Binderless briquetting of beneficiated fine discard coal from the Witbank coalfield

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Abstract. A patented binderless coal briquetting process involving dehydration and compaction was applied at pilot scale on beneficiated fine coal discard obtained from the Witbank Coalfield, South Africa. Laboratory test work was undertaken on the resultant binderless coal briquettes to assess their quality relative to the feed. Drop shatter tests were used to indicate the wet and dry mechanical strength of the briquettes post-production, weathering and blending. The total moisture content of the binderless coal briquettes was reduced significantly by 77%, while the calorific value improved slightly by 3%. Moreover, the briquettes showed reasonable resistance to breakage post-production, as well as under simulated weathering conditions. The positive results demonstrated in this study are consistent with similar studies conducted on inertinite-rich coals in South Africa and highlight a sustainable opportunity to reclaim much of the historical and arising fine coal discard.

1 Introduction

The South African coal mining industry generates approximately 60 Mta of discard coal due to limitations in the efficiency of processing technology [1]. A significant proportion of this discard (~6 million tonnes per annum) comprises fine and ultra-fine coal which has been proven to possess valuable carbon content, equivalent to run-of-mine coal [2-5]. However, this coal resource remains largely unexploited due to the difficulty and expense of reducing the high moisture, dust control, handling, and transporting the material, as well as the risk of spontaneous combustion in storage [6-8].

Coal agglomeration compacts fine coal into a manageable size and shape, facilitating easier handling and transportation [9]. Briquetting, pelletizing, and granulation are widely applied coal agglomeration methods, often coupled with the use of binder to increase bonding and to produce durable and water-resistant briquettes [10]. It is estimated that the use of binders in agglomeration accounts for as much as 60% of the operational costs, making it a costly compaction method [11].

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Binderless coal briquetting (BCB) has been proven to be an effective agglomeration method, with studies on South African coals showing that unweathered coal yields the most competent briquettes, particularly those made from vitrinite-rich coking coals [12-14]. In comparison, binderless coal briquettes made from inertinite-rich coals showed lower mechanical strength and water resistance, yet their quality was still proven to be acceptable [12-13]. Given that the inertinite maceral group dominates the bulk of South Africa`s coal resources, and by implication, the extensive discard dumps which litter the coalfields in the main Karoo basin, this presents an opportunity to alleviate part of the environmental decay resulting from historical and as-arising discards through the beneficiation and binderless coal briquetting of this discard coal [13-18].

River Energy (RE) specializes in beneficiation technologies capable of upgrading discarded coals, including a patented and licensed binderless coal briquetting process designed to upgrade low-value/waste coals through a low-cost process of dehydration and compaction. The binderless briquetting process has been proven since 2009 through a consortium led by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the recovery, beneficiation and briquetting of coal without a binder [19].

More recently, RE conducted briquetting trials on upgraded fine coal from the Witbank Coalfield, South Africa. This paper aims to contribute to the body of knowledge by sharing the key findings thereof.

2 Materials and methods

2.1 Standard analyses on the feed coal and binderless briquettes

The selected feed coal (12 tonnes) was obtained from a coal handling and preparation plant in the Witbank Coalfield. The processing of this coal includes ultra-fines (slurry) which is further processed through an ultra-fine coal beneficiation circuit to yield an upgraded fine coal product with at least mid-range qualities (~23 MJ/kg) at yields that significantly reduce the environmental and economic liabilities and costs typically associated with waste slurry handling and ongoing management. Standard chemical properties (total moisture, proximate analysis, ultimate analysis and ash analysis) were assessed through independent laboratories, in addition to a petrographic assessment being conducted on the feed coal to characterize its composition and rank, broadly following the ISO 7404 method outlined in Wagner *et al* (2018). The analyses mentioned above were repeated on the binderless briquette products for quality control and to evaluate the impact and efficiency of the binderless briquetting process on the feed.

2.2 Binderless coal briquetting process

The binderless coal briquetting production process was conducted on a limited capacity BCB pilot plant. The BCB plant is designed to handle feeds with high total moisture of up to 26% which are fed to a dryer for moisture removal at temperatures below 110°C (Figure 1). The dried coal is then fed to the briquetter, where it is briquetted and cooled to a safe storage temperature. The briquettes produced were sized at 50mm x 30 mm x 20mm, and sizing can be adjusted to specific requirements.

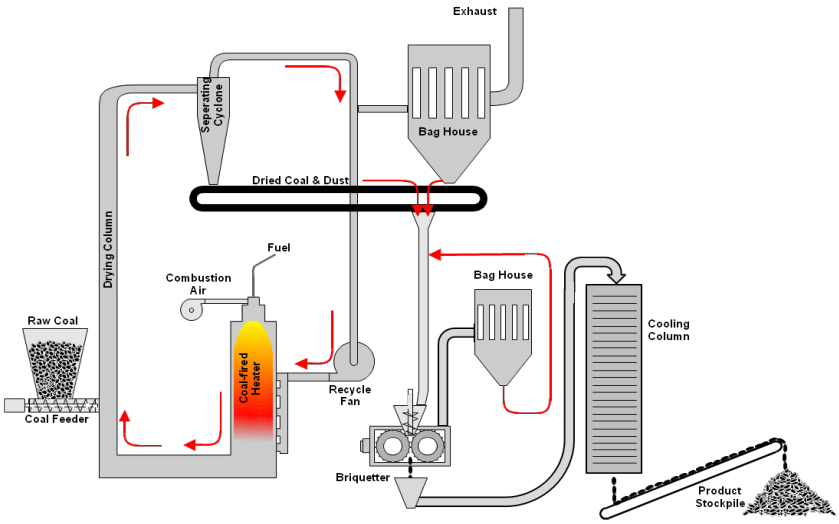

Fig.1. Generalised process for a flow binderless coal briquetting plant.

2.3 Briquette characterization

Several in-house methods were designed to assess the binderless coal briquettes' moisture uptake and mechanical strength. Among these, the drop shatter test ASTM D440 was included as it has been widely implemented in the literature and commercially to provide a rapid indication of briquette strength during the handling and transportation phase of mining [20, 21].

2.3.1 Moisture adsorption

The moisture uptake by the coal briquettes was investigated using an in-house moisture adsorption test. The mass and total moisture were measured on freshly produced briquettes that had cooled to room temperature. These briquettes were then transferred to a sealed desiccator where the relative humidity was fixed at 76% using a saturated salt solution. The masses of the briquettes were recorded daily over a period of 30 days to calculate the rate of moisture uptake as well as the equilibrium moisture.

2.3.2 Drop shatter test

The drop shatter test was used to infer the resistance to breakage of the binderless coal briquettes according to ASTM D440, with modification. For this research, a known mass of briquettes was weighed before being dropped twice from the standard height of 2m onto a steel plate. The sample was weighed and sized into coarse (+12.5mm) and fine (-2mm) size fractions and thereafter recombined before dropping further until drop 10. Each incremental drop represents the increased force exerted on the briquette during handling (e.g., stacker to stockpile, shovel to chute, loading into railroad cars, ship-holds) and transportation to the end user [20, 21].

2.3.3 Weathering performance

The weathering of coal stockpiles is known to have a deleterious impact on coal quality, strength, and technological performance [22]. Therefore, it was important to study the impact of atmospheric weathering on the mechanical strength of binderless coal briquettes when stored in stockpiles. The briquettes were placed in perforated aluminium trays outdoors under a covered area where they were exposed to solar radiation and wind. The briquettes were sprayed daily with tap water to simulate the impact of moisture. The experiment was conducted over seven days, concluding with sizing and drop shatter (2 drop) analyses.

2.3.4 Inner stockpile blending analysis

A test was conducted to study the moisture absorption and exchange within a stockpile when the binderless coal briquettes were blended with a -50mm + 0mm coarse washed reference coal product (calorific value, ~23 MJ/kg and Ash, ~26%). The initial particle size distribution and total moisture were measured for each blend component. Four blends were constructed using a blend ratio consisting of 20 parts briquettes and, 80 parts coarse coal. The blends were transferred into steel drums and tightly sealed. Weekly measurements of the total moisture and drop shatter (2 drops) sizing were taken for each blend component. The drop shatter tests were conducted on the blend and individual blend components respectively, on a dry and wet basis. That is, the latter were air dried overnight, while the former were dropped immediately after removal from the drums.

3 Results and discussion

3.1. Standard coal analyses on feed and binderless coal briquettes

The upgraded fine coal used for feed to the BCB plant had an average heating value of ~23.9 MJ/kg and ash content of ~23.8% (Table 1). The calorific value of the resultant binderless coal briquette product increased by 3%, while the total moisture decreased significantly by 77%, compared to the wet feed. This quality upgrade has positive implications on the trade value of the binderless coal briquette product, as well as the ease of transportation due to the significant decrease in moisture content.

Table 1. Feed vs binderless coal briquette quality on air-dry basis (a.d).

Analysis	Feed	Binderless coal briquette
Calorific value (MJ/kg)	23.87	24.61
Total moisture% (As received)	12.63	2.94
Proximate analysis%		
Inherent moisture	2.42	2.07
Ash	23.79	22.92
Volatile matter	22.17	22.82
Fixed carbon	51.63	52.20
Ultimate analysis%		
Carbon	60.91	62.56
Hydrogen	3.85	3.89
Nitrogen	1.47	1.55
Oxygen	6.67	6.16
Total sulphur	0.90	0.93

The petrographic assessment (Table 2) indicates that the beneficiated feed coal was an inertinite-rich (50.6 vol%, inc. mm), medium-rank C bituminous coal. Clay minerals (14.4 vol%) were the dominant mineral matter group in the feed. The presence of clay minerals has been shown to enhance the bonding of the coal constituents during briquetting [12].

Table 2. Petrographic characteristics of the feed coal.

Percentage mean random vitrinite reflectance (%RoVmr)		**St.dev.**	**Min**	**Max**
0.628		0.051	0.500	0.800
Coal Rank	Medium-rank bituminous C			
Petrographic composition (vol%)				
Maceral group	Including mineral matter		Mineral matter free	
Inertinite	50.60		63.41	
Vitrinite	28.60		35.84	
Liptinite	0.60		0.75	
Total Mineral matter	20.20		-	
Mineral Matter Group (vol%)				
Clays	14.40		-	
Silicates	2.40		-	
Sulphides	2.00		-	
Carbonates	1.40		-	

The texture of the feed (Figure 2A-C) and briquette samples (Figure 2D-F) were observed using a petrographic microscope to study the agglomeration between the macerals and minerals both pre- and post-briquetting. The photomicrographs of the feed coal show larger macerals and mineral particles embedded in a fine clay-rich matrix post-briquetting. Smaller maceral and minerals also constitute this matrix. The clay minerals also occur as finely distributed particles and thin bands on the macerals. Overall, the briquette photomicrographs show good bonding as all the coal components appear highly compacted. Cracks and fissures were apparent on some of the macerals and along their boundaries when high compressive strengths were exerted during the briquetting process. These features indicate zones of weakness along which the briquette would be prone to breaking when exposed to excessive force, or to increased moisture uptake when exposed to moisture.

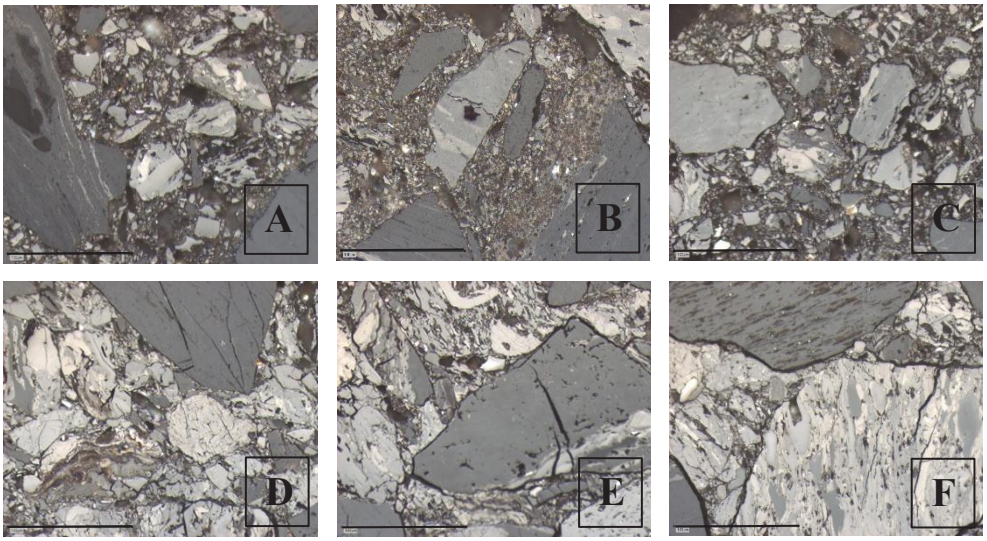

Fig.2. Feed coal (A-C), and binderless coal briquette (D-F) photographed under reflected light, oil immersion at x500 magnification. Scale bar = 100 μm**.**

3.2 Moisture adsorption

Figure 3 demonstrates that the binderless briquettes studied underwent rapid moisture adsorption in the first 3 days of the experiment, as the moisture increases from an initial 2.4% equilibrium moisture to 3.5%. This is followed by equilibrium at ≈ 4.7% between days 8 to 30. Therefore, it can be expected that the binderless briquettes will maintain a low inherent moisture (i.e., <5%).

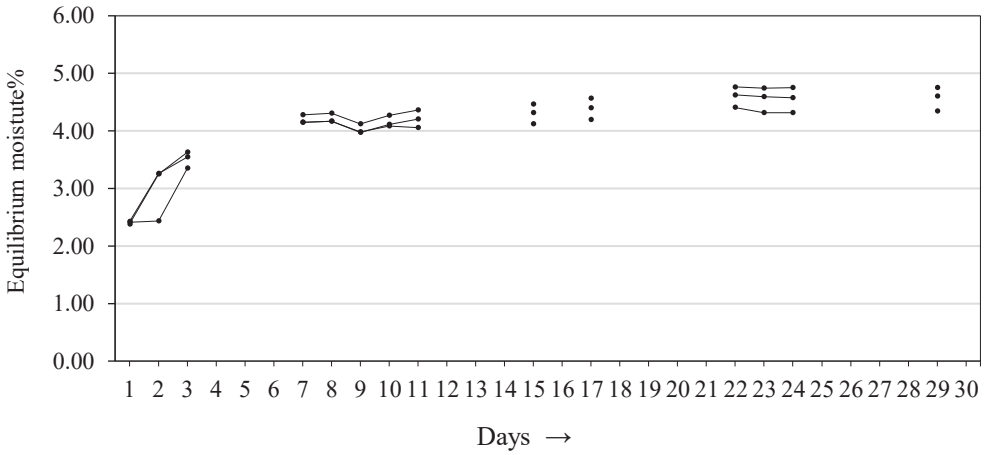

Fig.3. Moisture adsorption of binderless coal briquettes over 30 days

3.3 Drop shatter test

Figure 4 shows that the initial sizing (drop 0) of the briquettes 24 hours post-production indicates that 97% of the briquettes reported to the coarse fraction (+12.5mm), while only 1% constitutes the fine size fraction (-2mm). After 10 drops, more than half (61%) of the briquettes reported to the coarse fraction, while 15% of the material reported to the fine fraction. This indicates the briquettes had good resistance to breakage when exposed to severe force i.e., ten drops. Moreover, the fines generation were comfortably within the stipulations set by domestic and export coal users for product acceptance.

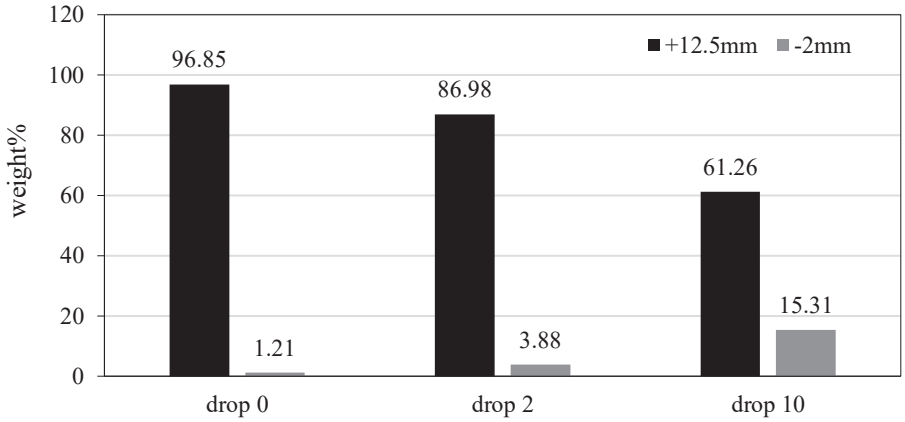

Fig.4. Drop shatter test 24 hours after briquetting.

3.4 Weathering performance

After a week of weathering, the briquette strength showed minor degradation as the coarse particles decreased by 11%, while the fine particles increased by 5% (Figure 5). This indicates the extent of breakage that may occur on the outermost layer of a stockpile which is directly exposed to atmospheric elements [23].

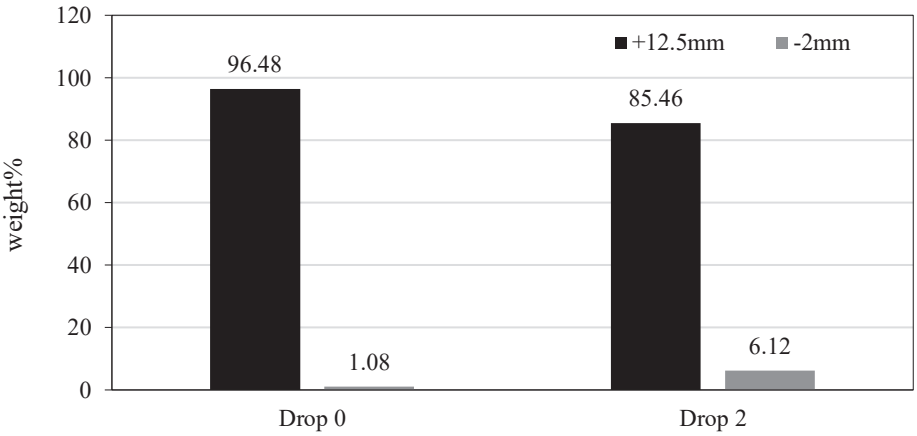

Fig.5. Drop shatter test after 7-day weathering trial.

3.5 Inner stockpile blending

The particle size distribution after the dry-drop shatter tests (Figure 6) for the inner stockpile test shows that the coarse briquette particles decreased to an average of 20% after 10 drops compared to the initial briquettes (Figure 6A). The fine particles increased from an average of 2%, to 42% after 10 drops (Figure 6B). The wet drop shatter results follow a similar trend. However, the extent of degradation appears to be slightly less, especially in the fine fraction.

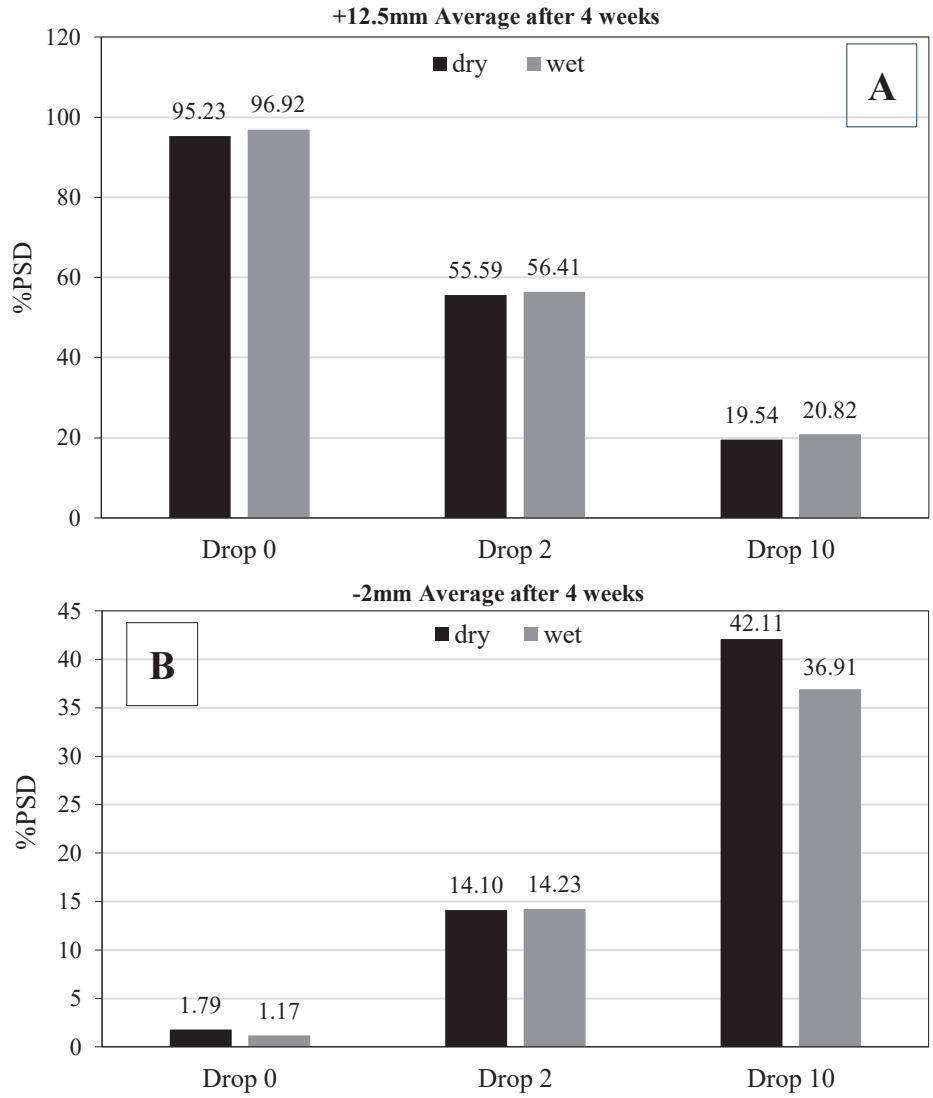

Fig.6. Drop shatter test for the inner stockpile test dry vs wet blend, (A) +12.5mm after 4 weeks, (B) -2mm after 4 weeks

As expected, the moisture exchange observed in the inner stockpile testing (Figure 7) shows an increase in the total moisture of the briquettes from a low level (1.6%) to a level of that exceeding the -50mm reference product (9.4%) after 7 weeks in storage. Correspondingly, the moisture content the -50mm reference product decreases from an

average of 7.9% to 3.8%. A mass balance check of the moisture exchange within the steel drum shows that the briquettes only absorbed 780g of the 1600g of moisture released from the -50mm product. Thus, approximately 820g of moisture was expelled (condensed) to the drum air, as water droplets were observed under the lids of the steel drums. Therefore, the overall moisture exchange in the experiment resulted in a 40% increase in moisture uptake due to the closed environment of the drum. In practice, it is expected that airflow within the stockpile would allow for dispersion of the excess moisture to the air, resulting in a lower net gain in moisture [24].

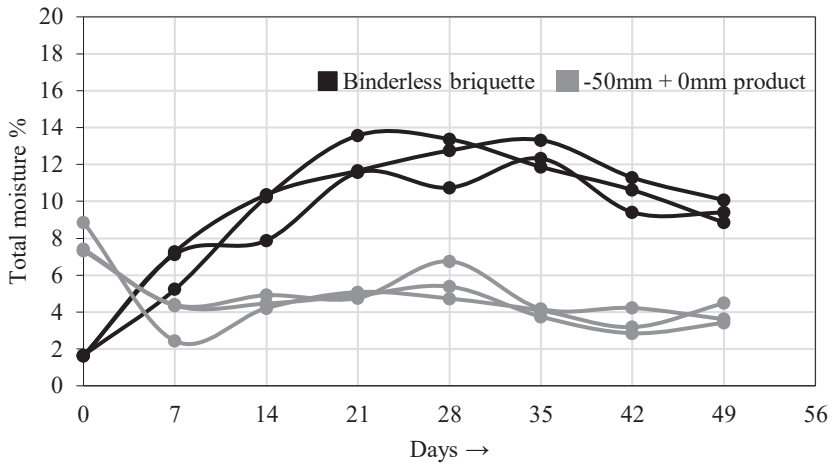

Fig. 7. Inner stockpile moisture exchange between a blend of binderless briquettes and a -50mm product.

The comparative overview of the resistance to breakage as determined by the drop shatter test for the various tests performed in this study is shown in Figure 8. The weathering and the dry-drop shatter tests (2 drops) resulted in the least breakage on the briquettes. In contrast, the prolonged (4 weeks) inner stockpile blending test resulted in a greater degree of degradation, more so when the wet briquettes were dropped. The extent of breakage after the 10-drop, dry-drop shatter test is comparable to that observed for the inner stockpile test (dry and wet). In practice it is expected that a relatively small percentage of briquettes would experience total inundation in water and the weathered briquettes would affect a relatively small percentage of briquettes on the surface of a stockpile as demonstrated by the drop shatter tests of the weathering test.

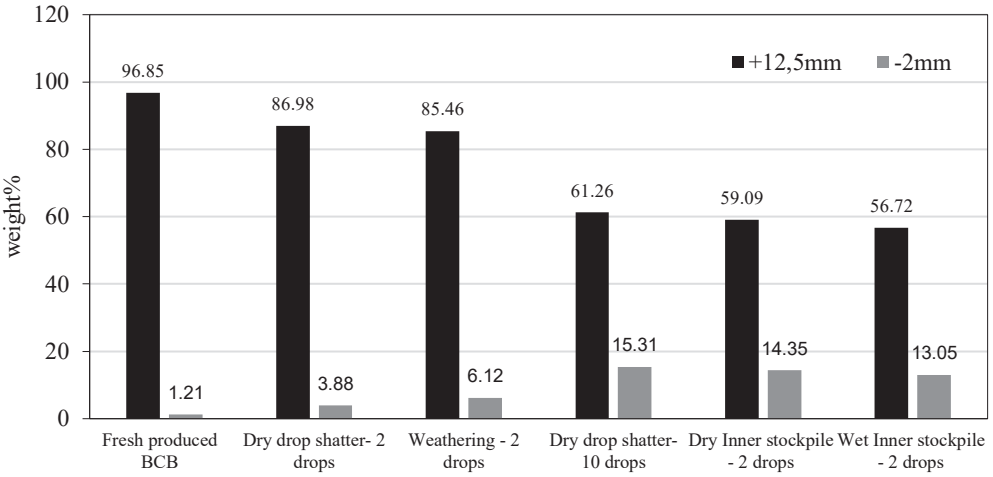

Fig.8. Comparison of binderless coal briquette strength as determined by the drop shatter test.

4 Conclusions

The recent binderless coal briquette test work demonstrates that the RE technology is capable of briquetting fine beneficiated discard-derived coals, resulting in a coarse product with a significant reduction in the total moisture content (77%) and a moisture-adjusted improvement in calorific value (3%). Moreover, the mechanical and weathering tests indicate acceptable durability that is appropriate for existing materials handling and stockpiling practices in the coal market. Additional test work is underway to ascertain the materials handling characteristics of the binderless coal briquettes as well as to assess the quality of binderless briquettes using blends of coarse and fine reclaimed discard coal, as well as refuse-derived fuels. The findings in this study are consistent with similar studies conducted on inertinite-rich coals in South Africa and highlights the imperative need for wider deployment of this technology as part of a sustainable solution towards coal waste handling in South Africa.

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References

1. N.J. Wagner, The characterization of weathered discard coals and their behaviour during combustion. Fuel, **87,** 1687-1697 (2008). https://doi.org/10.1016/j.fuel.2007.09.009
2. P.J. Lloyd, The potential of coal wastes in South Africa. J. South. Afr. Inst. Min. Metall. **100**, 69-72 (2000).
3. J.F. Reddick, H. Von Blottnitz, B. Kothuis, A cleaner production assessment of the ultra-fine coal waste generated in South Africa. South. Afr. Inst. Min. Metall. **107**, 811-816 (2007).

   https://www.saimm.co.za/Journal/v107n12p811.pdf

4. E. Muzenda, 2014). Potential uses of South African coal fines: a review, In 3-rd Int. Conf. on Mechanical, Electronics, and Mechatronics Engineering (ICMEME–2014), Abu Dhabi (UAE), March 19–20 2014, 37-39.
5. B. North, A. Engelbrecht, B. Oboirien, Feasibility study of electricity generation from discard coal. South. Afr. Inst. Min. Metall. **115**, 573-580 (2015). https://doi.org/10.17159/2411-9717/2015/V115N7A3
6. G.J. de Korte, Processing low-grade coal to produce high-grade products. South. Afr. Inst. Min. Metall. **115**, 569-572 (2015). https://doi.org/10.17159/2411-9717/2015/V115N7A2
7. P. Venter, N. Naude, Evaluation of some optimum moisture and binder conditions for coal fines briquetting. South. Afr. Inst. Min. Metall. **115**, 329-333 (2015). https://doi.org/10.17159/2411-9717/991/2021
8. R. Q. Honaker, J. Kohmuench, E. Dohm, G H. Luttrell, Cleaning of fine and ultrafine coal. In The Coal Handbook: Volume 1: Towards Cleaner Coal Supply Chains, Second Edition. L, 447-489 (2023). https://doi.org/10.1016/B978-0-12-824328-2.00022-4
9. T.O. Olugbade, O.T. Ojo, Binderless briquetting technology for lignite briquettes: a review. Energy Ecol. Environ. **6**, 69-79 (2021). https://doi.org/10.1007/s40974-020-00165-3
10. M. Özer, O.M. Basha, B. Morsi, Coal-Agglomeration Processes: A Review. Int. J. Coal Prep. Util. **37**, 131-167 (2017). https://doi.org/10.1080/19392699.2016.1142443
11. N.T. Leokaoke, J.R. Bunt, H.W.J.P. Neomagus, F.B. Waanders, C.A. Strydom, T.S. Mthombo, Manufacturing and testing of briquettes from inertinite-rich low-grade coal fines using various binders. South. Afr. Inst. Min. Metall. **118**, 83-88 (2018). https://doi.org/10.17159/2411-9717/2018/v118n1a10
12. S.J. Mangena, G.J., de Korte, R.I. McCrindle, D.L. Morgan, The amenability of some Witbank bituminous ultra fine coals to binderless briquetting. Fuel Process. Technol. **85**, 1647-1662 (2004). https://doi.org/10.1016/j.fuproc.2003.12.011
13. S.J. Mangena, V. M. Du Cann, Binderless briquetting of some selected South African prime coking, blend coking and weathered bituminous coals and the effect of coal properties on binderless briquetting. Int. J. Coal Geol.**71**, 303-312 (2007). https://doi.org/10.1016/j.coal.2006.11.001
14. S. Motaung, S. J. Mangena, G. J. de Korte, R. I. McCrindle, J. H. P. van Heerden, Effects of Coal Composition and Flotation Reagents on the Water Resistance of Binderless Briquettes. Int. J. Coal Prep. Util. **27,** 230-248 (2007). https://doi.org/10.1080/07349340701672102
15. M. Belaid, R. Falcon, P. Vainikka, K.V. Patsa. Potential and technical basis for utilising coal beneficiation discards in power generation by applying circulating fluidised bed boilers. In 2nd international conference on chemical, ecology and environmental sciences, London (UK), June 2013, 17-18 (2013)
16. A. Moyo, J.A. Filho, S. Harrison, J. Broadhurst. Characterising the environmental risks of coal preparation wastes: A study of fine coal slurry waste and discards from South African collieries. In IMWA 2018 Annual Conference; Pretoria, South Africa (2018)

17. N.J. Wagner, N. Malumbazo, R.M.S. Falcon. Southern African Coals and Carbons: Definitions and Applications of Organic Petrology (Struik Nature, Cape Town, 2018)
18. L.C. Mutyavaviri, C.H. Chihobo, D.C.Makepa, The ecological effects and valorization of coal fines-a review. Environ. Sci. Pollut. Res, **31**, 51045-51063 (2024). https://doi.org/10.1007/s11356-024-34620-z
19. L. Cornish, River Energy SA-Eskom's quick-fix solution: coal beneficiation. Inside Mining **6**, 38-40 (2013).
    https://hdl.handle.net/10520/EJC133937
20. S.R. Richards, Physical testing of fuel briquettes. Fuel Process. Technol. **25**, 89-100 (1990). https://doi.org/10.1016/0378-3820(90)90098-D
21. T. England. Task 4.4.1 – The Economic Agglomeration of Fine Coal For Industrial And Commercial Use: Phase 1, A Review of Past and Present Work both Locally and Internationally. COALTECH 2020 report (2000)
22. J. Kus, M. Misz-Kennan, Coal weathering and laboratory (artificial) coal oxidation. Int. J. Coal Geol. **171**, 12-36 (2017).
    https://doi.org/10.1016/j.coal.2016.11.016
23. M.T. Sebola. Weathering of coals from the Waterberg and Limpopo Coalfields, South Africa, Master Thesis, University of the Witwatersrand, South Africa, 2018

    J. Zhang, T. Ren, Y. Liang, Z. Wang, A review on numerical solutions to self-heating of coal stockpile: Mechanism, theoretical basis, and variable study. Fuel, **182**, 80-109 (2016).
    https://doi.org/10.1016/j.fuel.2016.05.087