Variations in the properties of partially burnt coal chars and implications on the blast furnace process

Julian Steer*, Richard Marsh*, Dane Sexton*,
Mark Greenslade¥

*Cardiff School of Engineering, Queen's buildings, Cardiff, UK
¥ Tata Steel UK, Port Talbot

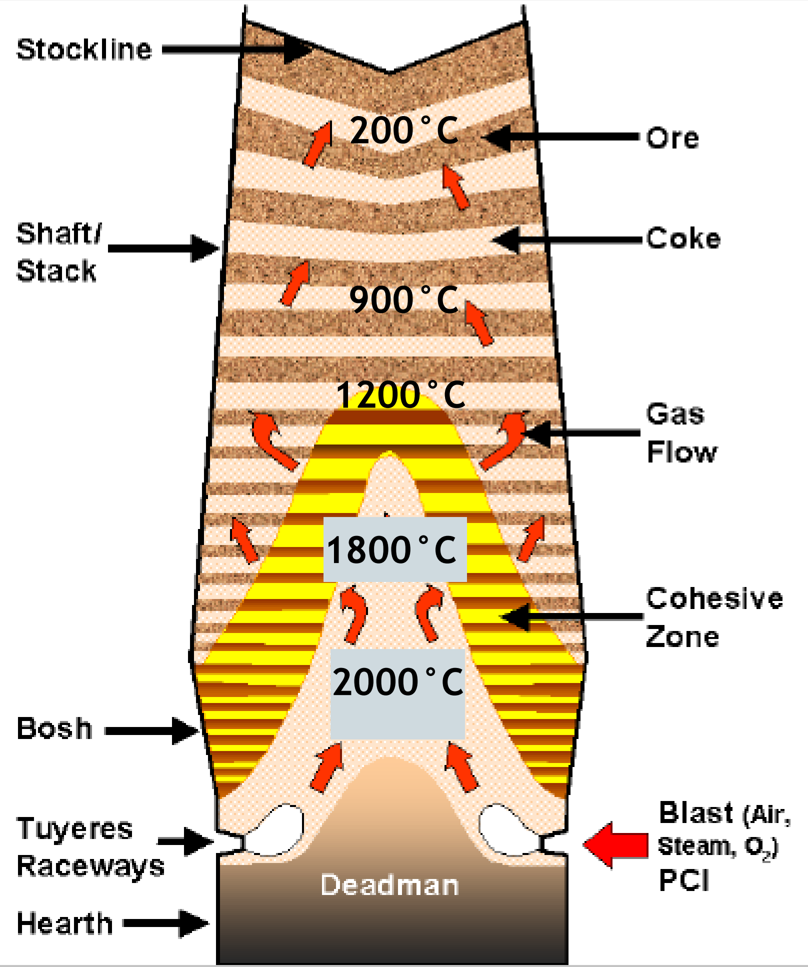
Aims

1. Investigate the suitability of coals for injection into blast furnaces
2. Compare the reactivity and properties of partially burnt coal chars
3. Determine the potential implications on the blast furnace process

Objectives

- Use a drop tube furnace to measure coal burnout and produce chars
- Use a thermogravimetric analyser/differential scanning calorimeter to analyse chars.
- Identify the properties affecting the char reactivity.
- Determine potential impact of partially burnt chars on the blast furnace
- Use advanced analytical techniques to explain observed differences in the burnout and gasification reactivities

Introduction - blast furnace coal injection



Assessment of refractory condition in a blast furnace hearth using computational fluid dynamics, Wright et al, 3rd international conference on CFD 2003

Blast furnace (cross section)

- Counter current heat-mass exchanger
- Wide temperature gradient
- Variable gas composition

Introduction – implications of partially burnt coal chars

- Particulate emissions (Blast furnace dust)
- Reduced burden permeability
- Thermal instability
- Reduced efficiency

Introduction – char preparation and testing

Drop tube furnace (DTF)

Coal burnout / Char preparation

1100°C in air

Thermogravimetric/DSC analyser

Char gasification testing

900°C isothermal test
with CO_2 flow at 100ml/min

X-ray photoelectron spectroscopy (XPS)

Surface analysis

Introduction – coal sample properties

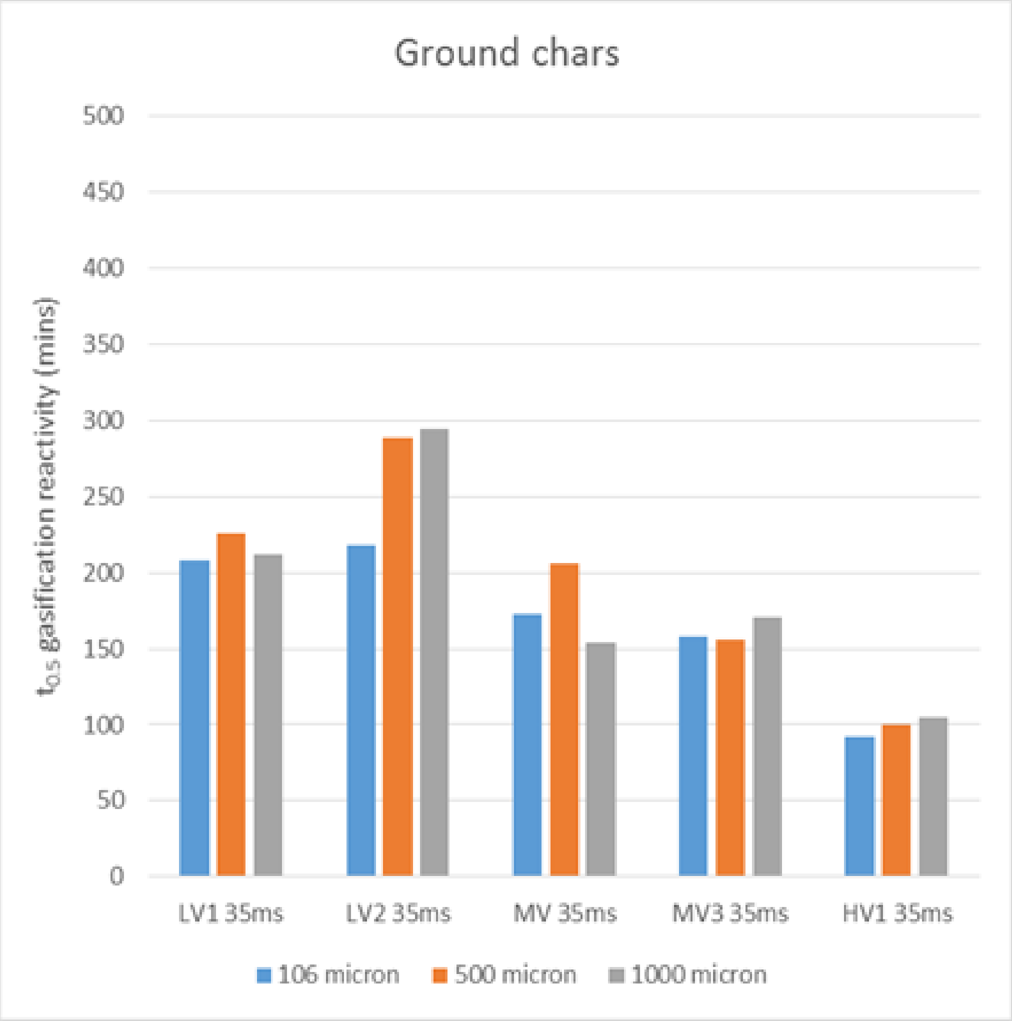
	Proximate analyses (oven dried)			Petrographic analyses			
Coal type	Volatile matter content (% wt)	Ash content (% wt)	Fixed carbon content (% wt)	Vitrinite (% vol)	Liptinite (% vol)	Inertinite (% vol)	Mineral matter (% vol)
LV1	8.2	5.8	86.0	83	1	14	2
LV2	12.5	8.6	78.9	60	0	39	1
LV3	14.4	4.7	80.9	78	1	18	3
MV1	24.4	7.8	67.8	52	1	46	1
MV3	20.3	7.8	71.9	78	1	20	1
MV4	17.6	5.2	77.2	72	6	20	2
HV1	33.0	6.9	60.1	71	10	17	2

Coal sample sieve classifications
100% <1mm 50%<250µm
100% < 500µm
100% <106µm

Physical and chemical effects in partially burnt chars

- Particle fragmentation and swelling
- Agglomeration
- Char gasification reactivity
- Different surface chemistry (functional groups and reactive sites)
- Carbon-carbon bonding (sp^2 hybridisation, bond rearrangements)
- Heatflow associated with gasification reaction

Results - Char gasification reactivity



Partially burnt chars

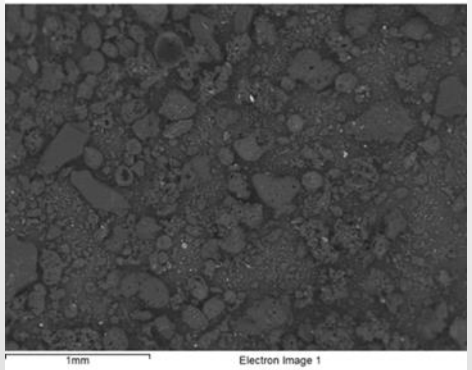
Reverse Boudouard gasification reaction

$$CO_2 + C \leftrightharpoons 2CO$$

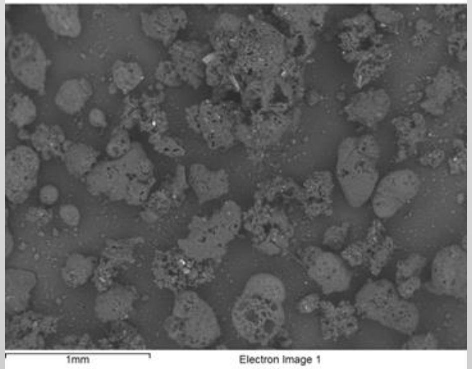
Gasification reactivity

$t_{0.5}$ = time to reach 50% conversion

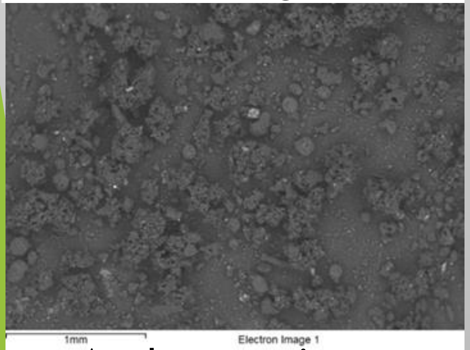
Results – Char physical property effects



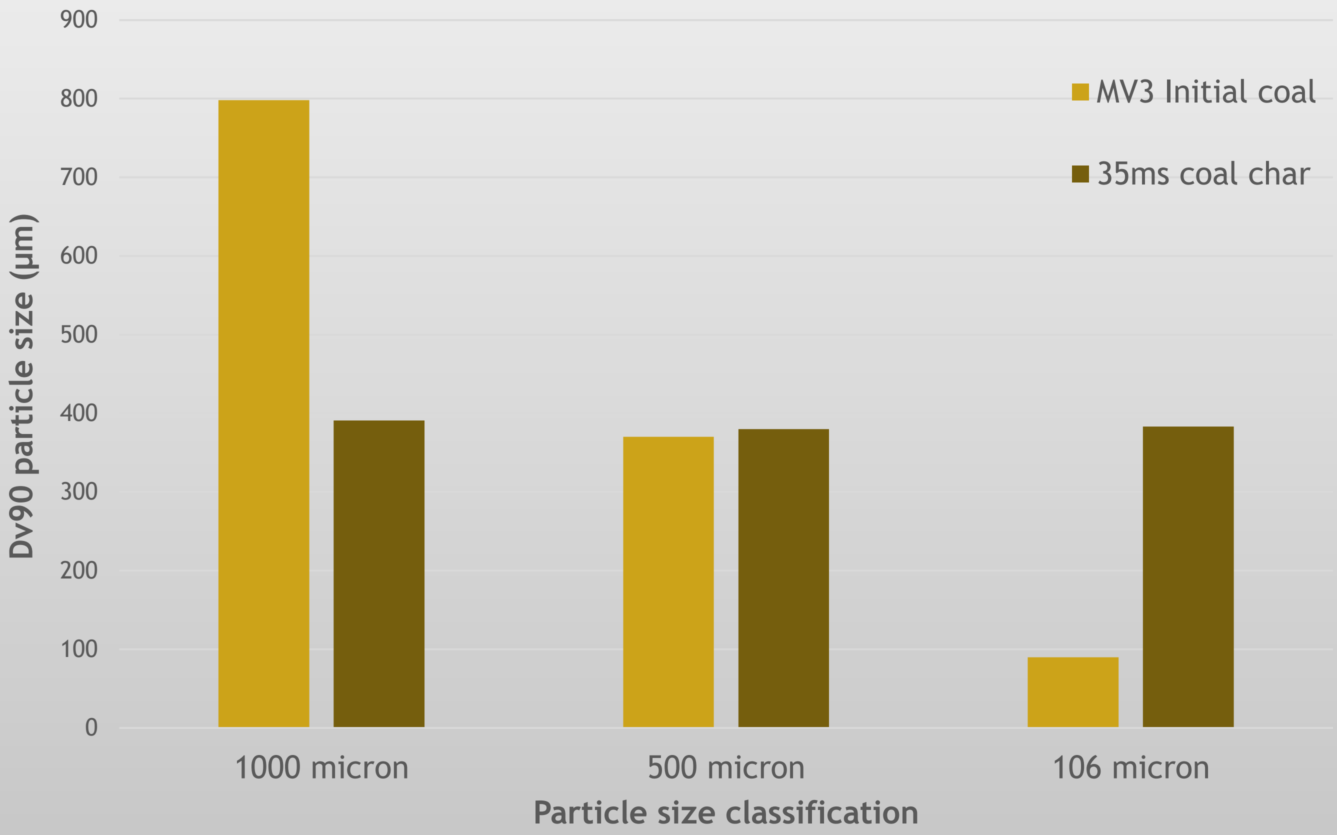
Fragmentation



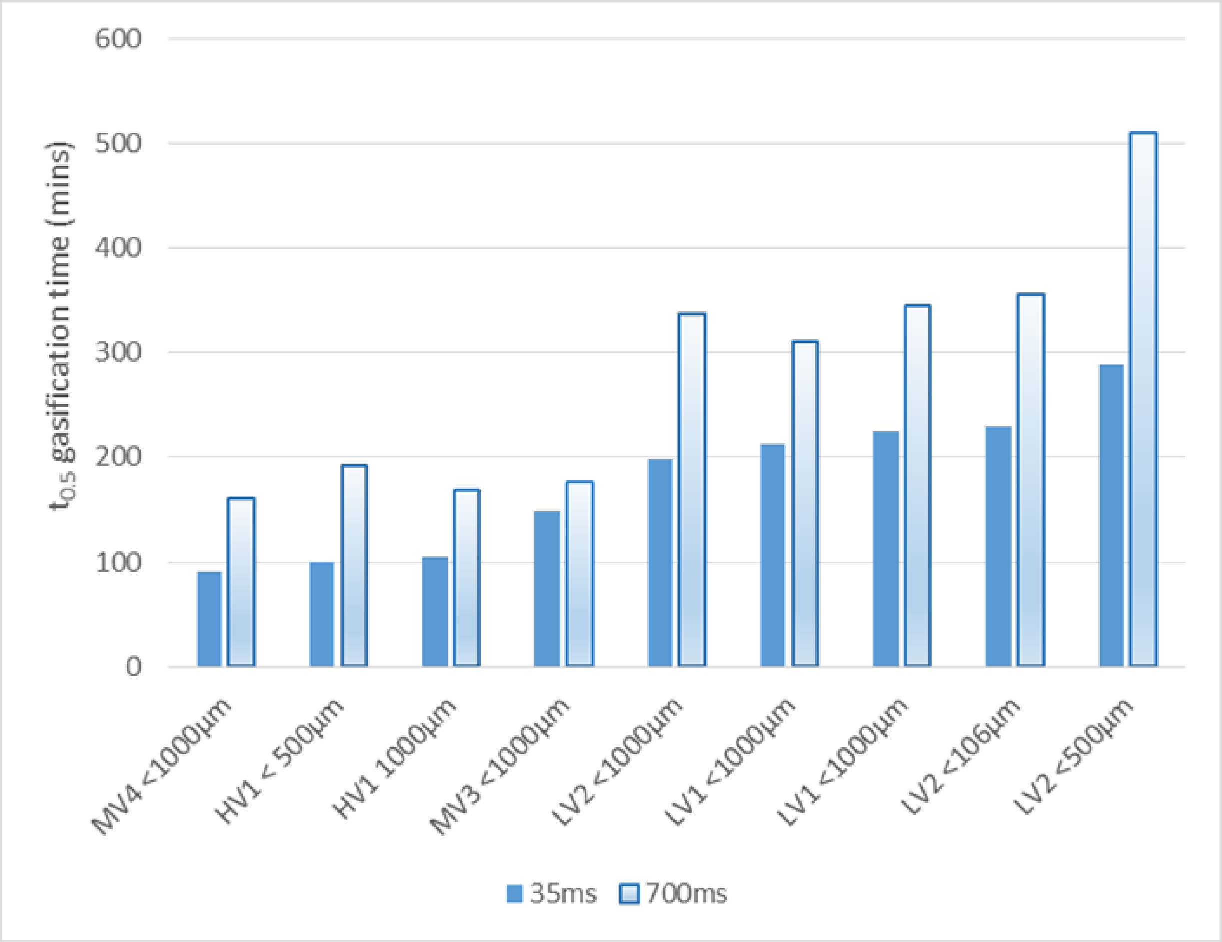
Swelling



Agglomeration



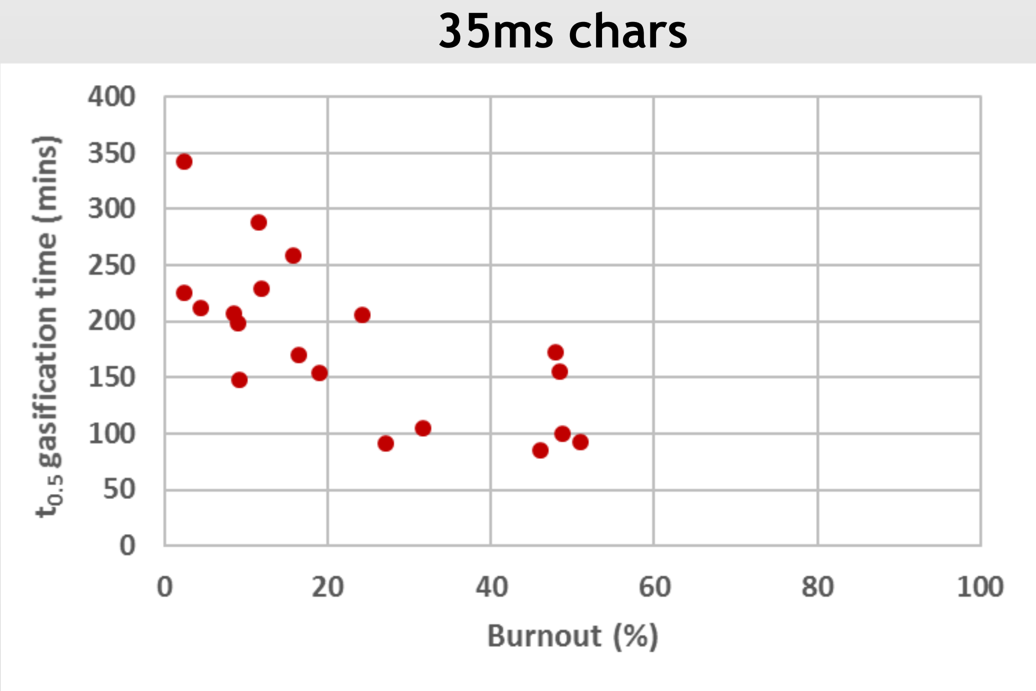
Results – Gasification reactivity versus DTF residence times

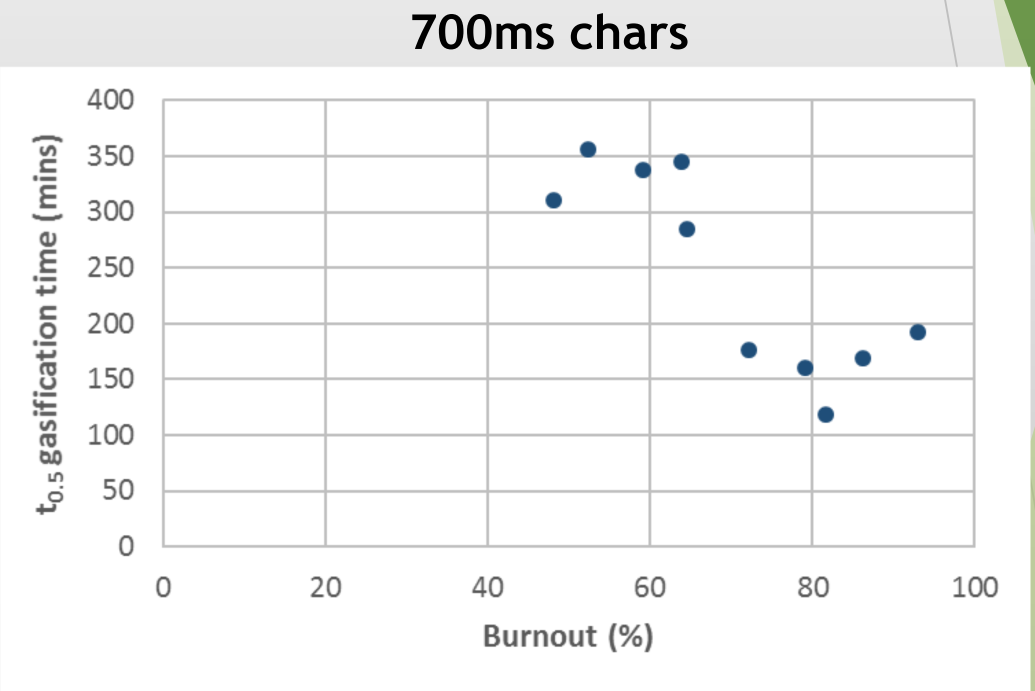


- Chars formed after longer residence times have lower gasification reactivity

- What changes have occurred to have affected the reactivity so much?

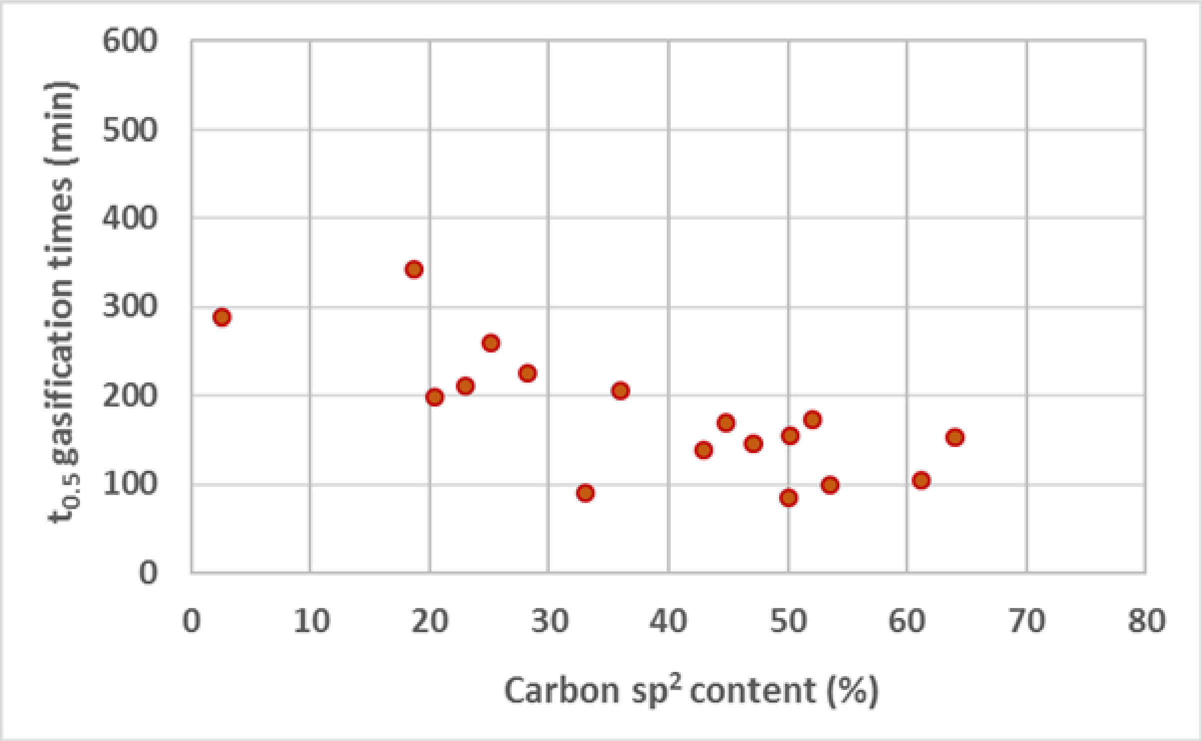
Burnout versus char gasification reactivity



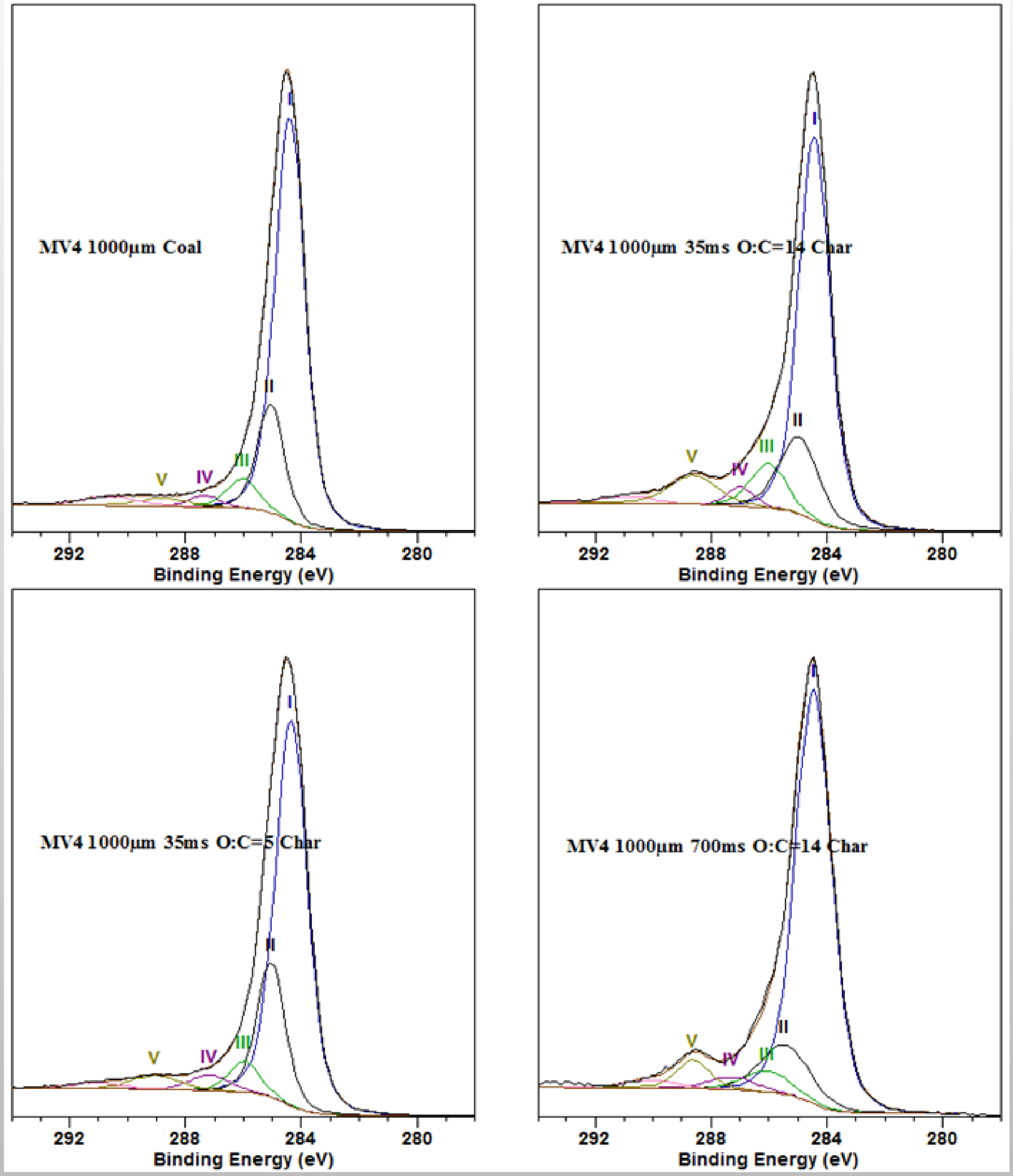


- Trend between char gasification reactivity and coal burnout
- Lower burnout coals could lead to char accumulation

Carbon sp^2 bonding and gasification reactivity for 35ms chars



- Increasing sp^2 trend with higher gasification reactivity
- No such correlation with 700ms chars
- Increased sp^2 content related to increased bond rearrangement and new reactive sites

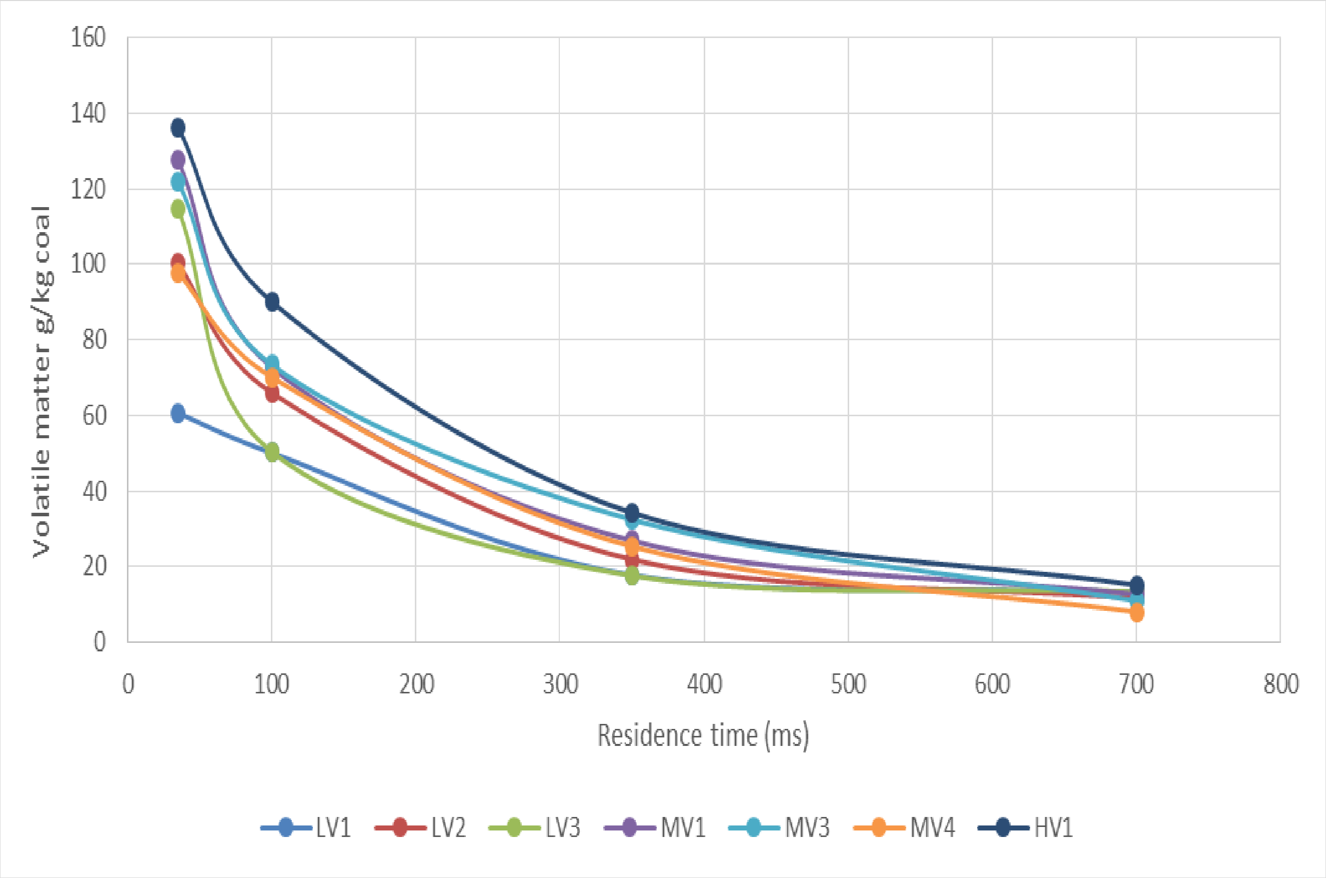


XPS Surface analysis C1s peak

Coal type	Total carbon-oxygen bonding (%)
MV3 Coal 1000 µm	16.2
MV3 Char O:C=14 1000µm 35ms	19.0
MV3 Char O:C=5 1000µm 35ms	11.3
MV4 Coal 1000 µm	8.3
MV4 Char O:C=14 1000 µm 35ms	15.5
MV4 Char O:C=5 1000 µm 35ms	10.9

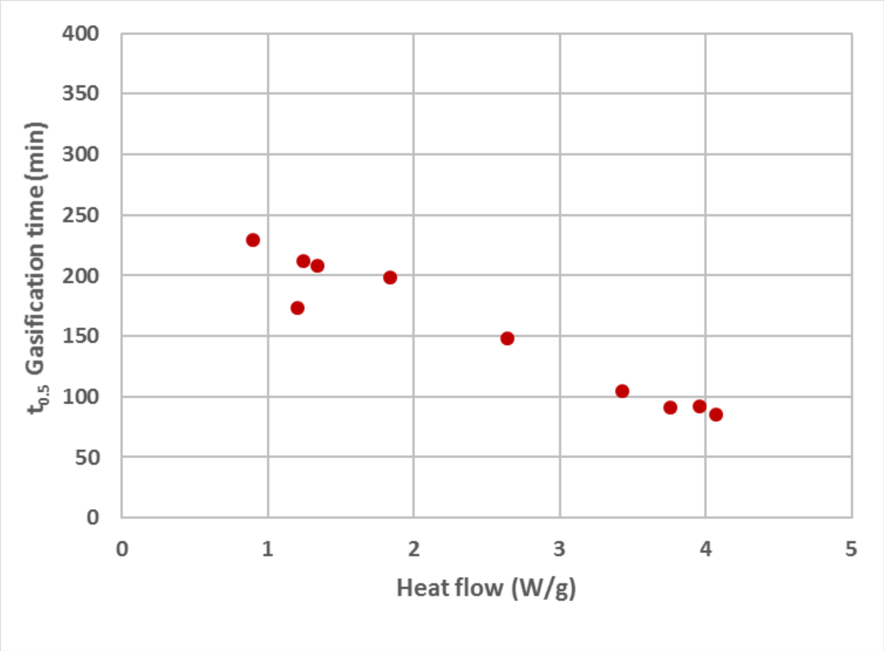
- Higher binding energy asymmetry due to carbon-oxygen bonding on the sample surface
- More carbon-oxygen peak broadening at higher oxygen:carbon ratio
- Increase in the carboxyl/ester type functional groups formed through surface oxidation

Residual volatile matter content in DTF char residues (1100°C)

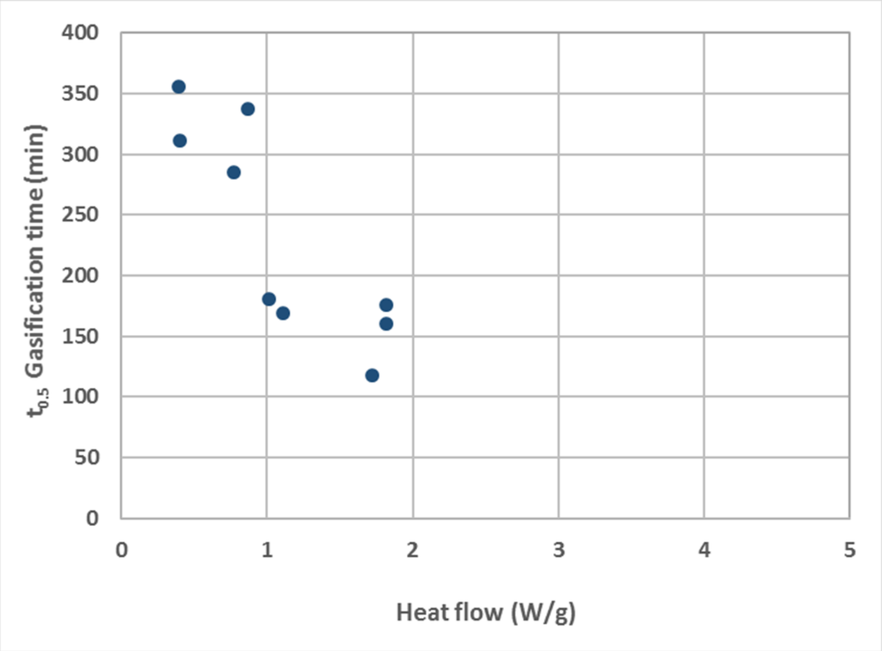


- 35ms residence times lead to chars with a significant volatile content remaining
- At higher residence times variation in volatile content in chars is reduced significantly

Relationship between char gasification reactivity and heat flow



35ms

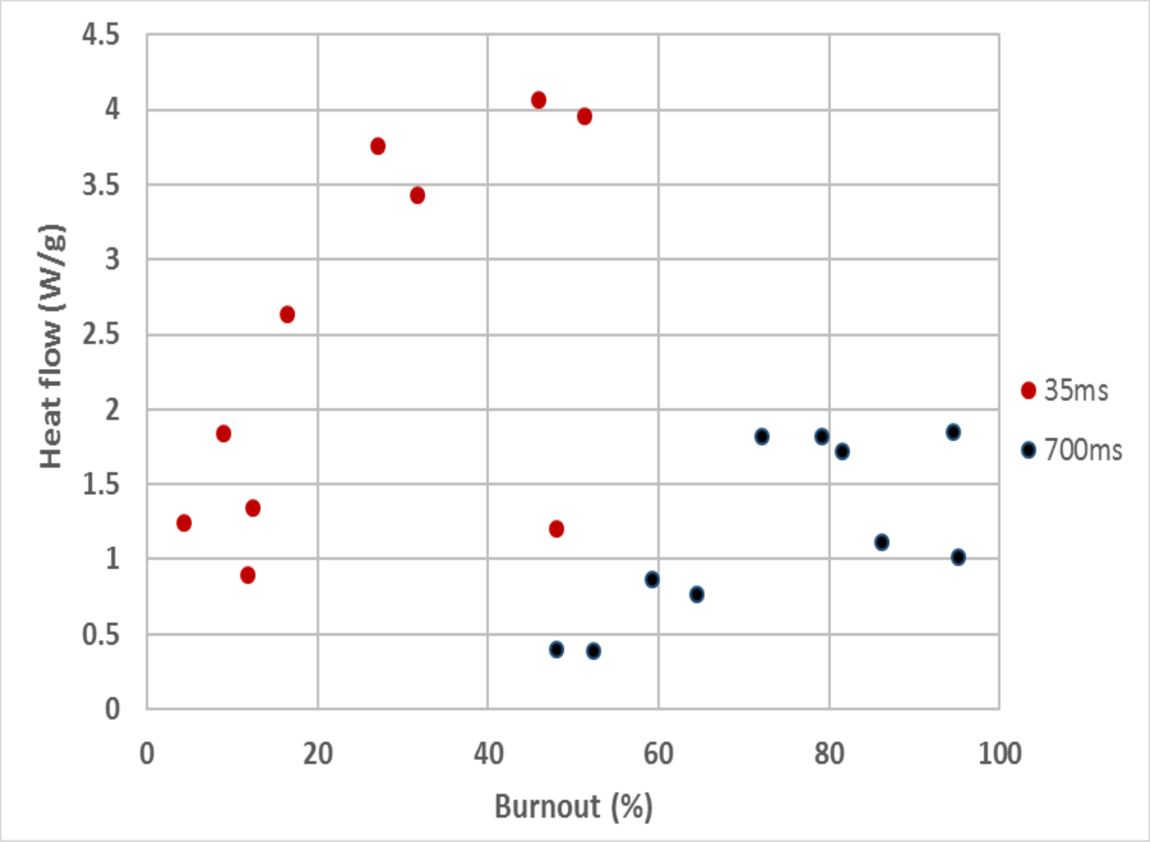


700ms

- Higher gasification reactivity chars have higher heat flows.
- Higher heat flows represent higher thermal requirement for gasification

- Much lower heat flow requirement

Relationship between coal burnout and char heat flow



- Higher burnout coals @35ms give chars with the highest heat requirement
- More complete coal burnout in the raceway will lead to chars with a lower thermal impact in the blast furnace

Conclusions

- The properties of partially burnt coal chars have implications on the successful utilisation of coal in the blast furnace.
- Chars with higher Boudouard gasification reactivity could have a greater thermal impact higher up the blast furnace.
- Coal type could impact furnace permeability due to properties such as swelling, fragmentation and agglomeration.
- Blast furnace coals are a balance of high reactivity for raceway utilisation and lower reactivity for chars in the shaft.

Variations in the properties of partially burnt coal chars and implications on the blast furnace process

Julian Steer*, Richard Marsh*, Dane Sexton*,
Mark Greenslade¥

*Cardiff School of Engineering, Queen's buildings, Cardiff, UK
¥ Tata Steel UK, Port Talbot