2020

Self-heating hazard investigation of conveyor belt rubber fines

Basil Beamish
B3 Mining Services Pty Ltd, basil@b3miningservices.com

Jan Theiler
B3 Mining Services Pty Ltd

SELF-HEATING HAZARD INVESTIGATION OF CONVEYOR BELT RUBBER FINES

Basil Beamish[1], Jan Theiler[2]

ABSTRACT: Conveyor belt fires have often been attributed to the heating of accumulated coal fines beneath the belt structure. However, could it be possible that conveyor belt rubber fines produced from friction of the belt in contact with defective rollers or other parts of the belt structure are a self-heating hazard source? The United Kingdom Health and Safety Executive issued a briefing note in December 2012 on the spontaneous heating of piled tyre shred and rubber crumb. This contained information on laboratory experiments that show rubber crumb and tyre shred are more susceptible to self-heating than cellulosic materials (like hay and straw) in conditions of high ambient temperature. No self-heating experiments have been reported for conveyor belt rubber in any form. This paper presents results of adiabatic incubation testing of conveyor belt rubber fines and slack coal fines collected from the immediate vicinity of a recent Queensland underground coal mine conveyor belt heating incident. Incubation test results show that rubber fines generated from conveyor belt friction are able to self-heat from a temperature as low as 84.5 °C. The spongy fibrous form of the rubber fines creates both a high permeability to airflow and a high surface area for oxidation reaction. In addition, the friction mechanism of the conveyor belt rubber fines generation would create an induced temperature required to alter the environmental boundary conditions to the point where self-heating is sustained. When the rubber fines are mixed with slack coal they increase the likelihood of the coal to incubate and create a spontaneous combustion event.

INTRODUCTION

Clothier and Pritchard (2003) noted that among the materials listed by Bowes (1984) that are susceptible to self-heating and spontaneous ignition, rubber-containing products are conspicuously absent. More recent studies (Chen, Yeh and Chang, 1997; Beyler, 2006) have focussed on the self-heating properties of Styrene-Butadiene Rubber (SBR), which is a major constituent of car and light truck tyre retread compounds. SBR is also used in the manufacture of conveyor belts, brake and clutch pads, hoses, extruded gaskets, moulded rubber goods, cable insulation and jacketing, and food packaging (Beyler, 2006). Production of SBR is often in the form of a crumb, which is then used to form the final product. The crumb can be transported and stored in large quantities at a fine particle size. A detailed study by Eremina, Zhurbinskii and Steblev (1991) on comminuted rubber crumb provides valuable insight to the self-heating characteristics of these rubber fines. However, little is known about the self-heating properties of conveyor belt rubber fines.

The United Kingdom recently issued a briefing note on the spontaneous heating of piled tyre shred and rubber crumb (UKHSE, 2019). The following comments are included in the briefing note:

- "Chopping and grinding of tyres produces a low density, porous material through which air may percolate. The total surface area of tyre chips or crumb particles may also be

[1] *Managing Director, B3 Mining Services Pty Ltd. Email: basil@b3miningservices.com Tel: +61 7 3375 4100*
[2] *Senior Mining Engineer, B3 Mining Services Pty Ltd. Email: jan@b3miningservices.com Tel: +61 7 3375 4100*

large compared with the volume occupied. The combination of permeability to air-flow and a high surface area means that a combustible material such as rubber is potentially susceptible to spontaneous combustion.

- "Surface symptoms of the onset of spontaneous combustion can be subtle: a slight sulphurous odour, condensation aerosols emerging from vents or evidence of oil contamination of rainwater draining through the tyre shred. The fire may intensify from smouldering to flaming as the combustion wave reaches the surface or if the pile is disturbed – allowing ingress of additional air."
- "Laboratory experiments show that rubber crumb and tyre shred are more susceptible to self-heating than cellulosic materials (like hay and straw) in conditions of high ambient temperature. Typically a given volume of tyre shred will spontaneously ignite at a lower ambient temperature than an equivalent volume of hay."

The description of a recent drift belt incident at a New South Wales underground coal mine (NSW Resources Regulator, 2019a) has many similarities to a recent Queensland conveyor belt incident and the symptoms described also fit the UKHSE briefing note, including the detection by the smell of burning rubber. The NSW Resources Regulator weekly incident summary documents the following:

"A fire was detected and extinguished by the workers in an underground coal mine. The workers were inbye of the boot end of the drift belt when they smelled burning rubber. On investigation, they identified a return roller running in fines and reported a 'light glow' from the fines. The area was hosed down and cleaned immediately."

It would appear that the cause of the New South Wales incident is attributed to heating of the coal fines with no consideration given to the possibility of the conveyor rubber as the source of heating. This seems to be the reasoning attached to many previous conveyor belt incidents. The coal in this particular incident is from the Bulli seam, which has an identical intrinsic spontaneous combustion propensity rating to the coal from the Queensland Mine of Low (based on an R_{70} value <0.5). The circumstances of these two incidents would seem to be more than just coincidence.

This paper presents the results of an investigation into the spontaneous combustion likelihood of Conveyor Belt Rubber Fines (CBRF) compared to Slack Coal Fines (SCF) from underground workings, using samples supplied of each material from the Queensland conveyor belt incident.

SAMPLE DESCRIPTION AND ANALYTICAL DATA

The CRBF is from severe mechanical abrasion of the 4-ply conveyor belt (Figures 1 and 2). It is in the form of a black spongy fibrous mass (Figure 3), which at a distance is visibly indistinguishable from the SCF obtained from the floor of the roadway adjacent to the incident location. At higher magnification the fibrous nature of the material is quite noticeable (Figure 4), with most of the fibres being less than 200 µm across. It is highly porous and permeable.

Figure 1: Sample of used conveyor belt that generated the CBRF

Figure 2: Sample of used conveyor belt that generated the CBRF, showing Polyester Nylon (PN) webbing embedded in rubber layers

Figure 3: Photograph of ROM CBRF mass

Figure 4: Digital microscope image of CBRF

Proximate analysis and calorific value results for the CBRF and SCF samples are contained in Table 1. The analytical values obtained for the SCF are consistent with a medium volatile bituminous coal. The CBRF has a very high volatile matter content that is consistent with a combustible material. This is emphasised by the calorific value of the CBRF being very similar to the SCF.

Table 1: Analytical data for CBRF and SCF samples

Analysis (air-dried basis)	CBRF	SCF
Moisture (%)	1.8	0.9
Ash (%)	5.5	12.4
Volatile Matter (%)	51.9	23.4
Fixed Carbon (%)	40.8	63.3
Calorific Value (MJ/kg)	29.12	30.15

Pure SBR is composed of 1.38% moisture, 98.58% combustibles (volatile matter + fixed carbon) and 0.04% ash content (Cheh, Yeh and Chang, 1997). The CBRF sample has a much higher ash content than pure SBR indicating the presence of significant inorganic material. Conveyor belt rubber is manufactured as Fire Resistant Anti-Static (FRAS) by the inclusion of inorganic additives. The most common additives are mineral fillers such as aluminium and magnesium hydroxide or other mixed mineral assemblages (Hull, Witkowski and Hollingbery, 2011).The results of an ash analysis of the CBRF and a cored sample from the conveyor belt shown in Figures 1 and 2 are contained in Table 2. These results are compared in Figure 5. It should be noted that the cored conveyor belt sample had and ash content of 16.5%.

Table 2: Ash analysis data for CBRF samples

Inorganic Constituent (wt %)	CBRF	Cored Conveyor Belt
SiO_2	6.8	5.9
Al_2O_3	2.8	69.2
Fe_2O_3	45.28	0.51
CaO	4.5	0.20
MgO	12.65	13.79
Na_2O	4.29	5.49
K_2O	0.20	0.39
TiO_2	0.12	<0.01
Mn_3O_4	0.427	0.002
SO_3	7.40	0.35
P_2O_5	0.66	0.90
BaO	<0.01	<0.01
SrO	0.03	<0.01
ZnO	16.10	3.17

The cored conveyor belt sample recorded high Aluminium contents, with lesser amounts of Magnesium and Sodium (Figure 5). These elements can be related to the inorganic additives included in the rubber for FRAS purposes. However, the CBRF is noticeably deficient in Aluminium and high in Iron with noticeable Zinc also being present (Figure 5). The most likely source of these elements would be from the friction mechanism with the steel conveyor structure that created the rubber fines, with the Zinc coming from either galvanised structure or paint. A minor amount of Calcium is also present in the CBRF sample, which may be due to a trace of stone dust being present in the sample. The low Aluminium content of the CBRF sample indicates it is deficient in fire retardant and this may be due to the fines being generated from friction of the outer side edge of the conveyor belt, which would also explain the fibrous nature.

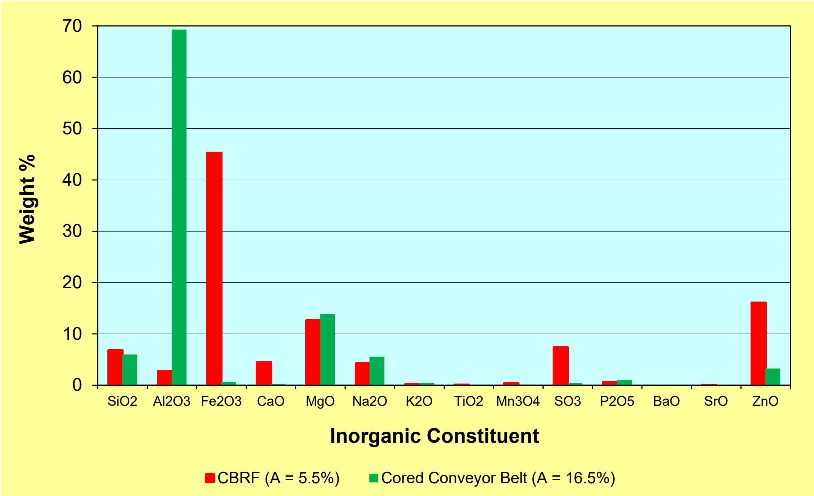

Figure 5: Trends for inorganic constituents from ash analysis of CBRF and cored conveyor belt samples

SELF- HEATING TEST PROCEDURES

Adiabatic oven R_{70} self-heating rate

Full details of the adiabatic oven are given in Beamish, Barakat and St George (2000). The sample to be tested is crushed and sieved to <212 μm in as short a time as possible to minimise the effects of oxidation on fresh surfaces created by the grinding of the coal. A 150 g sample is placed in a 750 mL volumetric flask and a unidirectional flow of nitrogen at 250 mL/min applied to the flask inside a drying oven. Precautions are taken to ensure the exclusion of oxygen from the vessel prior to heating the coal for drying. Hence, the air is flushed from the system at room temperature for a period of one hour. After one hour, the oven is ramped up to 110 °C and the coal is dried under nitrogen for at least 16 h to ensure complete drying of the sample. All R_{70} tests are performed on a dry basis to standardise the test results.

At the completion of drying, the coal is transferred into the reaction vessel and left to stabilise at 40 °C in the adiabatic oven with nitrogen passing through it. The reaction vessel is a 450 mL thermos flask inner. When the sample temperature has stabilised, the oven is switched to remote monitoring mode. This enables the oven to track and match the coal temperature rise due to oxidation. The gas selection switch is turned to oxygen with a constant flow rate of 50 mL/min. The temperature change of the coal with time is recorded by a datalogging system for later analysis. The oven limit switch is set at 160 °C to cut off the power to the oven, and stop the oxygen flowing when the sample reaches this temperature. When the oven cools down, the sample is removed from the reaction vessel, which is then cleaned in preparation for the next test. The results are used to classify the intrinsic spontaneous combustion propensity of the sample according to the rating scheme published by Beamish and Beamish (2011).

Adiabatic oven self-heating incubation

This test is designed to replicate true self-heating behaviour from low ambient temperature. As such, the normal in-mine temperature is used as the starting point for the test. The nature of the test also assumes that in the real operational situation there is a critical pile thickness present that minimises any heat dissipation (represented by the adiabatic oven testing environment) and there is a sufficient supply of oxygen present to maintain the oxidation reaction. A larger sample mass and lower oxygen flow rate is used, compared to the R_{70} test method, to produce conditions that more closely match reality (Beamish and Beamish, 2011).

The sample either reaches thermal runaway, or begins to lose heat due to insufficient intrinsic reactivity to overcome heat loss from moisture release/evaporation and/or heat sink effects from non-reactive mineral matter. The results are used to characterise the self-heating incubation behaviour of the sample as well as quantify if thermal runaway is possible and if so does this occur in a practical timeframe for the mine site conditions.

ADIABATIC SELF-HEATING RESULTS AND DISCUSSION

Intrinsic spontaneous combustion propensity

The R_{70} values for the CBRF and the SCF are 0 and 0.18 °C/h respectively. This indicates both samples have a low intrinsic spontaneous combustion propensity. The rating for the SCF is consistent with the rank and type of coal and fits within the range of previous results for the Queensland Mine. An R_{70} value of 0 obtained for the CBRF is consistent with the self-heating behaviour of rubber at an ambient temperature of 40 °C.

Self-heating incubation behaviour

Incubation testing of the CBRF from a start temperature of 25.1 °C with a moisture content of 2.0% shows no sign of self-heating from this low mine ambient temperature (Figure 6). After step-heating the sample temperature to 39.7 °C using the oven heaters and returning to adiabatic mode also shows no initiation of self-heating. A further step-heat to 69.6 °C also results in no sustained self-heating. However, a step-heat to 100 °C is able to initiate self-heating of the CBRF followed shortly after by thermal runaway (Figure 6). Consequently, these results suggest that self-heating is possible at a temperature between 69.6 °C and 100 °C.

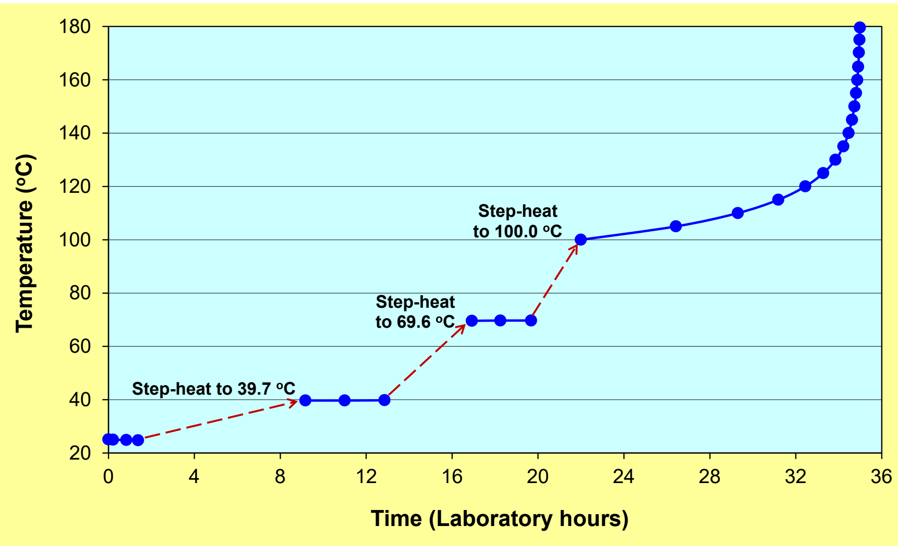

Figure 6: Adiabatic oven test results for CBRF showing self-heating incubation behaviour at successively elevated temperatures

Figure 7 shows the results obtained from starting a new incubation test on a duplicate of the CBRF sample at 84.5 °C. The sample initially slowly self-heats and then progresses to thermal runaway in an exponential manner, suggesting the oxidation reaction is following Arrhenius rate behaviour.

Incubation testing of the SCF from a start temperature of 84.5 °C with a moisture content of 3.8% shows and initial decrease in temperature due to moisture evaporative heat loss (Figure 7). After a substantial period of time, the heat balance between moisture evaporative heat loss and coal oxidation heat production equilibrates and remains balanced for 30 hours. Subsequently, the heat production from coal oxidation takes over resulting in temperature gradually increasing for an extended period of time before eventually accelerating to the point of thermal runaway. In practical terms the time for the SCF to incubate to a spontaneous combustion event is inordinately long and most likely would not occur under normal site conditions.

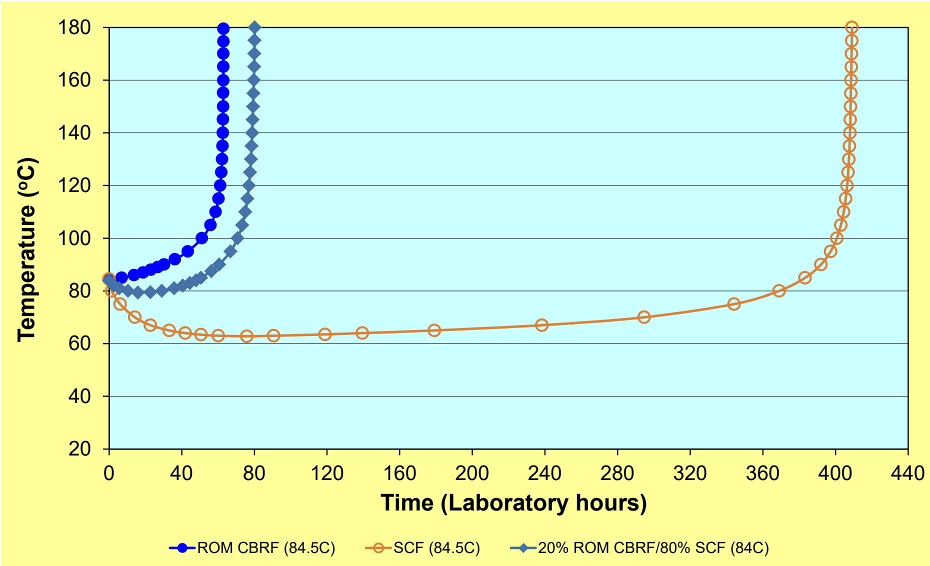

Figure 7: Adiabatic oven test results for CBRF, SCF and a 20%/80% blend of the two showing self-heating incubation behaviour to thermal runaway

The incubation test results for a sample blend containing 20% CBRF and 80% SCF are also shown in Figure 7. This sample blend initially decreases in temperature similar to the SCF, but the heat balance equilibrium point occurs much sooner and the temperature increase to thermal runaway occurs in a much shorter timeframe. This suggests only a minor percentage of the CBRF is needed to increase the likelihood of the SCF to incubate to a spontaneous combustion event in a practical timeframe.

These incubation test results clearly show that the CBRF can more readily self-heat than the SCF. In addition, if the CBRF accumulates with the SCF, this also increases the likelihood of the SCF self-heating. It is highly likely that the friction mechanism that created the CBRF would be capable of elevating the temperature of the material to the point of sustained self-heating. Also the insulating properties of the rubber would enable the development of a hot spot in a relatively thin pile of CBRF. For example, at 100 mm thickness temperatures of approximately 135 °C or higher may lead to spontaneous combustion of comminuted rubber crumb as shown in Figure 8 (Eremina, Zhurbinskii and Steblev, 1991). It should be noted that the particle size of comminuted rubber crumb (0.8-1.2 mm) is much coarser than the CBRF shown in Figure 4. Therefore, at 100 mm thickness the self-ignition temperature of 84.5 °C recorded by the CBRF from incubation testing is realistically consistent with these findings.

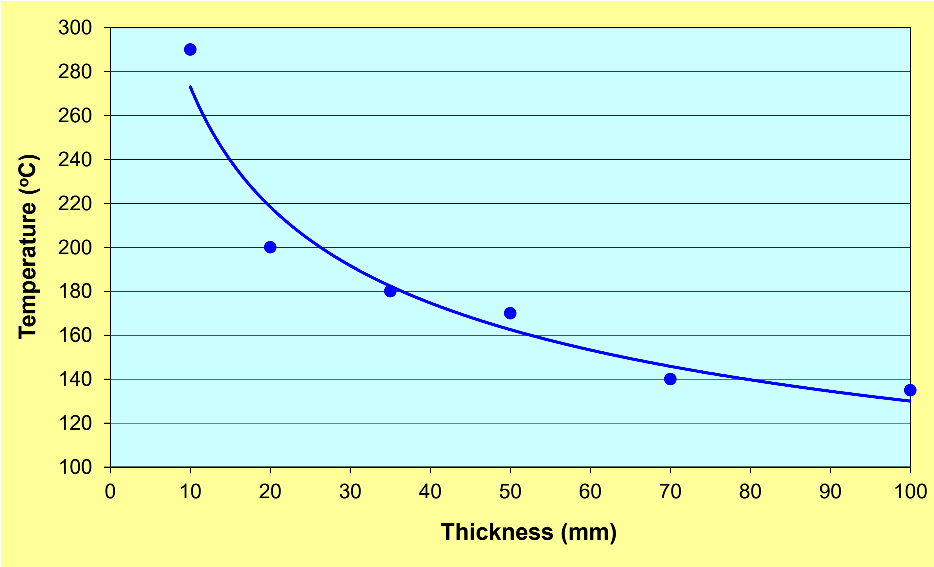

Figure 8: Dependence of comminuted rubber crumb self-ignition temperature on deposition thickness (modified from Eremina, Zhurbinskii and Steblev, 1991)

CONCLUSIONS

This is the first time that adiabatic testing has been conducted on rubber fines from any source. Incubation test results show that rubber fines generated from conveyor belt friction are able to self-heat from a temperature as low as 84.5 °C. The spongy fibrous form of the rubber fines creates both a high permeability to airflow and a high surface area for oxidation reaction. In addition, the friction mechanism of the conveyor belt rubber fines generation would create an induced temperature required to alter the environmental boundary conditions to the point where self-heating is sustained due to the excellent insulating properties of the rubber. When the rubber fines are mixed with slack coal they also increase the likelihood of the coal to incubate and create a spontaneous combustion event.

As a result of these new findings the principal cause of conveyor belt fires needs to be evaluated more closely with a detailed forensic examination of the materials involved. In the meantime a safety bulletin has been issued with the following recommendations (NSW Resources Regulator, 2019b):

- "Review the risk assessment for fires associated with conveyor systems."
- "Update the conveyor management plan to include the risk of spontaneous combustion of rubber fines."
- "Update belt inspection training material and procedures to make workers aware of the risk of rubber fines spontaneously combusting."

REFERENCES

Beamish, B and Beamish, R, 2011. Testing and sampling requirements for input to spontaneous combustion risk assessment, in *Proceedings of the Australian Mine Ventilation Conference*, pp 15-21 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Beyler, C, 2006. Self-heating properties of styrene-butadiene rubber, *Fire Materials*, 30: 215-221.

Bowes, PC, 1984. Self-heating: evaluating and controlling the hazards, HM Stationery Office (London).

Chen, K S, Yeh, R Z and Chang, Y R, 1997. Kinetics of thermal decomposition of styrene-butadiene rubber at low heating rates in nitrogen and oxygen, *Combustion and Flame*, 108: 408-418.

Clothier, PQE and Pritchard, HO, 2003. Atmospheric oxidation and self-heating in rubber-containing materials, *Combustion and Flame*, 122: 207-210.

Ermina, L, Zhurbinskii, S and Steblev, A, 1991. Fire and explosion safety of the production of comminuted rubber crumb, *International Polymer Science and Technology*, 18(8):21-23.

Hull, R, Witkowski, A and Hollingbery, L, 2011. Fire retardant action of mineral fillers, Polymer *Degradation and Stability*, doi: 10.1016/j.polymdegradstab.2011.05.006.

New South Wales Resources Regulator, 2019a. Weekly incident summary – Week ending Friday 31 May 2019, NSW Government. Available from: https://www.resourcesregulator.nsw.gov.au/__data/assets/pdf_file/0004/1137460/Weekly-incident-summary-week-ending-31-May-2019.pdf [Accessed: 7 June 2019]

New South Wales Resources Regulator, 2019b. Safety bulleting – Spontaneous combustion of rubber fines, DOC19/908437, SB19-12.

United Kingdom Health and Safety Executive, 2019. Spontaneous heating of piled tyre shred and rubber crumb – Briefing note [online]. Available from: <http://www.hse.gov.uk/rubber/spontaneous.htm> [Accessed: 30 May 2019].