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Self-Heating Behaviour of Heat-Affected Coal

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SELF-HEATING BEHAVIOUR OF HEAT-AFFECTED COAL

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ABSTRACT: Adiabatic oven testing of heat-affected and normal coal from the same location at Mandalong Mine shows substantial differences in intrinsic self-heating rates and self-heating behaviour. While initial self-heating rates of the heat-affected coal are greater than normal coal under site conditions, there is no sustained self-heating to thermal runaway due to a decrease in the number of reactive sites remaining in the heat-affected coal and greater inaccessibility to those sites that do exist. This behaviour is attributable to the vesicular nature of the heat-affected coal contributing to easy access to open pores resulting in the initial burst of self-heating. However, the thermal alteration of the coal also contributes to destruction of reactive sites and makes access to the remaining reactive sites in the micropore system of the coal more difficult.

INTRODUCTION

Adiabatic oven testing has been used routinely by Australian and New Zealand coal mine operations since the early 1980's to rate the propensity of coal to spontaneously combust (Humphreys *et al.,* 1981). Many different features of coal have been studied using this technique to establish their affect on self-heating rates. These include: changes in coal rank (Beamish and Arisoy 2008 and Beamish and Beamish 2012); coal type (Beamish and Clarkson 2006); and mineral matter composition (Beamish and Blazak 2005 and Beamish and Sainsbury 2008).

As coal rank increases due to the natural coalification process the coal changes both chemically and physically and this results in a decrease in the intrinsic self-heating rate of the coal. Some seams can come into contact with or are adjacent to igneous intrusions, and under these circumstances the coal is artificially rank advanced through the devolatilisation that takes place in response to the exceedingly high temperatures experienced by the coal (Ward *et al.,* 1989; Kwiecinska and Petersen 2004 and Singh *et al.,* 2007). This results in what is commonly referred to as heat-affected or coked coal. The self-heating behaviour of such coal is not reported in the literature and this paper presents the results of recent self-heating tests of both heat-affected and normal coal from the same location of the Mandalong Mine in New South Wales.

COAL SAMPLES AND ADIABATIC TESTING

Within the general vicinity of Main gate19 at Mandalong Mine a localised igneous sill has penetrated the upper part of the seam and reaches a thickness of roughly 80 cm. Approximately 1.5 m of heat-affected coal overlies the sill. This coal will be caving into the goaf as the longwall panel extracts the coal from below the sill. It is therefore important to establish the spontaneous combustion propensity of the heat-affected coal in comparison with the normal coal from the same area to ensure appropriate management practices are in place. In addition, due to the expected rank increase of the heat-affected coal due to thermal alteration, a high rank bituminous coal from the Goonyella Lower Seam is used in this paper to compare the self-heating behaviour.

The coal quality details of the samples are contained in Table 1. The normal Mandalong coal is high volatile A bituminous in rank and the heat-affected coal has decreased in volatile matter from 35.9% to 5.1%, which creates an artificial rank elevation equivalent to anthracite. The heat-affected coal also shows an increase in ash content due partially to concentration of the existing mineral matter as the coal

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devolatilised and injection of extraneous mineral matter from the intrusive fluids accompanying the sill emplacement.

Samples of both normal and heat-affected coal from MG19 have been tested using an adiabatic oven to establish their R70 values and to benchmark the time taken to reach thermal runaway (incubation period) under conditions more closely resembling those of the mine site. The R70 testing procedure is described by Beamish (2005) and essentially involves testing a dried, crushed coal sample under adiabatic conditions from a fixed starting temperature of 40° C. The incubation test procedure, known as SponComSIM™ testing, uses the coal in its as-mined moisture state from a starting temperature that reflects the site-specific conditions. The results obtained provide both an indication of the time taken to reach thermal runaway and the characteristic behaviour of the coal as self-heating progresses. This can be compared against case history coals of known self-heating behaviour as well as mine site experience.

Table 1: Coal quality data for coal samples from MG19, Mandalong Mine and high rank Goonyella Lower Seam

	Mandalong		Goonyella Lower Seam
	Normal Coal	**Heat-affected Coal**	
PROXIMATE ANALYSIS (air-dried basis)			
Moisture (%)	2.2	2.5	1.2
Ash (%)	18.5	28.2	21.9
Volatile Matter (%)	29.5	5.7	17.2
Fixed Carbon (%)	49.8	63.6	59.7
ULTIMATE ANALYSIS (dry ash-free basis)			
Carbon (%)	82.3	91.2	86.9
Hydrogen (%)	4.98	2.17	5.00
Nitrogen (%)	1.68	1.75	1.78
Sulphur (%)	0.38	0.19	0.56
Oxygen (%)	10.7	4.7	5.8
COAL RANK PARAMETERS			
Volatile Matter (%, dry mineral matter free)	35.9	5.1	20.4
Calorific Value (Btu/lb, moist mineral matter free)	14061	na	na
ASTM rank	hvAb	an	lvb

na – not applicable; hvAb – high volatile A bituminous; lvb – low volatile bituminous; an – anthracite

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ADIABATIC TESTING RESULTS AND DISCUSSION

R70 values and intrinsic self-heating rate behaviour

The R70 self-heating rate curves for the normal and heat-affected coal samples from MG19 are shown in Figure 1. The normal coal has an R70 value of 2.12 °C/h, which rates the coal as having a medium intrinsic spontaneous combustion propensity (Beamish and Beamish 2012). However, the heat-affected coal initially self-heated before the temperature levelled out at 62 °C and did not reach the standard 70 °C that is used to define the R70 value of the coal. Therefore, the R70 value of the heat-affected coal is recorded as 0.

Figure 1 also contains the self-heating curve for a high rank bituminous coal sample from the Goonyella Lower Seam. It can clearly be seen that the heat-affected coal has an initial self-heating rate that is faster than the Goonyella Lower Seam sample, but the two self-heating curves cross over after about 40 hours on test. Subsequently, the Goonyella Lower Seam sample proceeds to thermal runaway, whereas the heat-affected coal sample stalls. This is presumably related to a combination of both physical and chemical difference between the two coal samples. Heat-affected coals contain vesicles in the form of pits and cavities of variable sizes due to the escape of volatiles (Singh *et al.,* 2007). This enables easy access of oxygen to available reactive sites initially. However, a majority of the original reactive sites are destroyed due to the thermal alteration process from the igneous intrusion and the remaining reactive sites are contained in the much finer micropore system of the heat-affected coal, which has undergone significant annealing thus reducing the accessibility to these remaining reactive sites.

The heat-affected sample was step-heated to just over 100 °C to compare against the exponential self-heating rate of the Goonyella Lower Seam sample from this same temperature. The results are shown in Figure 2. Even at elevated temperatures the self-heating rate of the heat-affected coal is quite slow and there is no major rise in the self-heating rate until the coal temperature exceeds approximately 150 °C.
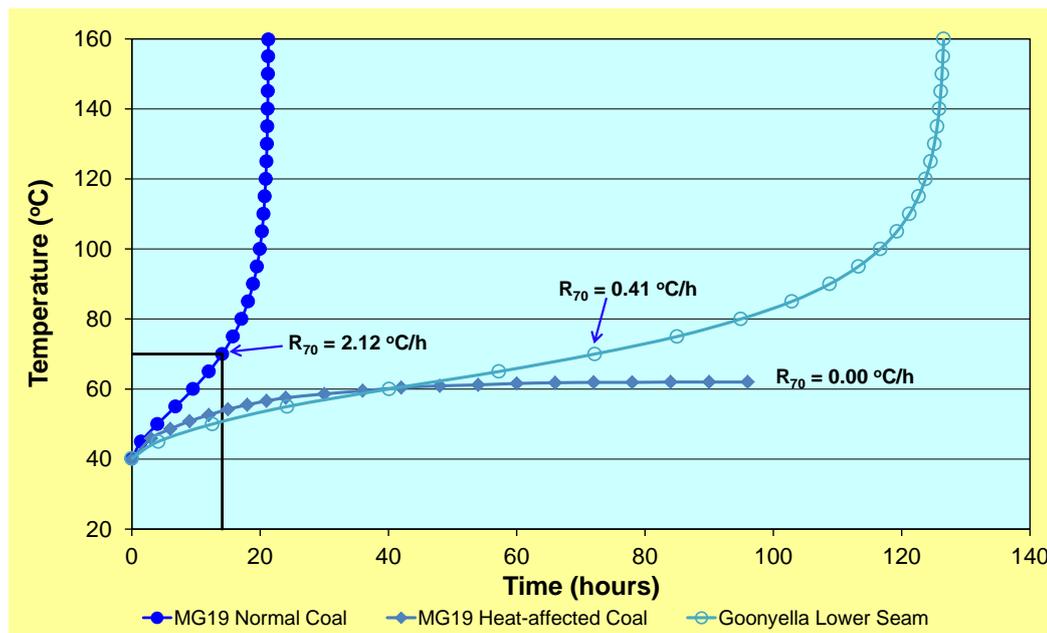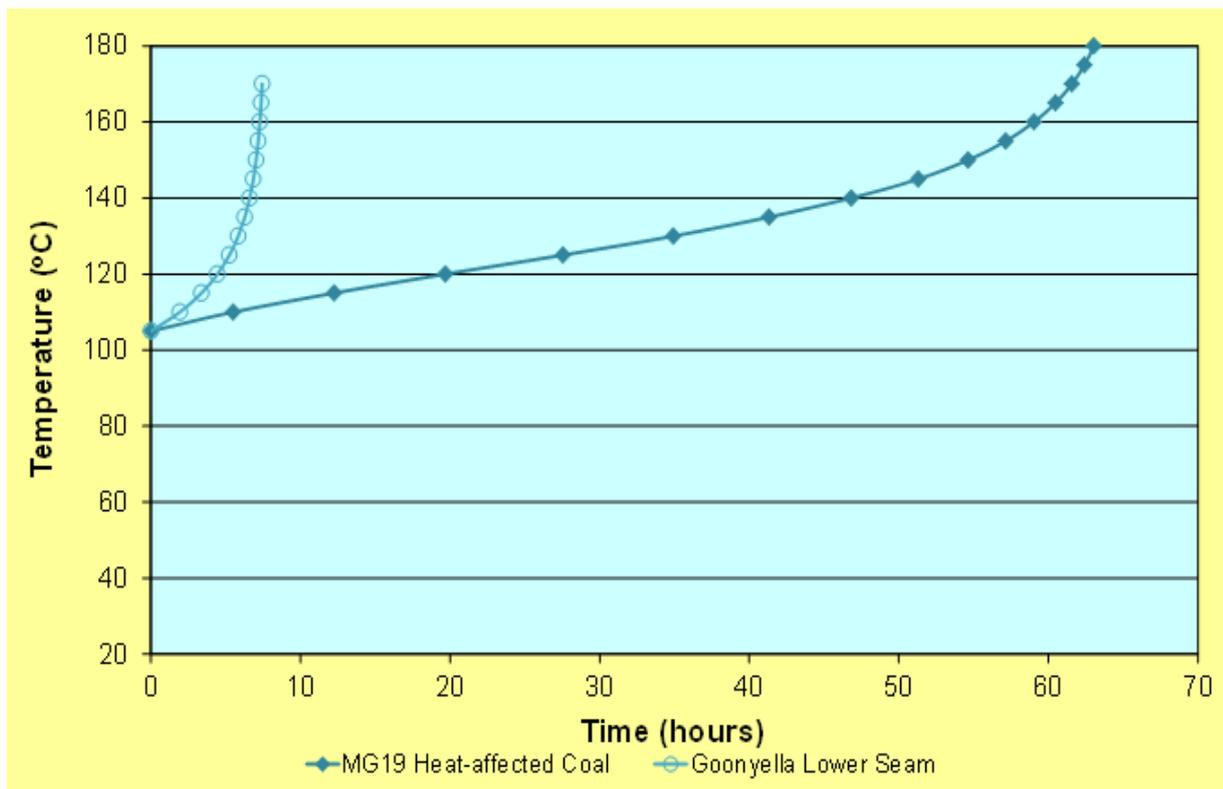

Figure 1: Adiabatic R_{70} self-heating curves for normal and heat-affected coal from MG19, Mandalong Mine compared against high rank bituminous coal from the Goonyella Lower Seam

Figure 2: Comparison between self-heating rates of heat-affected coal from MG19 and Goonyella Lower Seam coal at elevated temperatures

Incubation testing and self-heating behaviour

The SponComSIM™ test results for the heat-affected and normal coal from MG19 are shown in Figure 3. The initial self-heating rate of the heat-affected coal is greater than the normal coal, which again can be attributed to the open pore structure (vesicular nature) of the heat-affected coal. However, after reaching a maximum temperature of approximately 38 °C, the temperature of the heat-affected coal gradually decreases due to the overriding influence of moisture evaporation combined with hindered access and a decrease in the number of reactive sites. It is clear from these results and the results of the R70 self-heating rate testing that the heat-affected coal is not capable of reaching thermal runaway, unless it is exposed to a significant external heat source. Even then, it would take a considerably long time for the coal to reach thermal runaway. If the normal coal was present in a loose pile of critical thickness with sufficient continuous air supply and minimal heat dissipation, then spontaneous combustion incubation would be possible to elevated temperatures. However, this is strongly mitigated by the goaf inertisation practice in use at Mandalong, which utilises methane from the in-seam gas drainage system to inert the goaf atmosphere (Claassen 2011).

CONCLUSIONS

The results of adiabatic self-heating tests from normal and heat-affected coal, once again show that coal self-heating performance is not a simple predictable behaviour. Under ideal site conditions, the heat-affected coal is capable of initially self-heating above ambient temperatures, but due to the combined effects of moisture evaporation as well as limited access and the decrease in the number of reactive sites, sustained self-heating is not possible without the presence of a significant external heat source. The physical and chemical changes to the coal created by thermal alteration from an igneous sill have contributed to the self-heating behaviour observed. From a risk management perspective the caving of this coal into the goaf does not therefore create any additional risk of creating a spontaneous combustion event.
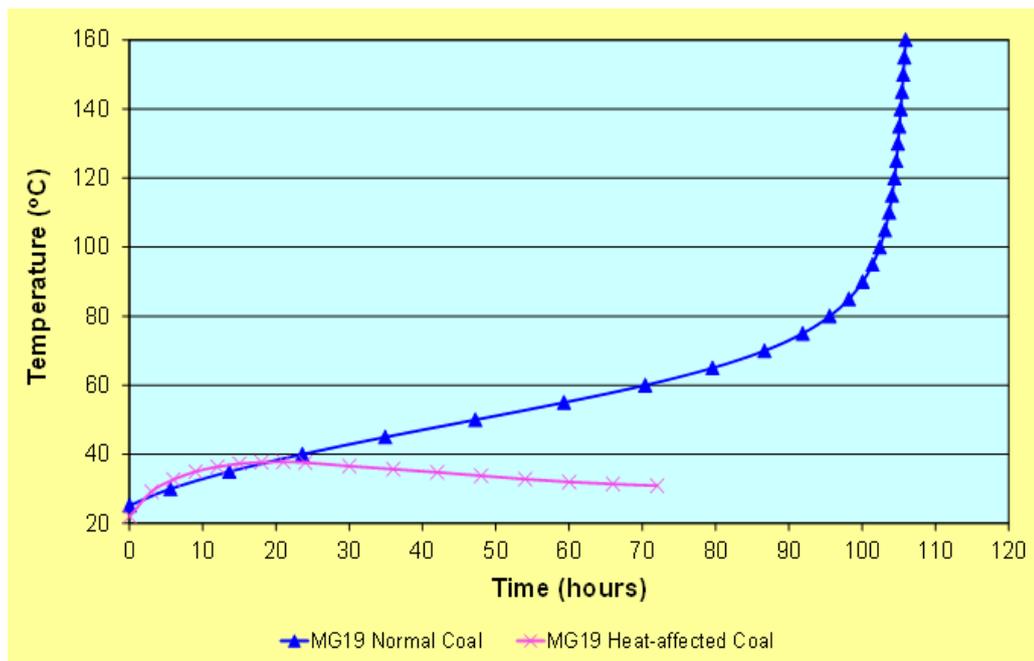
Figure 3: Adiabatic SponComSIM™ self-heating curves for normal and heat-affected coal from MG19, Mandalong Mine

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