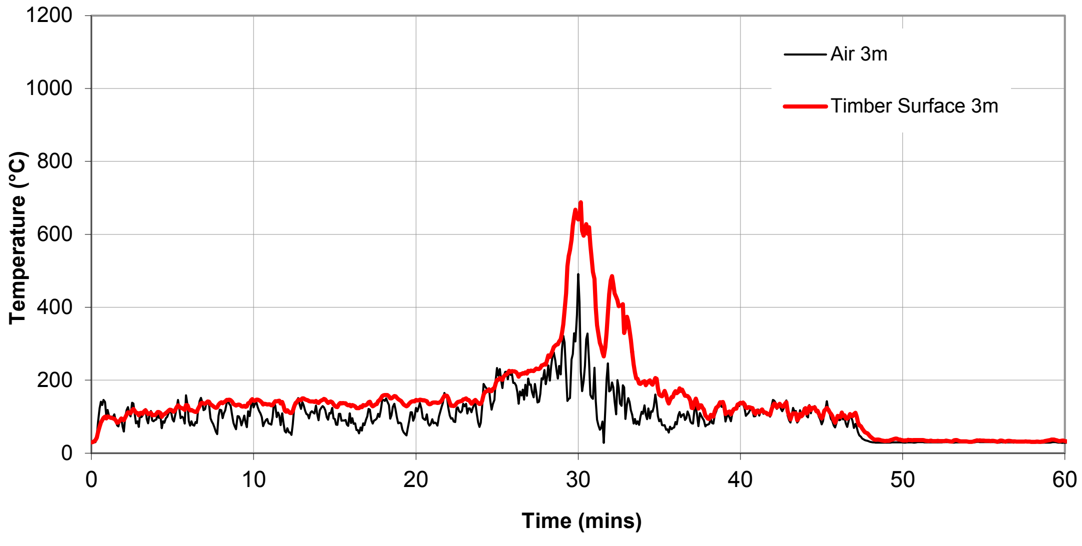


(b) Untreated Blood Wood (pole 3)

Figure 42 Temperatures at 1m height on uncoated poles

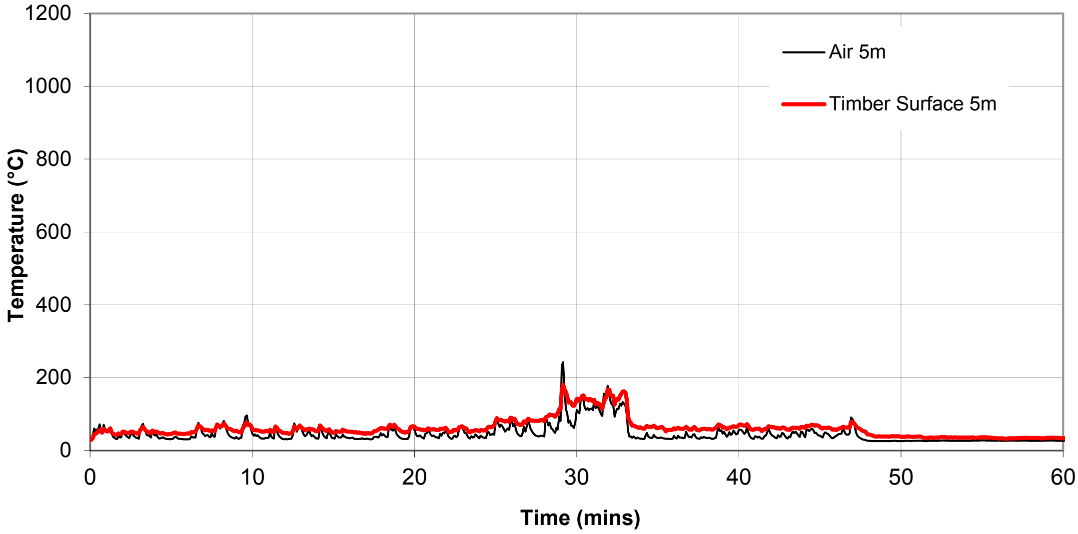


(a) Treated Spotted Gum (pole 1)

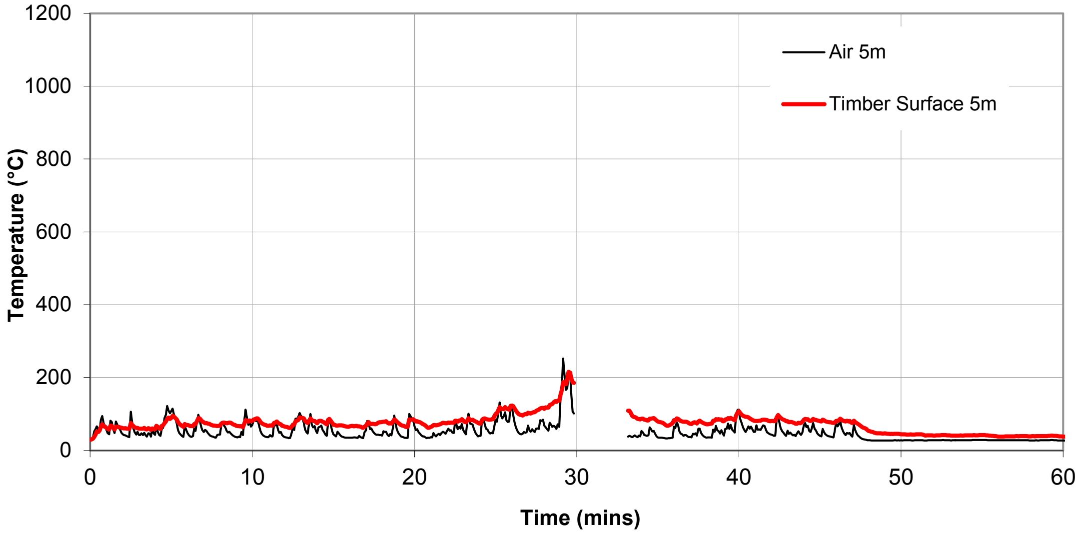


(a) Untreated Blood Wood (pole 3)

Figure 43 Temperatures at 3m height on uncoated poles



(a) Treated Spotted Gum (pole 1)



(b) Untreated Ironbark (pole 3)

Figure 44 Temperatures at 5m height on uncoated poles

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