



The amenability of some Witbank bituminous ultra fine coals to binderless briquetting

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Abstract

Five ultra fine bituminous coals from the Witbank coalfield were studied. Selected chemical and physical properties, coal petrographic characteristics and mineralogical compositions of the coals were measured. The coals were compacted, using a briquetting press, at various feed moisture contents. The formed briquettes were then tested for compressive strength and water resistance and the values correlated with the coal characteristics and the briquetting conditions. The coals were found to be amenable to conventional binderless briquetting. The bonding in the briquettes was found to be due mainly due to the impurities in the coals, particularly kaolinite. This may add a new perspective to the fundamentals of the binderless briquetting of bituminous coals.

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1. Introduction

Numerous industrial processes require coal in a coarse form for handling, transportation and as a feed for thermal applications. Mining and processing operations, however, inevitably result in large accumulations of coal fines.¹ The coal fines constitute up to 12% of annual run of mine tonnage. Until recently, in South Africa, coal fines have been pumped as slimes into the co-disposal discard dumps, old underground workings or slime dams. This operation is considered to be environmentally less acceptable.

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¹ Coal fines in this study refers to the coal with particle size of <1 mm.

Coal fines, whether beneficiated or not, can be added to the final coal product stream provided that coal quality constraints can be satisfied. To provide bulk, ease of handling and mechanical strength, it is important that coal fines be economically agglomerated into regularly sized lumps.

One of the methods that can be used for the agglomeration of coal fines is briquetting. This can be done at high temperature (i.e., hot briquetting), with or without the aid of a binder, or using pressure alone, at ambient temperature (i.e., conventional binderless briquetting). The latter method is more desirable, due to the high cost of binders and of the equipment that can withstand high temperatures in hot briquetting. The increased risk of spontaneous combustion also contributes to the limitations of hot briquetting.

In essence, the briquetting process agglomerates an aggregate of loose particles into a rigid monolith, in which the solid phase persists throughout the briquette. Several theories on binderless coal briquetting have been developed [1–6]. The fundamentals are qualitatively valid, but do not explain the behaviour of South Africa (S.A.) coals, particularly those from the Witbank coalfield.

Together with the natural forces that play a role in conventional binderless briquetting, rank, maceral composition, particle size distribution, moisture content, plasticity and hardness are, according to the literature, the important characteristics of coal in the process. Briquetting conditions such as pressure, temperature and compaction time are the important parameters in the binderless coal briquetting process [1–6]. It is beyond the scope of this work to review the fundamentals of the binderless briquetting process since as the literature [1–6], particularly Rhys Jones [2], explains them in detail.

Some Witbank bituminous coals can be compacted, without the addition of a binder, into briquettes that will not crumble during handling, storage and transportation, by using their natural bonding properties.

The main aim of this study was to determine the amenability of certain Witbank coals to conventional binderless briquetting² and to ascertain the characteristics of coals that are important in characterising their ability to form strong compacts. The Witbank coalfield was selected because it is a major source (43%) of S.A. steam coal for the export market.

Objectives in order to achieve these aims were to: (i) determine the selected chemical and physical properties, coal petrographic characteristics and mineralogical compositions of a range of coals from the Witbank coal field,; (ii) compact the coals at various feed moisture contents, using a conventional method; and (iii) to determine some physical properties (i.e., compressive strength, and water resistance) of the briquettes, relating them to the properties of the coals and to the briquetting conditions.

2. Experimental

2.1. Materials and apparatus

The samples studied were ultra fine coals³ from five⁵ collieries in the Witbank coalfield (Table 1).

² In this study, it is designated binderless briquetting.

³ Ultra fine coal in this study refers to coal with particle size of $< 500 \mu\text{m}$.

Table 1
Summary of the coal samples studied

Colliery	Product
SJM1	Thickened under flow
SJM2	Thickened under flow
SJM3	Thickened under flow
SJM4	Thickened under flow
SJM5	Flotation concentrate

2.1.1. Briquetting machine

Pillow-shaped briquettes were produced from a Komarek B-100A briquetting machine. The machine consisted of two rolls mounted on the ends of shafts cantilevered between bearing blocks. The main load-carrying bearings were mounted close to the inside face of the rolls, and a second bearing was mounted near the back of each shaft. The lower roll, shaft and bearing block assembly were held in a fixed position and could rotate about a pivot point located at the rear-bearing block. The hydraulic cylinders controlled the movement of the upper bearing block and in turn pressed the two front bearing blocks against fixed stops located behind the tie bars. The stops prevented rolls from making contact with each other.

Rolls were driven by a pinion and set of companion gears mounted in the rear of the bearing blocks. The paddle feeder agitated the material into the horizontal screw at the feed inlet that fed it into the rolls. The horizontal screw was driven by a variable speed drive unit and the paddle feeder by a constant speed gear motor. The maximum pressure that could be exerted on the material by the rollers was 2500 psi.

2.1.2. Compressive strength testing instrument

An Instron model 1195 testing instrument, operated in the compression mode at a crosshead speed of 2 mm/min, measured the strength of the briquettes. A briquette was crushed slowly between two flat, parallel metal plates with facial areas greater than the projected area of the briquette (i.e., 138 and 152 mm in diameter for the lower and upper plates, respectively). The load exerted was recorded on a chart in the form of a peak. The maximum height of the peak was the crushing load (N).

2.2. Test methods and procedures

Chemical, petrographic properties and some physical properties of the coal samples were determined at the SABS Coal Exploration and Technology (CET) Laboratory, Pretoria, according to standard methods [7–17].

The Hardgrove grindability indices (HGI) could not be determined on the samples, due to their fineness. The values used in this study were of similar coals, reported by Pinheiro et al. [18]. The coals studied were of the same origin and had similar petrographic properties and ash contents. The HGI of the SJM4 coal was not reported as the coal was of higher grade than those studied by Pinheiro et al. [18].

Qualitative and quantitative determinations of minerals in the coal samples were carried out at the Council for Geoscience (CGS) Laboratory, Pretoria. The samples were subjected

to whole rock powder X-ray diffraction (XRD) analysis using a Siemens D500 diffractometer equipped with Cu tube and graphite monochromator. Random powder preparations, obtained by pressing the powder in a plastic frame with round cavity against a rough filter paper, were scanned from 2 to 65° 2 θ , with a 0.02° 2 θ step size and counting time of 1 s/step at a tube voltage and current of 40 kV and 30 mA. The XRD patterns were evaluated using Siemens “DIFFRAC plus” software. The latter allows matching with the PDF-2 Database, of which sets 1–42 [19] were at hand. The semi-quantitative analysis was based on peak height percentages [20]. For most minerals, their strongest reflection was used; however, in the case of quartz and albite, for which the most intense peaks often overlap, other reflections were chosen.

2.2.1. Preparation and briquetting

Each of the Witbank ultra fine coals was air-dried and subsequently split into five homogeneous portions of 5 kg, respectively. Four portions from each sample were physically wetted to ca. 5%, 10%, 15% and 20% H₂O, automatically mixed for 15 min and subsequently conditioned overnight in sealed containers. The conditioned samples were then briquetted at 2500 psi. Briquettes were stored under ambient conditions for >7 days before they could be tested. They were then randomly sampled from each batch and tested for compressive strength and water resistance.

2.2.2. Compressive strength test

To test for compressive strength, the crushing load (in N) was measured on 10 ten briquettes from each batch and the average value converted to compressive strength (in kPa) with the aid of Eq. (1) [21]. For the batches of briquettes that yielded the standard deviations of 82 and greater, 20 measurements were carried out. The minimum target value for this technique was 350 kPa [22].

$$P = \frac{\text{Crushing load (N)} \times 1000}{\text{Cross-sectional area of plane of fracture (760 mm}^2\text{)}} \quad (1)$$

2.2.3. Water resistance test

To test for water resistance, 10 briquettes from each batch were immersed in water for 2 hrs and their crushing loads measured immediately after removal from water. Eq. (1) was again employed to convert the average maximum crushing load to compressive wet strength, which was expressed as water resistance. The minimum target value for this technique was also 350 kPa [22].

3. Results and discussions

Since As the coals were all from the Witbank coalfield, there was no significant difference between their coal petrographic properties (Table 2). The friability of the coals, except for SJM4 coal, was also similar (Table 3), and so were their particle size distribution (Table 4). Hence, from the coal petrographic point of view, they could be expected to behave similarly on binderless briquetting.

Table 2
Coal petrographic properties of the Witbank coals

Percentage (%)	SJM1 ^a	SJM2 ^a	SJM3 ^a	SJM4 ^a	SJM5 ^a
Vitrinite	35	32	33	25	34
Liptinite	6	4	5	4	4
Reactive inertinite	14	14	16	15	16
Inert inertinite	30	42	38	33	40
Total inertinite	44	56	54	48	56
Visible minerals	15	8	8	23	6
Reactives	55	50	54	44	54
$\bar{R}_f\%$	0.67	0.68	0.70	0.72	0.73
Rank ^b	Medium rank C	Medium rank C	Medium rank C	Medium rank C	Medium rank C

$\bar{R}_f\%$: Vitrinite mean random reflectance (in percent).

^a Particle size smaller than standard.

^b Classification is in accordance with UN-ECE [22].

3.1. Coal briquettes

3.1.1. SJM1 coal

Fig. 1 shows the adverse effects of moisture on the compressive strength of briquettes produced from SJM1 coal. Also included in Fig. 1 are the upper and lower limits of data for the 90% confidence interval, using Student's *t*-test. Optimum moisture content for SJM1 coal was observed at 3.6%, which was the moisture content for an air-dried sample (Table 3).

When tested for water resistance, the briquettes completely disintegrated after 2 hrs of water immersion. This indicated that the materials would not be suitable for storage outdoors and long-distance haulage in uncovered trucks during the rainy season.

In terms of compressive strength, the SJM1 coal studied was amenable to conventional binderless briquetting.

3.1.2. SJM2 coal

The effect of moisture on the compressive strength of briquettes produced from SJM2 coal is shown in Fig. 2, together with the upper and lower limits of data for the 90% confidence interval, using Student's *t*-test. The compressive strength increased with an

Table 3
Selected chemical and physical properties (air-dry basis) of the Witbank coals

Colliery	CV (MJ/kg)	% Ash	% H ₂ O	% Volatile matter	% S	% Fixed C	FSI	HGI	Grade ^a
SJM1	23.80	21.8	3.6	23.9	0.70	50.7	1 ^f	59	Low
SJM2	25.09	18.9	3.1	24.4	0.63	53.6	1 ^f	50	Medium
SJM3	25.87	17.7	2.8	24.2	0.56	55.3	1 ^f	52	Medium
SJM4	21.06	31.8	2.2	23.0	1.16	43.0	1/2 ^f	–	Very low
SJM5	27.52	15.3	2.6	24.3	0.71	57.8	1 ^f	55	Medium

^a Classification is in accordance with UN-ECE [22].

^f friable.

Table 4
Average particle size distribution of the Witbank coals

Particle size (μm)	% Yield
+ 500	3.58
+ 300–500	5.00
+ 212–300	12.02
+ 106–212	22.00
+ 75–106	25.66
– 75	30.78

increase in moisture until an optimum was attained at 5.9% H_2O , followed by a decrease on further addition of water. This may be attributed, at least in part, to the decrease in bonding that was brought about by the presence of moisture.

Briquettes produced from the SJM2 coal with feed moisture between 5.9% and 15.9% maintained their shapes after 2 hrs water immersion. At a feed moisture of 3.1%, briquettes were extremely wet and very weak after 2 hrs water immersion, while at 17.4% H_2O , they disintegrated completely to form a slurry. At optimum feed moisture content (i.e., 5.9% H_2O), water resistance was higher. It then decreased with an increase in feed moisture of the coal (Fig. 3).

When crushed during the water resistance test, briquettes that met the minimum requirements for compressive strength broke into ca. 90% of particles that, although not tested, appeared to be >2 mm in size. This suggested that the briquettes would be handleable when moist.

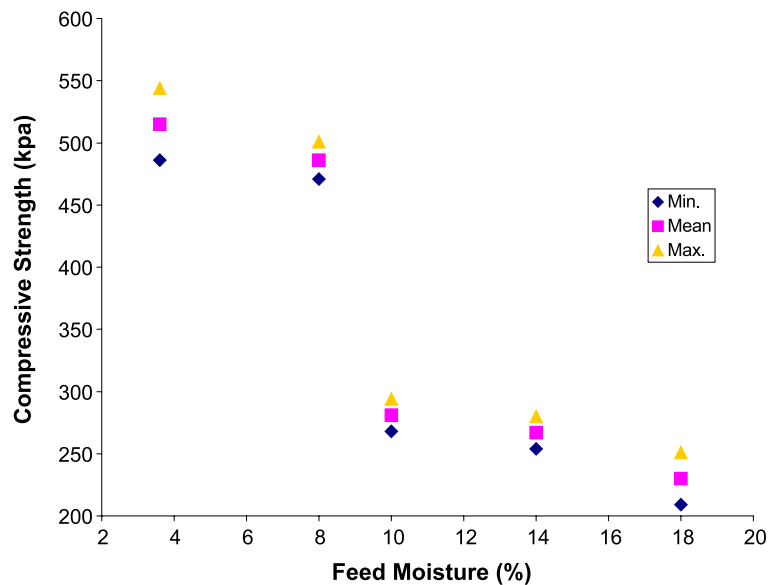


Fig. 1. Plot of compressive strength of briquettes against feed moisture content of the SJM1 coal, showing error limits.

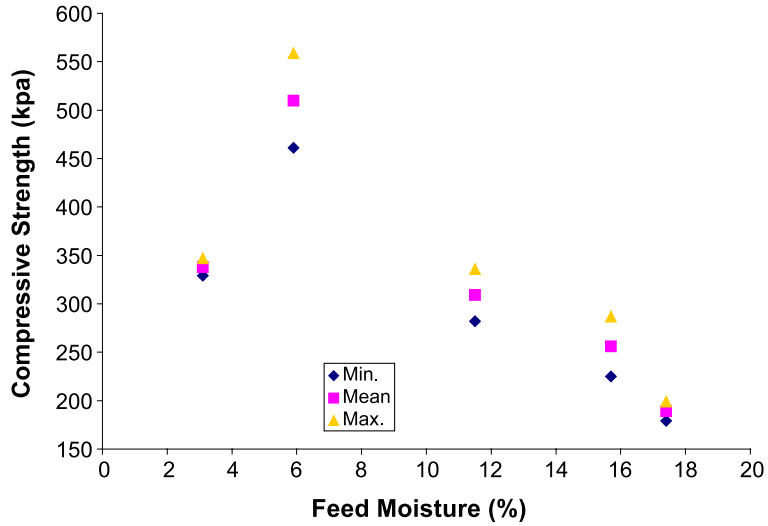


Fig. 2. Plot of compressive strength of briquettes against feed moisture content of the SJM2 coal, showing error limits.

Water evaporates due to an increase in temperature during the briquetting process. For binderless briquettes to be strong and water-resistant, it has been observed in this study that they should be glossy in appearance. However, during the compaction of the SJM2

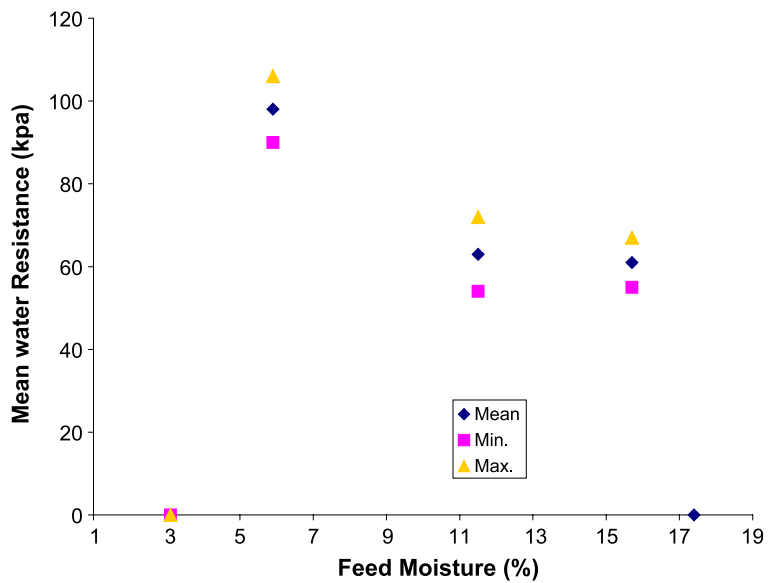


Fig. 3. Plot of mean water resistance of briquettes against feed moisture content of the SJM2 coal, showing error limits.

coals with >10% feed moisture, condensation and subsequent absorption of water was observed after the release of pressure. This might have adversely affected the glossiness of briquettes and thus their quality.

However, the results obtained when testing the SJM2 coal permitted a tentative conclusion that it may be briquetted without the use of a binder.

3.1.3. SJM3 coal

Fig. 4 shows the effect of moisture on briquette strength. Optimum moisture content for SJM3 coal was attained at ca. 5% H₂O. Compressive strength of briquettes decreased with further addition of water to the feed coal.

Briquettes also showed water resistance, although there was a decrease in strength subsequent to 2 hrs water immersion (Fig. 5). This decrease in strength was probably because coal is a porous material, and hence continued absorbing water until equilibrium moisture was attained.

However, when crushed during the water resistance test, briquettes that met the minimum requirements for compressive strength broke into ca. 90% of particles that, although not tested, appeared to be >2 mm in size. This suggested that briquettes would be

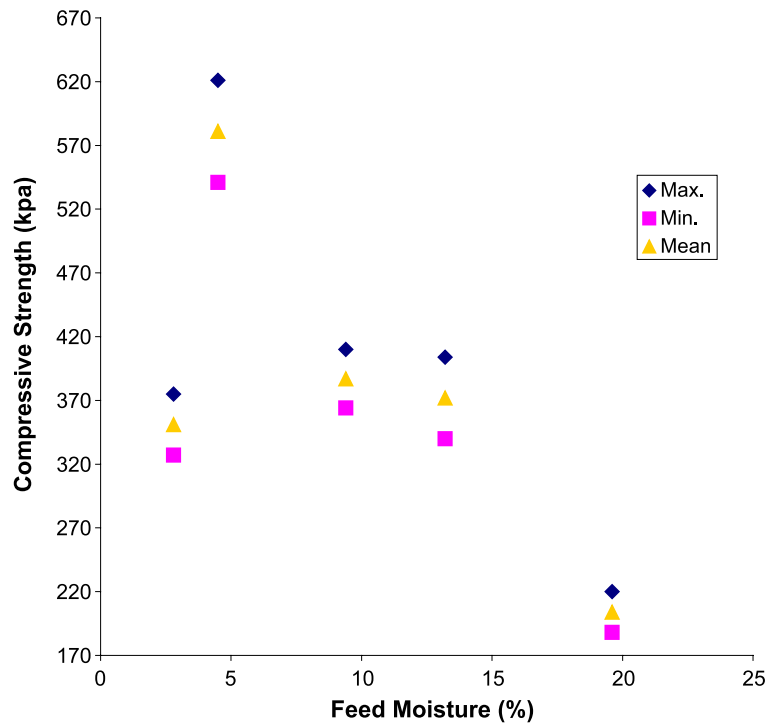


Fig. 4. Plot of compressive strength of briquettes against feed moisture content of the SJM3 coal, showing error limits.

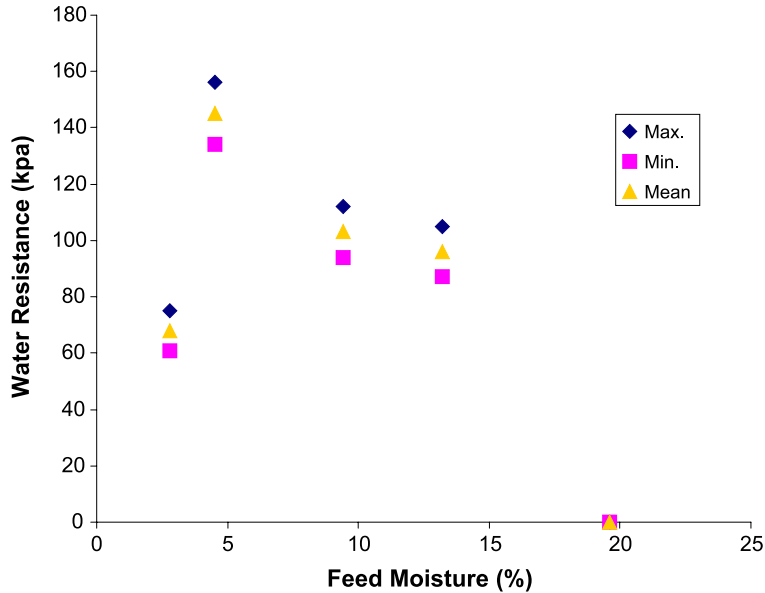


Fig. 5. Plot of water resistance of briquettes against feed moisture of the SJM3 coal, showing error limits.

handleable when moist, and hence may be suitable for storage outdoors and long-distance haulage during the rainy season.

Results obtained when testing the SJM3 coal also permitted the conclusion that it was reasonably amenable to binderless briquetting.

3.1.4. SJM4 coal

SJM4 coal can be used for electricity generation, although classified as very low-grade [23]. Indeed, Pinheiro et al. [24] reported an average ash content of 30.1% (air-dry basis) for the coals that were used for electricity generation in 1998.

With SJM4 coal, the addition of water had adverse effects on the compressive strength of briquettes. This is shown in Fig. 6, where the air-dry coal gave maximum compressive strength that decreased with an increase in feed moisture.

Briquettes produced from the SJM4 coal disintegrated completely subsequent to 2-hrs water immersion. However, in terms of compressive strength, it may be concluded that the SJM4 coal was amenable to binderless briquetting.

3.1.5. SJM5 coal

Data for compressive strength of briquettes produced from SJM5 coal are shown in Fig. 7. Briquettes produced from the air-dried coal were not well agglomerated and showed very low compressive strength. However, the addition of water to the feed coal led to a change in compressive strength of briquettes. Optimum feed moisture content was attained at 5.8%. The compressive strength of briquettes then decreased with increasing feed moisture of coal.

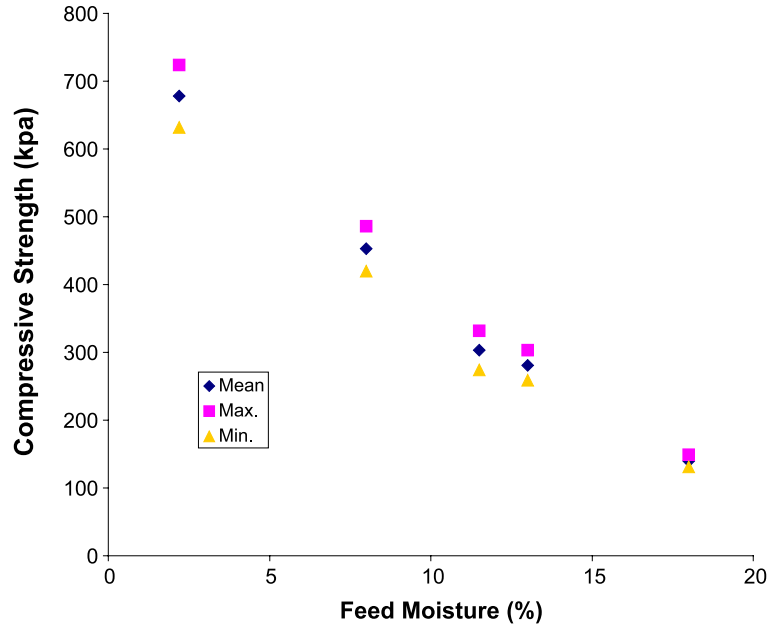


Fig. 6. Plot of compressive strength of briquettes against feed moisture content of the SJM4 coal, showing error limits.

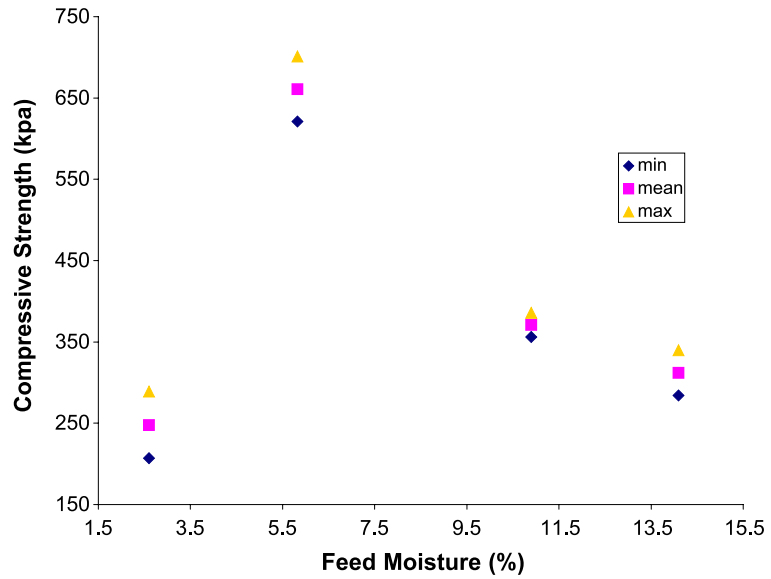


Fig. 7. Plot of compressive strength of briquettes against feed moisture of the SJM5 coal, showing error limits.

The strength of briquettes drastically decreased after 2 hrs water immersion (Fig. 8). However, when crushed during the water resistance test, briquettes that met the minimum requirements for compressive strength broke into ca. 90% of particles that, although not tested, appeared to be >2 mm in size. This also suggested that briquettes would be handleable when moist. Therefore, it may be concluded that the SJM5 coal was also amenable to binderless briquetting.

3.2. Bonding in Witbank binderless coal briquettes and effect of inorganic matter (clay minerals) on the binderless briquettes

Clay minerals, as Deer et al. [25] defined, are platy particles (all hydrous silicates of principally Mg and Al) in fine-grained aggregates which exhibit plasticity at appropriate water contents, lose adsorbed and constitutional water on heating and at high temperatures yield refractory materials. Deer et al. The authors [25] subdivided the clay minerals into four main groups: smectites, vermiculites, illites and kaolinites.

According to Schoonheydt [26], clay mineral refers to phyllosilicate minerals and to minerals, which impart plasticity to the clay and which harden upon drying or firing. Nevertheless, this study is restricted to the definition given by Deer et al. [25].

All the Witbank coals studied had similar rank and maceral compositions, so they might be expected to behave similarly during binderless briquetting. However, their behaviour was different and this was probably due to their varying ash contents (Table 2).

Conveniently, the ash content is determined in coal to quantify the concentration of impurities present [14]. In reality, coal contains minerals and not ash [27]. The variation of

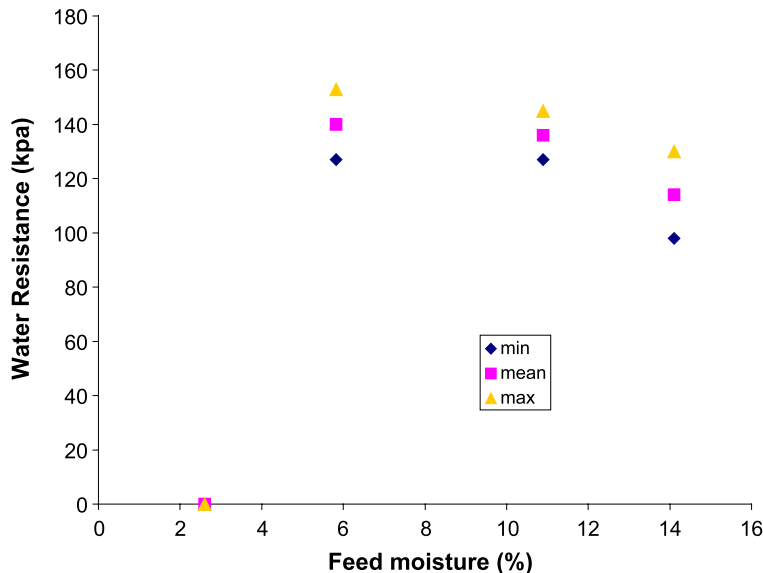


Fig. 8. Plot of water resistance of briquettes against feed moisture of the SJM5 coal, showing error limits.

ash content prompted the qualitative and quantitative determinations of minerals in the coal samples.

X-ray diffraction (XRD) determinations (on the coal samples) revealed the predominance of kaolinite in the coals studied (Table 5). Gaigher [28] observed this during his investigation on mineral matter in some S.A. coals. The kaolinite domination in these coals can probably be attributed to two facts: (i) The hinterland that supplied the detritus was rich in kaolinite; and (ii) The coals have been formed in acidic environments [27], which also favour the formation of kaolinite [25].

Kaolinite, which is known to exhibit plastic properties at appropriate water content [25], is probably responsible for the bonding in binderless briquettes produced from the Witbank coals studied. As some clay minerals (including kaolinite) adsorb water and some even swell through the intercalation of water [25], disintegration and significant decrease in strength subsequent to 2-hrs water immersions of briquettes also support this hypothesis.

Correlations between compressive strength and percentage ash and kaolinite yielded correlation coefficients of 0.12 and 0.61, respectively (Fig. 9). However, the correlation between maximum compressive strength and the summation of percentage ash and kaolinite contents yielded a correlation coefficient of 0.98. This suggests a direct causal relationship between the two variables (Fig. 10).

The plot of maximum compressive strength against the summation of percentage kaolinite, ash and illite contents gave the correlation coefficient of 0.89 (Fig. 11). Owing to the fact that illite is not as plastic as kaolinite [25], it may be concluded for the coals studied that its presence is not advantageous towards binderless briquetting.

Fig. 12 shows a good correlation ($R^2=0.96$) between maximum compressive strength of binderless briquettes and the summation of percentage kaolinite, feed moisture and ash contents of the coal. However, the R^2 value for the correlation between the maximum

Table 5
Mineralogical compositions of the Witbank coals

	SJM1	SJM2	SJM3	SJM4	SJM5
Pyrite	2	4	5	13	9
Quartz	10	6	11	5	7
Anatase	0	0	2	0	3
Calcite	21	31	15	9	5
Ankerite	0	0	0	0	0
Siderite	2	3	10	2	0
Dolomite	7	9	11	4	13
Rhodochrosite	0	0	0	2	0
Jarosite group	28	3	0	4	3
Gypsum	0	1	0	0	2
Illite	0	0	0	17	0
Kaolinite	29	33	46	42	56
K feldspar	1	7	1	1	2
Plagioclase	0	3	0	0	0
Zeolites	0	0	0	Trace	0
Total	100	100	100	100	100

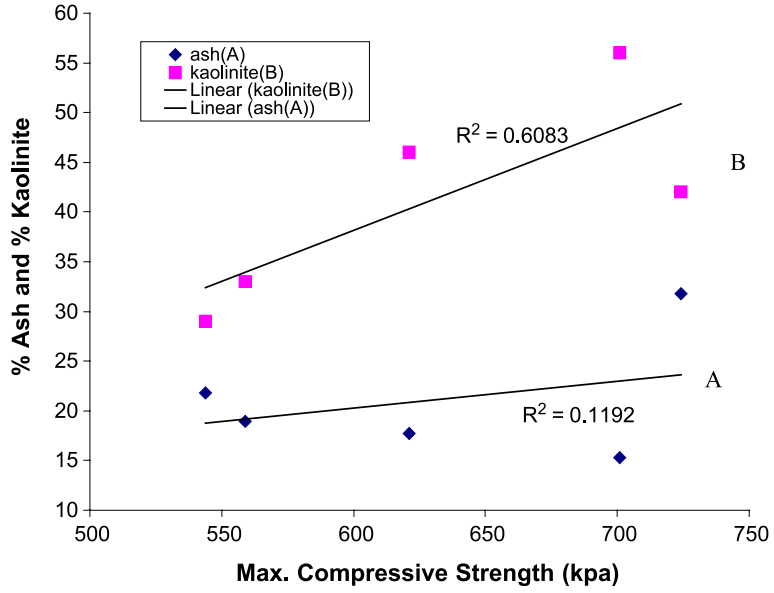


Fig. 9. Correlations between maximum compressive strength of briquettes and % ash and kaolinite, respectively, of the Witbank coals with similar coal petrographic properties.

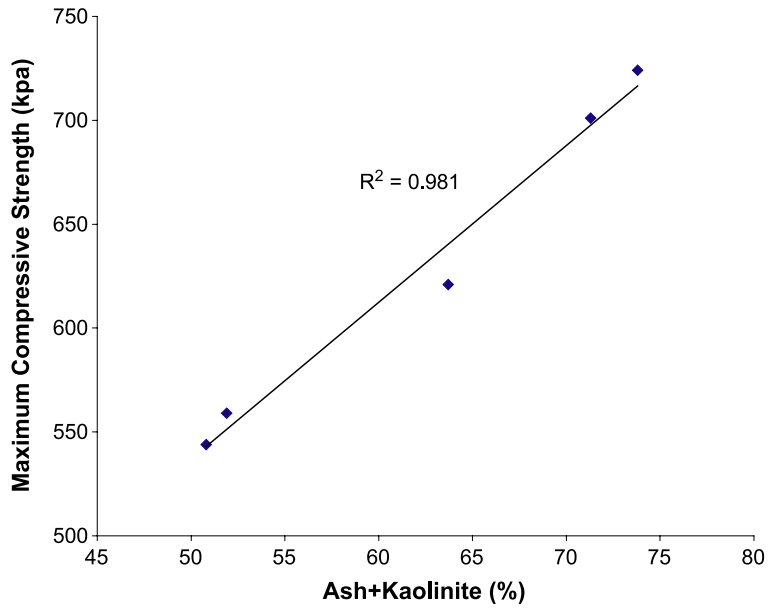


Fig. 10. Correlation between maximum compressive strength of briquettes and the summation of % ash and kaolinite contents of the Witbank coals with similar coal petrographic properties.

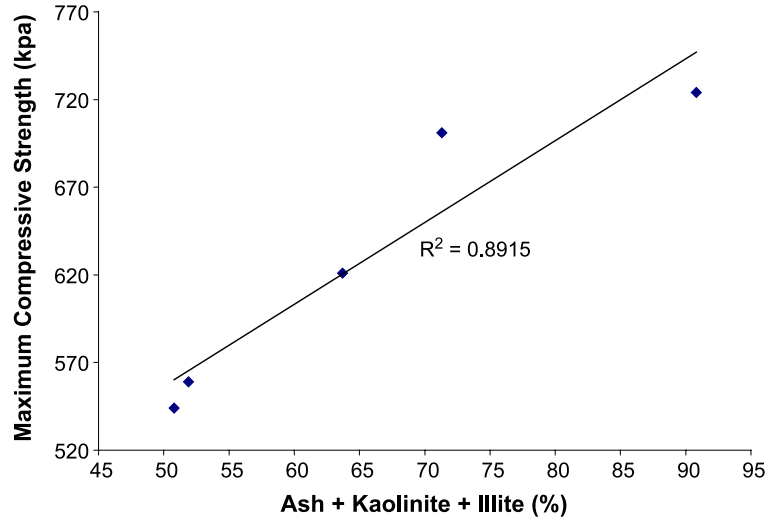


Fig. 11. Correlation between maximum compressive strength of briquettes and the summation of % ash, kaolinite and illite contents of the Witbank coals with similar coal petrographic properties.

compressive strength of binderless briquettes and the summation of percentage kaolinite and feed moisture is relatively low (i.e., $R^2 = 0.49$). These may serve to confirm the known fact that kaolinite exhibit plastic properties at an appropriate moisture content.

Figs. 11 and 12 also show the importance of the ash content of the coal in the bonding mechanism during binderless briquetting. In fact, the ash content in this case indicates the

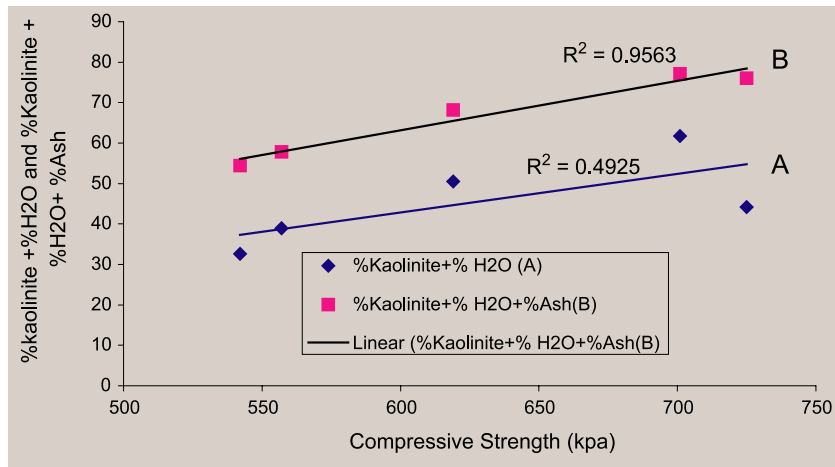


Fig. 12. Correlation between maximum compressive strength of briquettes and (A) the summation of % kaolinite and feed moisture and (B) summation of % ash, kaolinite and feed moisture contents of the Witbank coals with similar coal petrographic properties.

amount or level of impurities, in the coal, at which the effect of clay and other minerals in the coals become significant during the bonding process in binderless briquetting.

Results obtained from testing the Witbank coals with similar coal petrographic characteristics and particle size distributions permit the possible conclusion that the bonding in their binderless briquettes emanated mainly from the impurities of the coals, particularly kaolinite. This may add a new perspective to the fundamentals of binderless briquetting. Indeed clay, particularly bentonite, was one of the earliest materials to be used as binder for coal briquetting [3]. Briquettes made with clay clay-type binders are, however, not water-resistant and have a relatively high ash content.

4. Conclusions

Results obtained when testing the coals used in this study permit the following conclusions. These conclusions apply to the coals studied but may also be at least qualitatively valid for many other coals.

- All the coals tested were amenable to binderless briquetting.
- The bonding in the binderless briquettes produced from all the Witbank coals tested in this study resulted mainly from the inorganic matter, particularly kaolinite.
- There is an optimal moisture content at which clay minerals in the coals are plasticised to improve the adhesion of particles and thus giving maximum strength to the briquettes.

This study will assist in providing the South African coal industry, in both steam and metallurgical coal areas, with a more specific scientific basis on which to form decisions when venturing into the field of mass economic briquetting of fine coal.

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