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Characterization of Indiginously Developed KPK Coal Briquettes

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Abstract: The aim of this study was to look into the feasibility of using the run of mine waste coal micron size particles in producing value added coal briquettes. Varying strengths of low cost and readily available starch and poly vinyl acetate (PVA) were used as the organic binders. In devising a mechanism for the local (KPK region of Pakistan) low cost coal up-gradation, this work has looked into developing the coal briquettes of acceptable combustion and mechanical properties. This has been achieved by identifying the optimum composition of run of mine micron sized waste coal, binding and filler materials to give the acceptable levels of compression strength, and ease of combustion in both open and confined places. A mechanical briquetting machine was indigenously designed with the aim of low cost local technology transfer. The briquetted products were then analyzed for their mechanical properties by the Universal Testing Machine (UTM). The surface structure and/or composition were also explored with the help of a Scanning Electron Microscope (SEM). The UTM results showed that the briquettes made with starch binder had good compression strength (4000N) in comparison to others. This was also confirmed by the SEM analysis which showed low surface porosity for starch blended briquettes. The low surface porosity also resulted in showing a high water absorption resistance and shatter index hence giving high compression strength values.

Keywords: KPK Coal, Coal briquettes, Coal characterization, Organic binders

1. INTRODUCTION

The present energy crisis in developing countries such as Pakistan has forced the national and local governments to look for the affordable ways to utilize the indigenous low cost energy resources such as coal. The Khyber Puktunkawa (KPK) province, located in the North-West of Pakistan, has considerable reserves of low ranked coal and its effective up-gradation and utilization can help meet the growing domestic and light industrial local energy demands. Coal is the world's most readily available and widely used low cost energy source. It is mainly due to this reason that a keen interest in energy acquisition from coal has been shown since long. Considerable amount of research resources have continued to be allocated to devise, develop and demonstrate the clean and efficient use of coal to reduce the environmental and investment uncertainties. This is especially made possible by the continuing developments in carbon capture and storage technologies (IEA, 2010) in line with the plan of action and commitment agreed by G8 leader in 2005 at Gleneagles summit (G8, 2005).

Coal, despite being considered as a dirty energy option, remains a favorable choice for energy generation due to its unrivaled advantages of low price, ease of transport, storage, availability of infrastructure and expertise, diversity of generation capacity and the levels of required investment (IEA, 2005). At present, an estimated 42% of global electricity production is from Coal. The current coal reserves of all types are estimated to be around 900 billion tones, sufficient for 150 years at the current rates of consumption (BGR, 2009). In comparison with the developed world, where high grade coal is mostly used for electricity generation, the indigenous low grade coal reserves in the third world countries such as Pakistan (~185,175 million tons) are mostly exploited for local and light industrial heating use (NEPRA, 2004). This is mainly due to the high costs and non-existence of suitable technology and trained manpower for coal up-gradation to generate electric power on a large scale. Hence, most of the mining operations remain manual and produce considerable amount of fines which are sold at low prices in comparison with their lumped counterparts.

In the wake of current financial standing which restricts the Pakistan's national and local governments to invest in large scale coal up-gradation and power generation projects, despite the escalating energy crisis, there is a pressing need to develop and devise some indigenous ways to harness the power of coal for local use. This is especially applicable for the ecologically concern but financially attractive growing deposits of run of mine coal waste in the fine particle size (<1000µ) range. The interest in this area is not new and several studies have looked into the mechanical and combustion characteristics of briquetted fuel products made from coal, sewage sludge and municipal solid waste or a combination of these (Massaro *et al.,* 2014). This has resulted in forming the basis for this work to devise, characterize and access a low cost coal up-gradation technique (Habib *et al.,* 2013) by developing and disseminating an indigenous coal briquetting technology

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that is aimed to cater the needs of the local market with least possible initial investment, operating cost, experience and technical knowhow.

Manufacturing and testing of coal briquettes had no standard method established until 1990, when Richard first identified four important physical properties (i.e., resistance to crushing, impact, abrasion, and water penetration) for testing of commercial coal briquettes (Richards, 1990). Mehmat and Gulhan reported the production of ammonium nitro-humate and its use as an environmentally sound binder in the manufacturing of coal briquettes (Meahmat and Gulhan, 2010 and 1997). This binder was cheaply produced by reacting aluminum hydroxide with Elbiston lignite and gave good binding characteristics. The reported effects on the mechanical properties were enormous but no effect on thermal characteristics was reported in their work. Berkowitz had reported the influence of coal particle size on the strength of manufactured coal briquettes (Berkowitz, 1979). The work showed that the mechanical properties such as strength significantly depended on the coal particle size. Decrease in particle size showed increased briquette strength due to an increased rate of adhesion among the coal particles as a result of decrease in porosity (Meahmat and Gulhan, 2010). Taylor's experiments with lignite char and pitch resulted in showing enhanced mechanical properties in the manufactured coal briquettes (Taylor and Coban, 1987; Taylor, 1988; Taylor and Hennah, 1991). Clark and Marsh have shown that pitch blended with raw coal had great effect on the desired pore shape, size and wall characteristics, subsequently resulting in improving the mechanical strength of the briquetted product (Clark and Marsh, 1989). Rubio *et al* had reported enhanced strength coal briquettes by investigating the pitch blended coal briquettes (Rubio *et al.*, 1999). They looked into the morphology of pitch blended charcoal briquettes by Scanning Electron Microscope (SEM) and found that pitch covered and filled the inter-particle spaces, hence reducing the porosity in the final product. This reduction in porosity was considered the main factor in enhancing the briquette strength. In contrast to the use of binder, some binder-less coal briquetting techniques have also been reported in the literature (Sun *et al.*, 2014), however, these require additional pretreatments such as heat treatment before briquetting of coal.

In this work, two organic binding materials of starch and polyvinyl Acetate (PVA) were used to assess the mechanical strength characteristics of briquetted coal. The measurements were made by using the Universal Hydraulic Tensile Testing Machine (UTM model Testometric UK, 500-1000KN) which gave the results of mechanical strength in the form of compressive strength (CS)) and Impact Resistance Index (IRI). Furthermore the surface microstructure of the briquetted product was analyzed by the Scanning Electron Microscope (SEM model JSM-5910 JEOL Japan) to reveal the inter-bonding characteristics of coal, filler and binding materials.

2. MATERIAL AND METHOD

2.1 Coal Briquetting Technique

The process of coal briquetting started with the sourcing of waste run of mine powdered coal. After sourcing the suitably sized raw coal powder, whose size characterization is given in **(Fig. 1)**, it was mixed with the desired binder. Depending upon the required characteristics of briquetted product, fillers can be added at this stage. Coal, binder and filler weight compositions for all samples are enlisted in **(Table 1)**. The well mixed mixture was then shaped with the help of a compression force in a cylindrical shaped container. Coal briquettes were then removed and sun dried for further analysis and processing. The actual construction and working of the briquetting machine is presented in our previously reported work (Habib *et al.*, 2013).

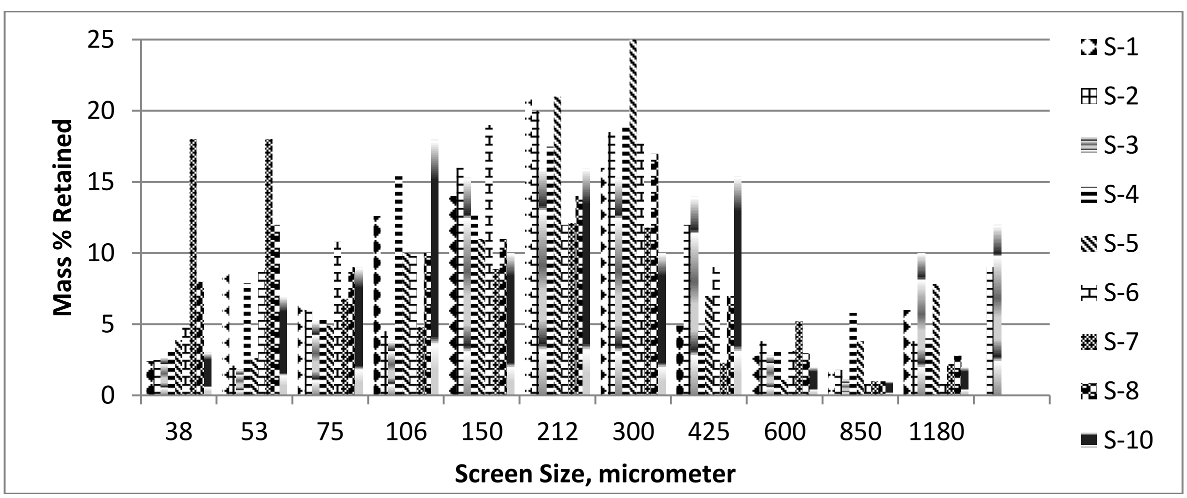


Fig.1: Particle size analysis of raw coal samples. "S" in the figure represents the sample number.

Table-1: Composition of coal briquetted samples.

	Coal, gm	Starch Binder, gm	PVA Binder, gm	Tire rubber filler, gm
sample-1	600	50	0	0
sample-2	800	75	0	0
sample-3	700	80	0	0
sample-4	1000	70	0	0
sample-5	1000	80	0	0
sample-6	1000	90	0	0
sample-7	700	0	60	0
sample-8	600	0	80	0
sample-9	700	60	0	40
sample-10	600	70	0	40

2.2 UTM Analysis

UTM (Testometricss U.K M-500 100KN) is a widely used instrument to determine the mechanical properties such as compression, and tensile strength of different solid samples. To find the compressional strength of the briquetted sample it was placed in-between the two plates of the hydraulic press in such a way that the flat surface of the sample rested on the horizontal plate .

2.3 Scanning Electron Microscope analysis

In an effort to understand the surface morphology of the manufactured coal briquettes, Scanning Electron Microscope (SEM) analysis was performed at the Centralized Resource Laboratory of the University of Peshawar. The main aim of this analysis was to look for comparative visual analysis of surface properties such as inter-particle pore size. The SEM micrographs were taken at 100 and 400X magnifications to get a close up look into the surface morphology and pore structure. The analysis gave an insight into the role of binding agent in reducing the porosity of the different coal briquetted samples.

3. RESULTS AND DISCUSSION

3.1 Coal briquetting and UTM analysis

A constant load at pressing speed of 2mm/min was applied on each briquetted sample with the help of a motorized screw. The motorized screw reduced the distance between the plates until cracks appeared in the test structure. At this cracking and/or breaking point the compressive strength was calculated and stored in the connected computer. The UTM results presented in this work related crack propagation with the applied force. The UTM results of all test samples are shown in Fig.2–4 to compare the mechanical properties of deflection, area, deflection at break/peak, deflection at yield, energy at break/peak, yield, ISO9969 ring stiffness,, inner diameter comparison, load at break/peak, strain at break/peak, stress at brake/peak, yield and Young's Modulas among all samples.

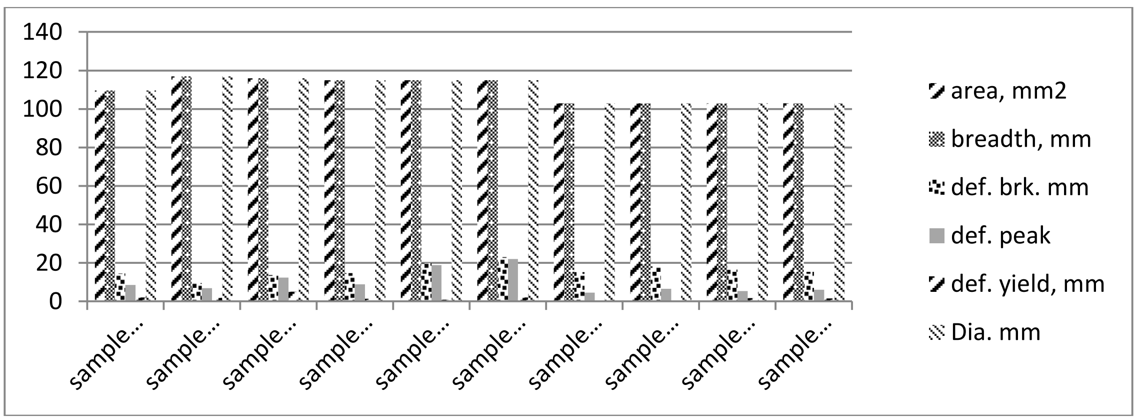


Fig. 2: Area, breadth, deflection at break, deflection at peak, deflection at yield and diameter comparison of different coal briquetted samples.

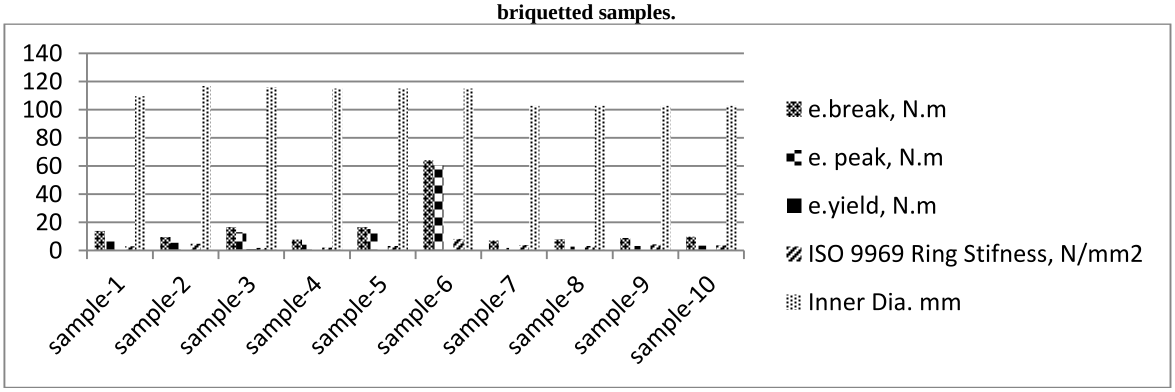


Fig.3: Energy at break, peak, and yield, ISO9969 ring stiffness and inner diameter comparison of different coal briquetted samples.

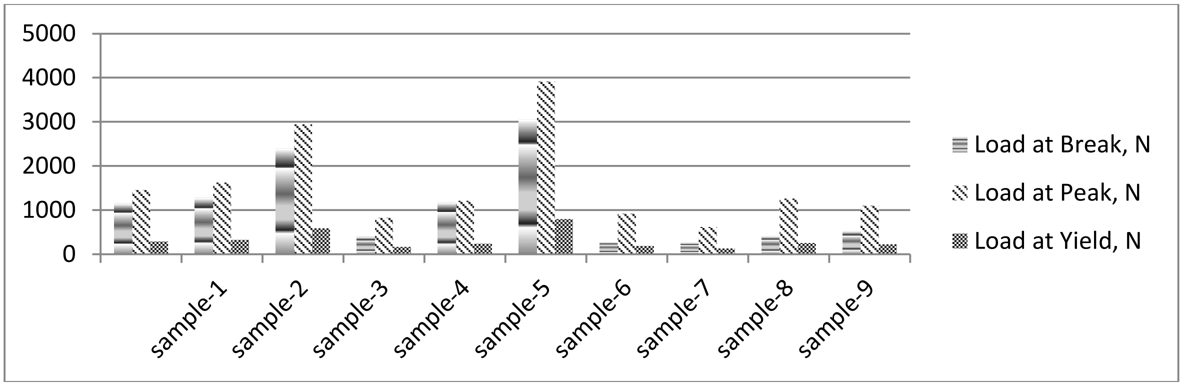


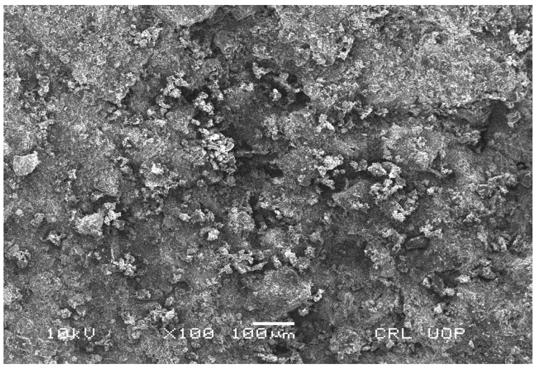
Fig. 4: Load at break, peak and yield of coal briquetted samples.

An anaysis of (**Fig. 2)** revealed that sample-6 had the highest UTM deflection standing followed by samples 1, 3 and 5. The rest of the samples showed nearly the same deflection behavior in the small applied force range of 500N. As can be seen in Fig. 2, no significant difference in the values of area, breadth, deflection break, deflection peak, deflection yield and diameter of all samples was seen. However differences in energy at peak and break of sample no 6 was highest among all followed by samples 3 and 5 (**Fig.3**). As shown in (**Fig. 4)**, the best load taken at break, peak and yield was shown by sample-5 followed by samples no 2 and 1. The best strain at break, peak and yield was demonstrated by sample 6 followed by 5, 3, and 1. These values when compared with the sample composition given in Table 1, revealed that the different compressional strength values were dependent upon the amount of starch which was used as a binding agent blended with coal. The improved mechanical properties may be linked with increased weight percentage of starch binder (Taylor, 1988; Clarke and Marsh, 1989; Mani *et al.,* 2003), which could have led to improved bonding in-between the coal particles. Samples 6 and 3 gave compressional strength values in excess of 1500N, which were considered acceptable for the purpose of storage and transportation (Meahmat and Gulhan, 2010; McMullen *et al.,* 2005). An analysis of Fig. 2 shows that the sample stress increased ascendingly with the application of the external load. Small cracks started to appear in the manufactured structure at an applied force of ~1200N. The breaking point was recorded near 1500N for sample Nos. 1,2,4,5,7,8,9 and 10 after which the sample breakage was recorded as shown by the descending line. For KPK Dovala coal briquettes, an analysis of **(Figs 2, 3 and 4)** showed a compressional strength value of 800N for 7% by weight starch binder, which increased to 1200N with 8% starch binder addition and recorded an impressive 4000N with 9wt% starch binder addition with corresponding increase in Young's Modulus and absorbed stress value as given in Table 1. The use of End of Life (EOL) shredded tires as a filler (4%) in sample Nos. 9 and 10 with starch binder (7%) did not show any significant increase in the mechanical strength of the manufactured coal briquettes. The results showed that the addition of tire rubber actually weakened the inter-particle bonding and hence a decrease in compressional strength values in comparison with non-filler added samples with starch binder was recorded (Brett *et al.,* 1995).

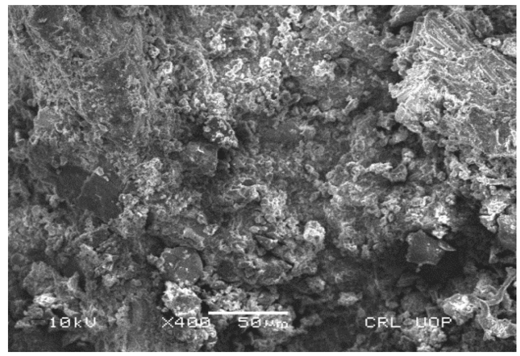
3.2 Scanning Electron Microscope analysis

A comparatively reduced surface porosity of coal briquetted sample was visually observed in starch blended coal briquette as shown in **(Fig.5a)**. Porosity has an inverse relation with the measured mechanical properties; hence the prediction of increased strength with low porosity was confirmed for this sample. Less porous structure also absorbs comparatively small quantity of atmospheric moisture hence showing a positive impact on the combustion profile. Mechanical properties such as Shatter Index (SI) and the Water Resistance Index (WRI) of the less porous sample were observed to increase. Hence these samples were comparatively considered better for storage and transportation purposes. A closeup look of the same coal briquetted sample at 400 X magnification **(Fig.5b)** confirmed the enhanced comparatively pore-less starch bonding of the coal particles.

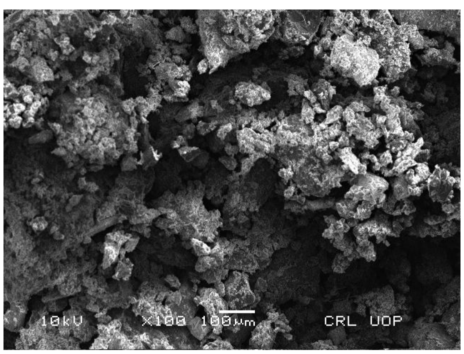
SEM image of the PVA blended coal briquette at 100X magnification is shown in **(Fig. 5c)**. It shows a comparatively more porous structure as the pore size was large in comparison with the starch blended coal briquettes. One possibility of increase in pore size in this case can be the existence of weak inter-particle forces imparted by PVA. The PVA binder and particles did not agglomerate well with each other as is evident from the existence of a hollow shell type structure in the micrograph. The enhanced porous structure in this sample resulted in increased susceptibility of the sample to absorb moisture resulting in comparatively lesser SI and WRI). The above SEM analysis confirmed that the PVA blended coal briquettes had low mechanical strength in comparison with starch blended coal briquettes. These observations were also confirmed with a close up look into the surface structure at 400X magnification as shown in **(Fig. 5d)**. SEM micrograph for the surface morphology of starch plus rubber bonded coal briquettes is shown in **(Fig. 5e and f)**. These images give an estimate of the surface porosity of the sample which contained shredded tire rubber particles as filler addition with coal bonded by starch. The existence of cylindrical rod shaped rubber particles prohibited the complete mixing of binder with coal particles resulting in showing very weak mechanical properties in comparison with other test samples, as discussed in earlier sections. As a result of high porous structure these samples had comparatively high tendency to absorb moisture from the surroundings (Yaman *et al.*, 2001). The strength analysis revealed lower SI and lower WRI for these samples. Due to poor compressive strength the manufacturing of high porosity briquettes is not recommended as the product exhibit poor transportation and storage characteristics (Daud, 2008).



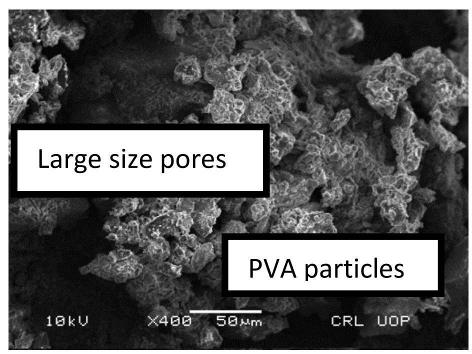
a. Starch blended coal briquette taken on 100 magnifications.



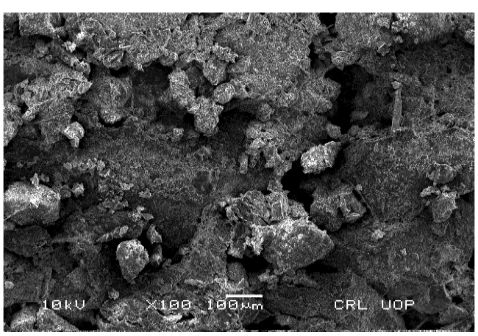
b. starch blended coal briquette taken on 400 magnifications.



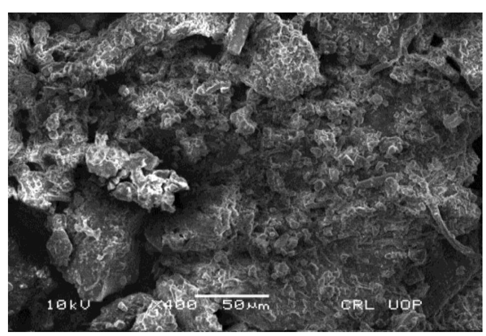
c. PVA blended coal briquette taken on 100 magnifications.



d. PVA blended coal briquette taken on 400 magnifications



e. Starch + rubber blended coal briquette taken on 100 magnifications.



f. Starch+ rubber blended coal briquette taken on 400 magnifications.

Fig. 5: SEM micrographs of coal briquetted samples.

4. CONCLUSIONS

From quality control analysis of mechanical properties through UTM and SEM, It was found that starch binder exhibited good binding characteristics among all. Starch (9-10 wt%) bonded samples gave maximum compression strength values of 4000N which is of reasonable acceptance in the local briquetting market. High strength briquettes help prolong the briquetted coal age and is useful for its transportation, storage and marketing. From this experimental work it is also concluded that the use of PVA resulted in giving low compressional strength of the manufactured sample which at times was as low as 1200N. The use of shredded tires as a filler gave the least mechanical characteristics to the test sample and is therefore not recommended as filler addition in the investigated samples in this study.

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