# Natural Fragmentation Model of Zirab Coals, Iran

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**Abstract:** Iran's coals occur in the Alborz range (north) and Central Iran basins. The Zirab is typical coalfield in the Alborz coal basin. From litho types of view, the coals are mainly clarovitrinite to clarodurite type which are used as source of coking coal for metallurgical factories. During the research we used 10 typical samples from Zirab coal mine to estimate fragmentation model of natural particle-size distribution of these coals. Prediction of natural fragmentation properties from coals was the main aim of this research. In order to calculate the natural fragmentation model at any stage of the extraction (or sizing) operation, we tried to find similar models that combine both natural fragmentation and degradation through natural crushing. The results our research suggest a power-law and a log-normal behavior for the distribution of the smaller and larger coal fragments, respectively. We show that the probability function that models the production of particles of different size from an initial mass and sorts that distribution is related to mass and compositional factors of coal particles. Also, our studies showed that during the fall of coals from 4m height, fragmentation followed a range of 10 percent, per time for particles smaller than 5 mm diameter. It means that if the processes would repeat 10 times, 100 percent of coals would crush to the size of less than 5 mm.

**Keywords:** Fragmentation model, Zirab coal mine, Central Alborz, Iran.

## INTRODUCTION

Fragmentation is an irreversible kinetic phenomenon which occurs in many physical and chemical processes. Because of broad range of applications, many recent studies have been carried out to investigate the kinetics of the processes by introducing simple fragmentation models [1-3]. In [2] Mc Grady and Ziff presented a model of fragmentation in which the rate of break up depends on the size of the fragments. Some models of binary fragmentation were introduced which revealed composite power-law distributions for the mass and size of the fragments. Another behavior of distribution which is observed in many different processes has a log-normal form [3]. The log-normal behavior is known to be able to describe the size distribution in a wide variety of geological situations, such as that of rocks in a boulder field and volcanic ash flying [4-25]. An experimental work on the shock fragmentation of long thin glass rods was carried out by Ishii and Matsushita [3]. The results of fragment size and mass distributions at small falling heights showed a log-normal form for larger fragments and a power-law form for smaller fragments. Now, we investigate some experimental work on the natural fragmentation involving log-normal distributions and the transition of the distributions from a log-normal form to a power-law one and vice -versa [3]. The fragment size and mass distributions for the coal pieces with different lengths and diameters during the natural fragmentation. Natural particle size fragmentation occurs in many important geological processes. Because of its wide applicability as well as in minerals industry there has been considerable interest in predicting theoretically the evolution of the particle-size distribution during the fragmentation. The economics of many operations in the minerals industry depend on the particle size distribution and natural fragmentation is usually the first step in creating size distribution. Natural fragmentation during the excavation, blasting and subsequent ore minerals. Previous models of fragmentations in soft and hard rocks are useful for economics of many operations in the minerals industry. This paper presents an investigation about amount of coal particles produced during mining, handling and transporting before crushing and milling.

## MATERIALS AND METHODS

Iran's coals occur in the Alborz range (north) and Central Iran basins. The Zirab is typical coalfield in the Alborz range coal basin. The coal bearing sequences in this range are contained in the Upper Triassic to Middle Jurassic Shemshak Formation, which consists mainly of sandstone, shale, siltstone, and claystone. From litho type's point of view, these coals are mainly clarovitrinite to clarodurite type which are used as source of coking coal for metallurgical factories. The coking coals have relatively high vitrinite (60-90%), and low inertinite (10-20%) and liptinite (5%) contents. The dominant macerals of the vitrinite group are telinite and collinite. Syngenetic pyrite, marcasite, detrital quartz, siderite, calcite, illite, and kaolinite are the main minerals in these coals. These coals seem to have strength of 5 to 10 MPa similar to those tested before in the Zirab coal mine [4-6]. During the research we used 10 typical samples from Zirab coal mine. For this experiment, samples of bright banded pure coal were collected from coal seams. The coals were chosen such that they represent a wide variety of coal type and textures.

Before fragmentation, the dimensions of coal samples were measured. The dimensions of extracted coals from the mine varied from very fine-grained to boulder size. The original dimensions of coal samples in this research varied from $11*9*3.5\ cm^3$ to $22*15*10\ cm^3$. The details of dimensions can be seen in Table **1**. The coal samples were fragmented by 3 times onto a cemented hard floor in similar throwing velocity of natural falling from a height. The mate-

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rial used was air-dried coals, and the height of the fall was 4.0 m. The fragmentation took place in large plastic bags. The mass of each fragments were measured by analytical balance. The dimensions of fragments group were measured by analytical sieves. Dimensions and masses of the each fragment group are given in Tables **2-4**. We did not measure the number of fragments but they varied from 2 to 1000 depending on the size of the coal sample (Figs. **1**, **2**).

**Table 1. The Primary Size (in cm) of Coal Samples as A, B and C**

| C | B | A | Sample No. |
|---|---|---|---|
| 7 | 14 | 14 | 1 |
| 7 | 15 | 20 | 2 |
| 3.5 | 12 | 12 | 3 |
| 8 | 10 | 15 | 4 |
| 6 | 10 | 16 | 5 |
| 6 | 9 | 16 | 6 |
| 6 | 9 | 11 | 7 |
| 6 | 12 | 13 | 8 |
| 10 | 10 | 22 | 9 |
| 9 | 9 | 16 | 10 |

**Table 2. Mass (in gr) and Dimensions (in mm) of the Each Fragment Group in the *First* Time from 4m Height**

| Sample No. | 50mm | 37.5mm | 19mm | 4.75mm | Pan | Total |
|---|---|---|---|---|---|---|
| 1 | 863.85 | 138.64 | 302.99 | 196.5 | 65.99 | 1572.08 |
| 2 | 2365.53 | 63.5 | 144.99 | 85.12 | 43.3 | 2703.17 |
| 3 | 575.79 | 0 | 44.23 | 21.49 | 13.73 | 675.29 |
| 4 | 1117.27 | 234.91 | 141.13 | 98.55 | 29.01 | 1652.69 |
| 5 | 1006.61 | 128.18 | 231.18 | 105.37 | 32.96 | 1508.4 |
| 6 | 862.72 | 139.45 | 308.89 | 161 | 39.59 | 1536.69 |
| 7 | 401.34 | 152.8 | 178.59 | 69.22 | 28.31 | 849.6 |
| 8 | 646.27 | 78.13 | 255.26 | 196.72 | 69.65 | 1266.87 |
| 9 | 1280.21 | 0 | 149.75 | 39.8 | 13.66 | 1487.57 |
| 10 | 395.31 | 0 | 249.76 | 162.34 | 75.79 | 890.84 |

## RESULTS AND DISCUSSION

Modeling and simulation of blasting and fragmentation has reached the point where can be constructively used to explore the interactions between mine and mill and to indicate changes which have the potential to improve mining companies profitability. Case histories such as that illustrated in this and other papers (by physicists and geologists) plus growing experience in the field show that it is possible to improve the overall economic performance of mines. One of the main questions is that how much natural fragmentation breakage of coal particles during the extraction, hauling and dumping process of the mining operations. The other important question is that the natural fragmentation obeys any modeling and simulation. In the previous researches have been found that the breakup rate is independent of the size of the material and all fragments are produced with equal probability. Also, dimensionality is depended to mass distributions after shock fragmentation. Those models suggest a power-law and a log-normal behavior for the distribution of the smaller and larger fragments, respectively [7, 8].

**Table 3. Mass (in gr) and Dimensions (in mm) of the Each Fragment Group in the *Second* Time from 4m Height**

| Sample No. | 50mm | 37.5mm | 19mm | 4.75mm | Pan | Total |
|---|---|---|---|---|---|---|
| 1 | 432.01 | 203.28 | 428.25 | 344.02 | 152.97 | 1592.82 |
| 2 | 2014.9 | 131.73 | 282.48 | 179.83 | 91.14 | 2700.08 |
| 3 | 351.03 | 107.37 | 118.97 | 53.35 | 24 | 668.94 |
| 4 | 944.4 | 115.64 | 275.53 | 214.61 | 67 | 1639.32 |
| 5 | 743.81 | 185.79 | 337.56 | 170.24 | 66.58 | 1529.21 |
| 6 | 667.94 | 50 | 351.47 | 347.66 | 96.5 | 1533.65 |
| 7 | 79.33 | 224.34 | 289.99 | 156.01 | 66.03 | 847.99 |
| 8 | 316.86 | 27.12 | 478.22 | 302.53 | 120.79 | 1264.02 |
| 9 | 862.34 | 87.54 | 341.84 | 145.09 | 47.9 | 1503.23 |
| 10 | 304.43 | 67.32 | 152.11 | 232.34 | 126.63 | 907.96 |

**Table 4. Mass (in gr) and Dimensions (in mm) of the Each Fragment Group in the *Third* Time from 4m Height**

| Sample No. | 50mm | 37.5mm | 19mm | 4.75mm | Pan | Total |
|---|---|---|---|---|---|---|
| 1 | 369.21 | 139.84 | 408.3 | 435.15 | 213.39 | 1586.78 |
| 2 | 1985.58 | 68.42 | 307.78 | 209.5 | 128.38 | 2699.66 |
| 3 | 332.11 | 106.14 | 123.74 | 71.2 | 30.86 | 667.9 |
| 4 | 522.99 | 303.25 | 443.48 | 250.78 | 95.32 | 1642.49 |
| 5 | 658.32 | 187.17 | 381.08 | 190.27 | 86.72 | 1520.97 |
| 6 | 651.72 | 49.95 | 287.94 | 389.68 | 133.19 | 1528.14 |
| 7 | 0 | 134.02 | 378.77 | 217.96 | 98.44 | 832.17 |
| 8 | 73.41 | 148.03 | 489.22 | 366.91 | 159.82 | 1258.72 |
| 9 | 841.07 | 147.44 | 231.5 | 195.1 | 68.32 | 1503.24 |
| 10 | 318.19 | 48.76 | 116.05 | 242.16 | 156.84 | 897.49 |

To these questions, during this research coal samples were dropped vertically onto a flat hard floor from fixed height of 4m. The results of the cumulative mass of the pieces versus the particle-size diameter were plotted in Fig. (**3**). Now, we discuss the similarities between the results from our results and those from the experiments that discussed above. For a falling height of 4 m the mass of fragments on their size were plotted. The data was fitted to a curve calculated by assuming that the size distribution could be described by a log-normal distribution. The fitting gave size values of 37.5 mm mesh sizes. The fitting is also excellent for the fragments larger than 40 mm mesh sizes which is a length scale around the coal pieces diameter. The size distribution of fragments smaller than 30 mm mesh sizes seemed to have a power-law form but the cumulative mass

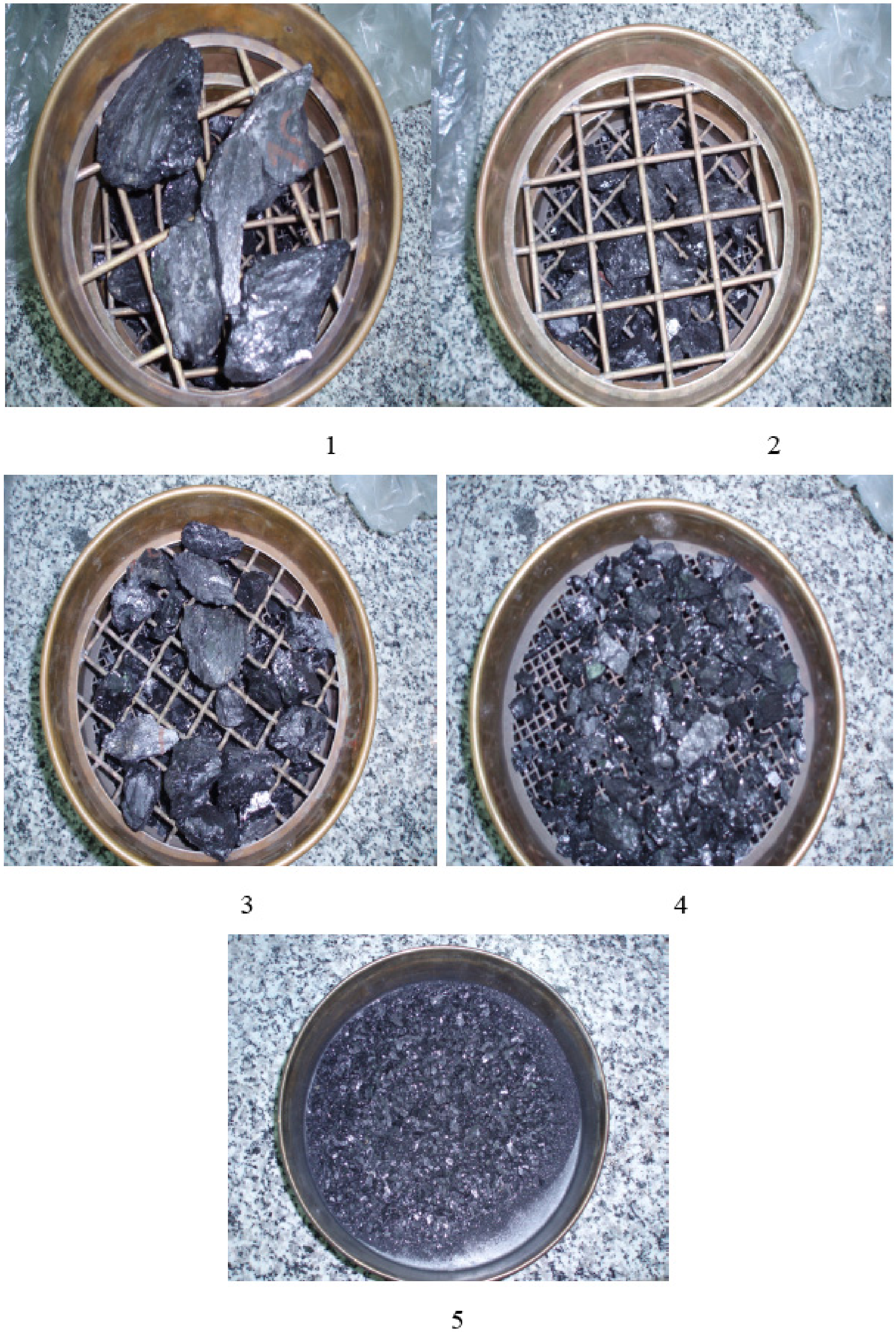

**Fig. (1).** Mesh size in the *first* step of falling from height of 4m (sample No.10).

variation for larger fragments started to show a power-law dependence on their size and mass. At this falling height, the distributions exhibited a log-normal form for larger fragments and a power-law form for smaller ones. The crossover was seen to be at length scales around the coal pieces diameter. This is due to the fact that fragments smaller than the coal pieces diameter; undergo a three-dimensional fracture, whereas the larger fragments are produced by one-dimensional breaking [9-11].

Our studies showed that natural fragment distributions that obey scaling laws and degradation model [12-21]. We observed that during the fall of coals from 4m height, frag-

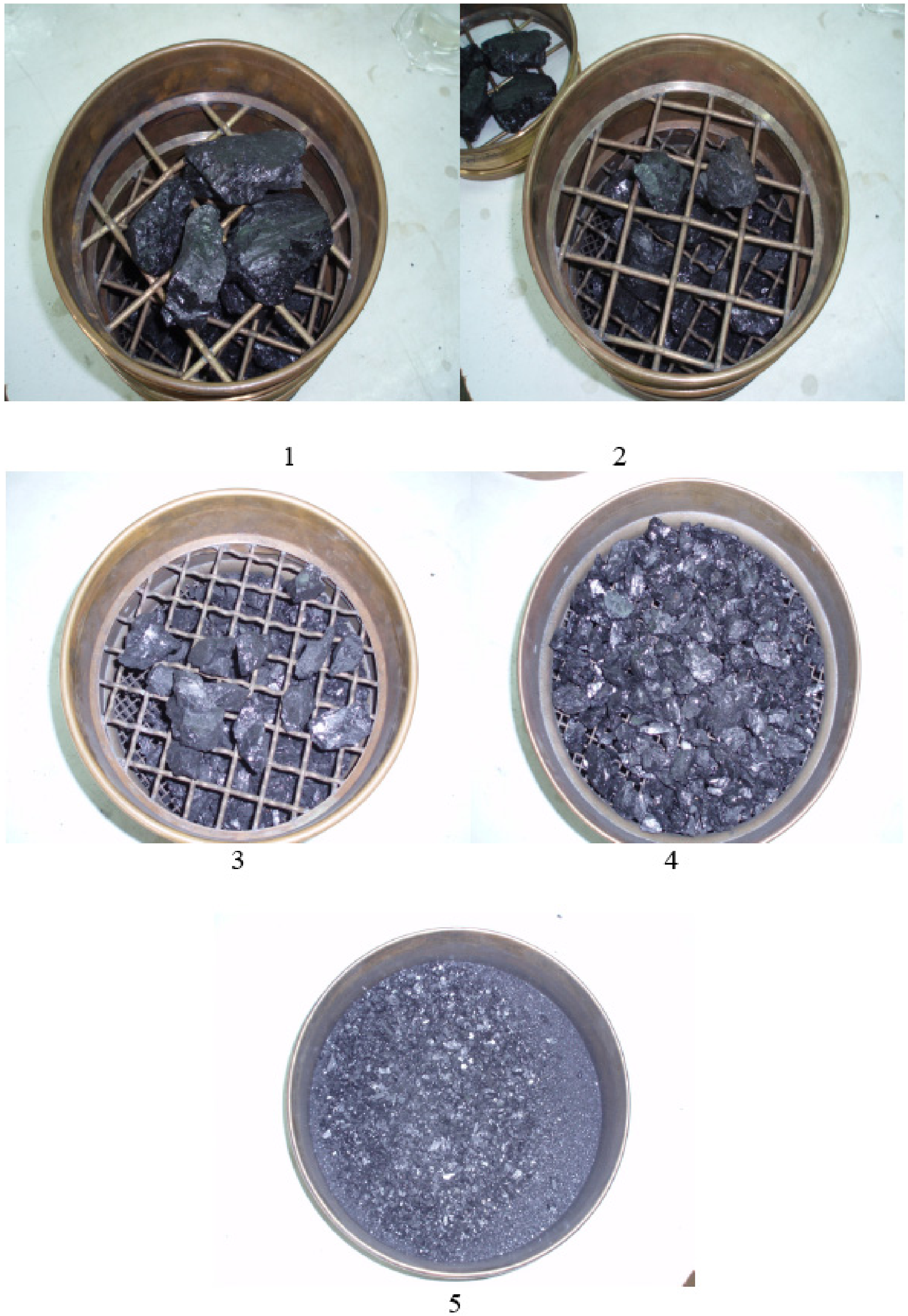


**Fig. (2).** Mesh size in the *third* step of falling from height of 4m (sample No.10).

mentation followed a range of 10 percent, per time for particles smaller than 5 mm diameter (Figs. **2-5**). It means that if the processes would repeat 10 times, 100 percent of coals would crush to the size of less than 5 mm. Coal is an inherently friable material, but it consists of a heterogeneous mixture of strong and weak bands that respond differently during fragmentation. Also, the scaling exponents depending on the overall morphology of the coal particle sizes. We suggest that during the short time of the fragmentation process the system becomes continuously driven and that the observed power law is a result of self-organized critical state. Also, our data show that the natural fragmentation obeys a degradation model. The model is an energy-based size reduction process that is a necessary intermediate step between blasted material and ROM (Run of Mine) for soft materials that experience significant breakage during the extraction, hauling and dumping process of the mining operation. Coal is such a material.

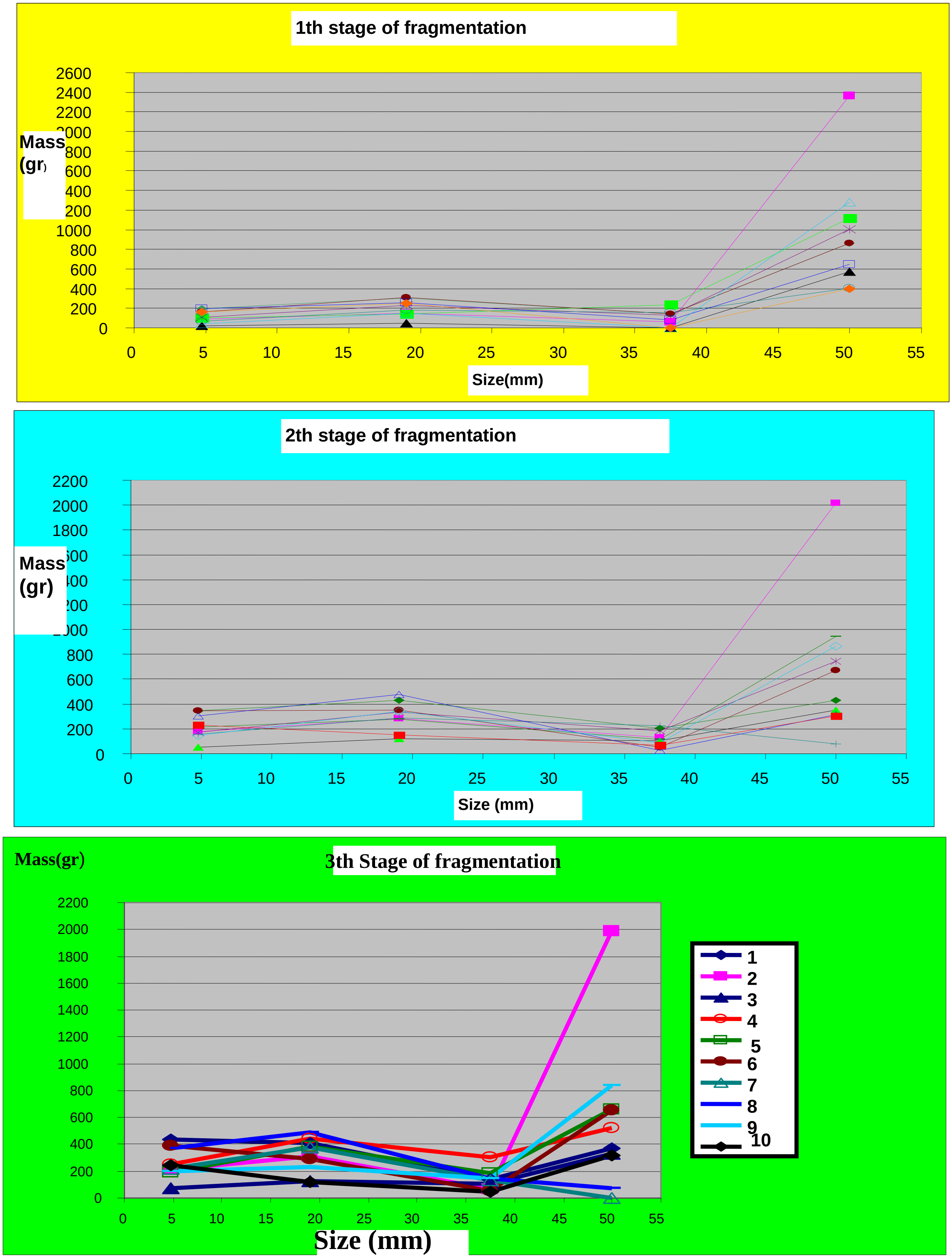


**Fig. (3).** The plot of mass of coal fragments versus size mesh in 3 stages of falling from height of 4m for 10 studied samples.

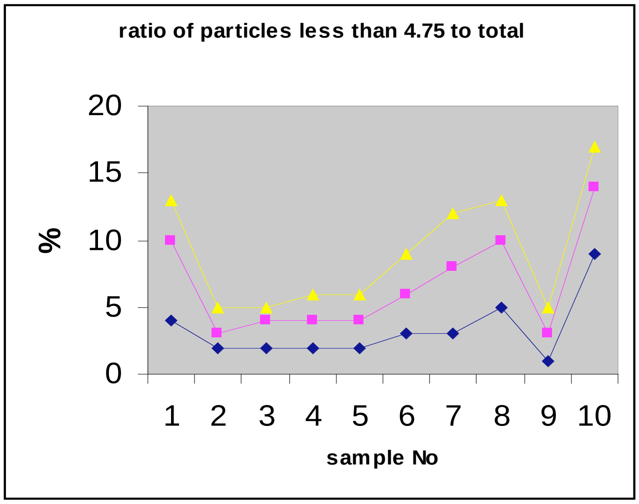


**Fig. (4).** The percent of coal fragmentation in 3 stages for particle less than 4.75 mm mesh size (First stage=∇, Second stage= , Third stage= ◊).

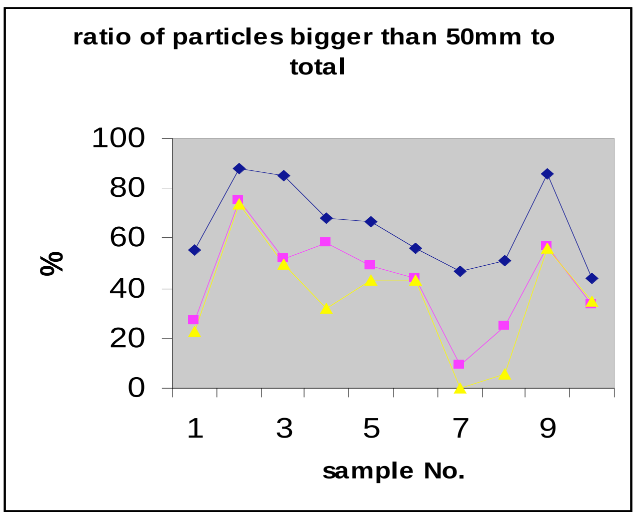


**Fig. (5).** The percent of coal fragmentation in 3 stages for particle bigger than 50 mm mesh size (First stage=∇, Second stage= , Third stage= ◊).

## CONCLUSIONS

Prediction of natural fragmentation from coal samples requires an accurate characterization of mass and size distributions. The objective of this study was to test the validity of a mass and size-based fragmentation model to describe natural fragmentations in coals. The results show there is evidences that cumulative natural fragmentations in coals follow a power-law distribution, consistent with a fractal fragmentation model. Fragmentation fractal dimensions of the coal pieces decreased in the order of large to small fractions. During the fall of coals from 4m height, fragmentation followed a range of 10 percent, per time for particles smaller than 5 mm diameter. It means that if the processes would repeat 10 times, 100 percent of coals would crush to the size of less than 5 mm. This implies that the natural fragmentation in coals has essential rules for breakage of coal particles during the extraction, hauling and dumping process of the mining operations.


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