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Characterization of Mining Surface Deformation and Fissure Development in Daliuta 52307 Working Face

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Abstract: With the increasing mining depth in western Chinese coal mining areas, traditional theories for shallow thin-bedrock mining are no longer fully applicable to new conditions with thick overburden. This study focuses on the Daliuta Coal Mine 52307 working face (burial depth: 190m, mining height: 6.7m), aiming to characterize surface deformation and fissure development under high-intensity mining with thick bedrock. Surface observation stations were established to monitor subsidence and fissure evolution during mining. Results show that surface cracks lag behind the working face, with three main types: tensile-opening, hysteretic extrusion, and stepped crack. Tensile cracks exhibit a "open-large-closed" cycle with an average duration of 4.8 days, while stepped and extrusion cracks are mostly permanent, experiencing "open-unchanged" behavior. A critical lag distance of 38m discriminates between crack types: lag distances >38m yield extrusion cracks, whereas <38m produce stepped cracks. Dynamic prediction using CISPM software reveals that subsidence and horizontal deformation values correlate with mining advancement speed, with errors within 20% after full mining. The study also identifies dynamic fissure angles (89°) and closure angles (93°), emphasizing tensile deformation as the primary cause of surface fissures. This research provides insights into the coupling mechanism between unbalanced overburden fracturing and surface fissure development in thick-bedrock areas, supporting green and safe mining practices.
Keywords: mining surface deformation; fissure development; lag distance; dynamic prediction

I. Introduction

Chinese western region is rich in coal resources, with 90% of the country's identified resources, 65% of which are concentrated in the three provinces (regions) of Jin, Shaanxi and Mongolia. The development of coal resources in the western mining areas has gone through decades, with the Shendong mine as a typical representative, its coal mining technology and equipment technology has changed dramatically within a few decades. from the late 80's to the beginning of this century, the main mining coal seams are buried with thin bedrock, shallow depth, overlying thick loose sand layer, etc., the depth of the coal seams is generally within 100m, and the thickness of the bedrock is generally in the range of 30-80m, or even thinner. Through the unremitting efforts of a large number of experts and scholars, a series of important research results have been obtained around the overlying rock breakage law and surface crack development law under this condition, which provides a guarantee for safe and efficient production of mines [1,2]. However, as the development of coal resources in the west increases, the conditions of coal seam existence have changed greatly, and some old mines are gradually depleted of shallow coal resources, thus entering the stage of lower group coal mining, and the thickness of the overlying bedrock is gradually increasing, and more and more mines are mining coal seams with the buried depth of thickness greater than 150m, such as Daliuta Coal Mine, where the average depth of the 5-2 coal mining has reached 170m, and the average depth of the Bultai Coal Mine, where the 4-2 coal mining has reached 450m, and the average depth of the Bultai Coal Mine, where the average depth of the overburden coal mining has reached 4.5m. Coal mining average depth of burial reached about 420m; and in the western part of some newly developed mines, the depth of burial is also much greater than 150m, such as the latest development of the Yuhang mining area of 10 million tons of mines Xiao Jihan Coal Mine, the first face of the coal seam depth of burial has reached 350m, the existing shallow thin bedrock mining overburden breaking theory cannot be fully applied to the new mining conditions [3].

Many scholars have also conducted relevant research on coal seams with greater burial depths. Li Yajun et al. took the post-mining surface subsidence characteristics of the 5-20105 working face in the Qinglongsi Coal Mine as the research object and comprehensively employed on-site observation, theoretical calculation, and regularity analysis to obtain the surface deformation and damage laws during and after the working face mining under the condition of surface wet collapsible loess [4]. Xu Zhuhe et al. took the typical working face in the Shendong mining area as the engineering background. To grasp the evolution law of the overburden structure under shallow-buried high-intensity mining and the surface damage laws and mechanisms under different mining conditions, they adopted numerical simulation, on-site measurement, and theoretical analysis methods. They found that the dynamic development of surface cracks in the middle of the working face has the characteristics of "double periods + stable period" [5]. Tang Fuquan et al. used a low-altitude unmanned aerial vehicle photogrammetry system to obtain digital orthophoto images of the coal mining subsidence area and combined with specific algorithms to precisely extract features, revealing the types and development laws of cracks in the study area [6]. Gao Ping et al. studied the rock strata movement characteristics of the working face with thick coal seams through numerical simulation methods [7]. Zhang Huan et al. investigated surface cracks in the Shendong mining area and analyzed the overburden displacement, stress distribution, crack evolution, damage characteristics, and surface subsidence at different advancing distances with numerical simulation, establishing theoretical models of overburden fragmentation and surface subsidence [8]. Tao Tao et al. used deep learning methods to identify surface cracks in unmanned aerial vehicle images and simultaneously explored the crack development laws and the mutual influence between surface conditions and underground mining [9].

The main mining seams in the western mining area often have one or several layers of thick hard rock layers, which play a controlling role on the overall overburden movement, but due to the existence of these thick rock layers, the overburden is more prone to non-equilibrium fracture phenomenon. For example, in Daliuta coal mine, 52307 has a burial depth of 170m, a mining height of 6.8m, and a working face width of 301m, and the observation of mine pressure shows that the overburden rock movement develops upward with a certain hysteresis, and the mechanism of the overburden rock movement transferring in space and time is still not clear [10]. As 52307 working face is covered by a main key layer, 3.7m from 5-2 coal roof, according to the theory of key layer, after the breakage of the main key layer, there will be a big step down of the overlying rock layer, and there will be a serious dynamic pressure phenomenon in the working face, but according to the on-site observation, the stent does not appear to be a strong mining pressure phenomenon such as the pressure frame or the serious downward shrinkage of the live columns. It shows that after the main key layer breaks, the over-lying load layer will not transfer the load to the stent immediately, and its breakage has a certain lag [11].

On the other hand, we can also see that, due to the simple geological conditions of mining in the western mining area, the high-intensity mining method of large mining height and rapid advancement is usually adopted, which is easy to lead to the strong movement of the ground surface, triggering the surface to produce large cracks and deformations, which in turn triggers the occurrence of secondary disasters [12,13] such as the destruction of roads, the cracking of houses, and the rupture of underground pipelines. The surface cracks generated by mining are closely related to the breakage of mining overburden, and the non-equilibrium breakage caused by high-intensity mining will have a crucial impact on the development of surface cracks [14,15]. At the same time, it should be seen that the surface cracks are affected by the nature of topsoil layer. In order to accurately grasp the spatial and temporal evolution of surface cracks, it is urgently needed to comprehensively study the mining parameters, overburden structure, nature of topsoil layer, etc., and to construct a prediction model for the development of surface cracks [16].

Therefore, it is urgent to carry out the research on the development characteristics of the coupling between unbalanced roof breakage and surface cracks under high in-tensity, which is of great significance to the green, safe, and efficient mining of thick bedrock area in western mines.

II. Daliuta Coal Mine 52307 Working Face

Daliuta well 52307 working face is near horizontal coal seam, coal thickness 7.1~7.4m, average 7.2m, average depth of coal seam H0 is about 190m, length of working face is 301m, advancing length is 4,462m, adopting one-time full-height coal mining technology, design mining height is 6.7m, width of working face is 6m, size of coal pillar is 20m. 52306 working face is on the south side (has been mined), and 52501 working face is on the north side (not mined). The south side is 52306 working face (already mined back), and the north side is 52501 working face (not mined back), and there is no other coal seam mining activity overlying the 5-2 coal seam [17].

In order to fully study the subsidence pattern of the ground surface as well as the rock movement pattern above the surface of the drill holes, two observation stations were established, namely, the open cut eye station 1 and the deep base point station 2.

The group set up an observation station on the surface above the open cut eye of the 52307 working face in Daliuta well, and set up the observation line A in the advancing direction with 23 working measurement points, respectively from A10~A14 in the outer gully of the boundary of the well field with the length of the observation line of 268m, and from A15~A32 on the surface above the working face with the length of the observation line of 358m, and the control points of the three are A7, A8 The observation line B is arranged perpendicular to the advancing direction of the working face, with a total of 18 working points, respectively from B2 to B13 and B15 to B20, the length of the observation line is 358m, and the control points are G2, G3 and G4, with a total of 47 points, and the spacing between the points is 20m [18].

In order to accurately grasp the surface subsidence near the deep base point, an observation station is set up on the surface near the deep base point of SJ1, and the observation line C is set up in the advancing direction, numbered C1~C41. 10 measurement points are arranged 100m on each side of the deep base point, and the spacing between the measurement points is 10m, respectively, C11~C30, and the spacing of the remaining measurement points is 20m. According to the actual arrangement, the length of the measurement line is 648.6m. length is 648.6m [19].

The main parameters of the observatory are shown in Table 1.

Table 1 Main parameters of the 52307 working face observatory design

Line name	survey point number	Actual length of survey line (m)	Distance between measurement points (m)	Number of working points	Number of control points
A	A10~A32	626	20	23	3
B	B2~B13 B15~B20	358	20	18	3
C	C1~C41	649	10, 20	41	3
sum		1633	-	82	9

The group established a surface observation station and completed connection measurements at the 52307 working face of Daliuta well on September 18, 2015, and carried out the first full-scale observation on February 14, 2016 before the workface was mined back to obtain the initial planimetric and elevation coordinates of the observation points. From February 14, 2016 to January 5, 2017 a total of 29 level measurements and 22 level measurements were taken on line A of the foliation cut eye observation line, and 5 level measurements and 8 level measurements were taken on line B [20].

III. Characterization of Surface Deformation and Fissure Development in Mining Operations

Daliuta Coal Mine 52307 working face was established on September 18, 2015, and as of March 30, 2016, the surface cracks were observed and recorded at the same time as the measurement of the A line of the observation line of the open cut eye. The distribution of cracks in the middle of the working face is basically parallel to the working face, and some of them are curved towards the direction of the air-mining zone, and the overall crack pattern shows a “C” shape.

At the beginning of mining back to the working face, the dynamic surface cracks are mainly distributed in the middle of the working face. As the working face advances forward, when the working face advances to about 450m, fewer permanent cracks are found above the cutting eye of the working face, in the two sides of the trench and its vicinity.

During the normal mining of Daliuta 52307 working face, the surface cracks were observed continuously. After site investigation, the surface collapsed severely during the mining process, and various different forms of ground cracks appeared at the site, such as: tensile tension cracks are shown in Figure1 (a), lagging extrusion cracks are shown in Figure1 (b), and steppedfissures are shown in Figure1 (c).

(a) Tension-opening crac (b) Hysteretic extrusion type crack (c) step crack

Fig.1: 52307 Working face surface crack classification

From the field observation, it can be seen that the surface cracks in the working face have the following characteristics:

1) Characteristics of tensile crack development

Through the analysis of the surface tensile cracks and the advancing degree of the underground working face, it is known that all the surface cracks in the Daliuta 52307 working face lag behind the working face, and the position of the surface cracks appearing is always lagging behind the mining position of the working face by a distance relative to the working face, which is called the lagging distance of the cracks.

From March 11, when the working face was pushed to 112.3m and cracks were observed, the number of newly appeared hysteretic tensile cracks and the spacing of the cracks were statistically analyzed every day, as shown in Table 2 below.

Table 2 Tensile Crack Statistics

Date of observation/month.Day	Working face advance distance/m	Number of newly discovered cracks/article	Average spacing of cracks/m	Working face advance speed/m/d
3.11	112.3	6	3.7	8.9
3.14	129.7	5	4.8	4.6
3.18	152.3	3	3.3	7.5
3.21	172.2	9	4.4	8.1
3.23	188.8	3	6.6	10
3.29	225.9	4	4.0	7.0
3.30	232.0	3	4.0	6.1

After regression analysis, the relationship between the average spacing of tensile cracks found per day of 52307 face mining and the mining speed was obtained, and the regression relationship is plotted in Figure 2.

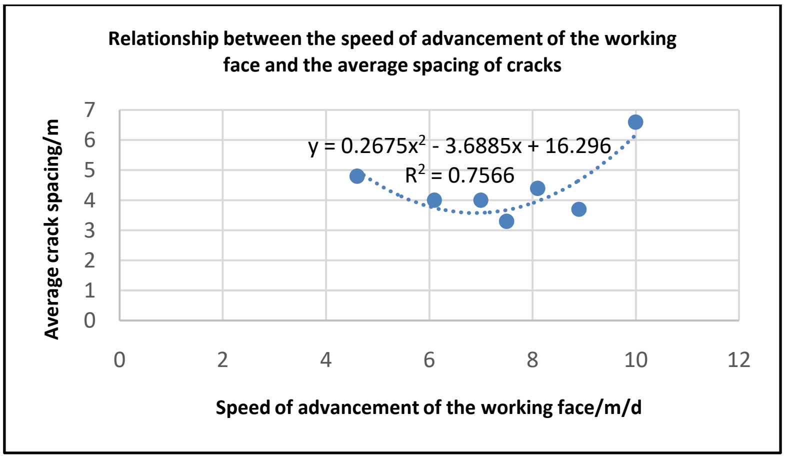

Fig. 2: Relationship between the speed of advancement of the working face and the average spacing of cracks

2) Characteristics of step-like fracture development

Stepped cracks are formed due to the breakage of overburden rock caused by mining until the surface collapse, generally lagging behind the working face, and their mechanism is divided into basic top breakage principle based on thin plate theory and key layer theory.

After analyzing the stepped cracks in the 52307 working face of Daliuta, it is concluded that the occurrence of stepped cracks is greatly related to the lag distance of the cracks, the subsidence value and the horizontal deformation value of the surface point of the cracks.The statistical table of the information of the stepped cracks in the 52307 working face is shown in the following Table 3.

Table 3 Step Crack Information Statistics

Date of observation	Degree of workface advancement/m	Crack number	Position of the crack from the cutting eye/m	Crack lag distance/m	Sinking/ mm	Horizontal movement /mm	Deformati on/mm/m	Crack step height/cm
3.14	129.7	38	116.4	-13.3	200	-350	34	18
		39	117.8	-11.9	196	-220	32	21
3.23	188.8	57	150.8	-38	260	-285	11.7	16
3.24	195.5	60	172.2	-23.3	293	-280	9.7	18
		61	179.9	-15.6	195	-170	12	18

When analyzing the stepped cracks in the 52307 working face of Daliuta, it was found that these cracks were in the tensile deformation zone rather than the generally considered compression zone, and their deformation values and subsidence values were relatively large. The regression analysis of crack lag distance, subsidence value and deformation value can be obtained by regression analysis of subsidence value, horizontal deformation value and crack lag distance, and the regression relationship graphs are shown in Figure 3 and Figure 4.

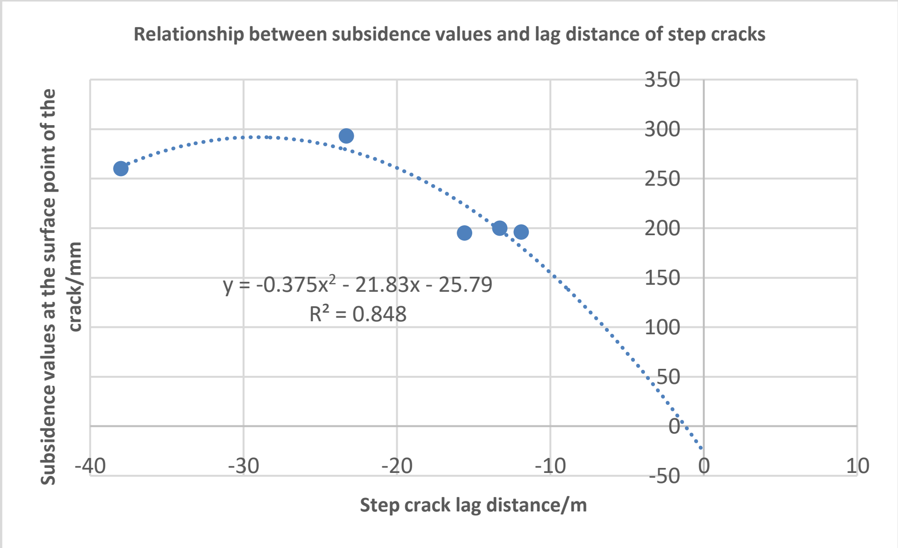

Fig. 3: Relationship between subsidence values and lag distance of step cracks

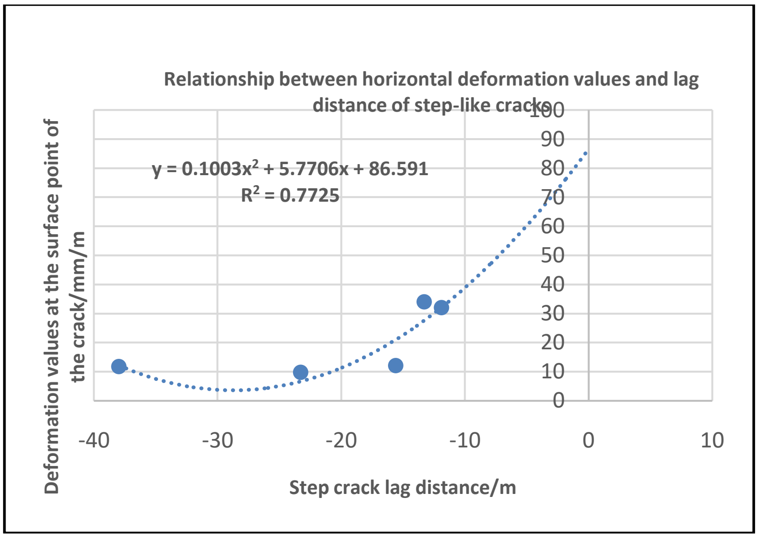

Fig. 4: Relationship between horizontal deformation values and lag distance of stepped cracks

Extruded cracks and step cracks are lagging behind the working surface, and the crack lag distance is a key factor in discriminating between extruded and step cracks. Table 4 gives the lag distance and deformation values of extruded cracks and step cracks.

Table 4: Extruded Cracks and Step Cracks Statistical Tables

Crack number	Type of crack	Lag distance/m	Deformation value/mm/m	Tension/compression zone
8	extruded	58.1	-26	compression zone
9	extruded	55.7	-25	compression zone
38	stepped	13.3	34	tensile zone
57	stepped	38	11.7	tensile zone
60	stepped	23.3	9.7	tensile zone

As shown in Table 4, the crack lag distance is the key basis for determining extrusion cracks and step cracks. The smaller the hysteresis distance, the more likely to occur step cracks; on the contrary, extrusion cracks will occur. The area where step cracks first occur is in the tensile deformation zone, and then changes to the compression deformation zone.

3) Crack development time

The traditional view is that the dynamic cracks first open and then gradually close with the advancement of the working face, and the width of the cracks generally shows a single-peak cycle from small to large and finally closes. After counting all the cracks in the 52307 working face, the development time of tension-type, extrusion-type and step-type cracks were analyzed respectively.

(1) Characteristics of development time of tensile type cracks

Daliuta tensile cracks are located at the back of the working face, generally experiencing the process of “open-large-closed”, with smaller deformation value and shorter duration, averaging 4.8 days, and the distance pushed by the working face is 40m at the maximum, 17.4m at the minimum, and 24.8m at the average.

(2) Characteristics of development time of permanent type open cracks

In the process of advancing forward of the working face, some open cracks are no longer closed after opening, only experiencing the process of “open-large-unchanged”, these cracks are generally located in the vicinity of the eye of the working face opening and cutting, with a duration of 7.6 days on average, and the distance pushed through by the working face is 48.9m on the maximum, 33.3m on the minimum, and 41.5m on the average. The average is 41.5m.

(3) Development time characteristics of stepped cracks

Stepped cracks are destructive cracks, once produced, the change amplitude is very small, almost no longer change, only experienced the process of “open - unchanged”, these cracks are generally located in the back of the working face, the duration of an average of 5.2 days, the distance pushed by the working face is 27.8m, the minimum distance is 19.7m, the average of the working face is 24.3m.

(4) Characteristics of development time of extrusion type cracks

Extruded cracks are destructive cracks like step cracks, but the degree of destruction is much smaller than that of step cracks, and once generated, the magnitude of change is very small and almost no longer changes, only experiencing the process of “open - unchanged”, these cracks are generally located at the back of the working face, with the duration of an average of 5.3 days, and the distance pushed by the working face is maximum 33.3m, minimum 19.7m, and average is 24.3m. The maximum is 33.3m, the minimum is 21.8m, and the average is 29.5m.

4) Dynamic prediction of step-like cracks in the open cut eye

CISPM software is different from other surface subsidence prediction software programs in that it can predict the dynamic process of surface subsidence. The CISPM dynamic prediction module was used to analyze and verify the development of the open-cut eye cracks in the Daliuta 52307 workface. When using the CISPM dynamic anticipation module, the advancement distance of the working face as well as the advancement rate per day are the key factors.

Based on the advancing degree and advancing speed of the working face shown in the time characteristics of permanent type open-cut crack development, the dynamic subsidence and deformation curves of the working face pushed to 129.7m, 188.8m, and 195.5m are obtained.

The average depth of Daliuta 52307 working face is 190m, and it is generally believed that when the length of the working face is greater than or equal to 1.2-1.4 times the mining depth, the working face reaches full mining. On March 24, the working face advance distance is 195.5m, at this time the working face has not reached the full mining, so it is expected to get the subsidence and deformation value is much smaller than the measured value; when the lag distance of the stepped crack increases, the subsidence value and the deformation value increases, the closer to the measured value, which is in line with the general deformation law of the surface movement.

5) Dynamic prediction of the open-cutting eye tensile cracks

To analyze and count the Daliuta tensile cracks, the daily observed tensile cracks from March 11 to March 30 were dynamically predicted, and the deformation values obtained were compared with the actual values, and the actual and predicted values of the observed cracks were positive, indicating that these cracks were in the tensile deformation zone; before March 24, when the working face had not reached full mining, the dynamically predicted horizontal deformation values were much smaller than the actual values. Before March 24, when the working face has not reached the full mining, the dynamically predicted horizontal deformation value is much smaller than the calculated actual value. On March 29 (the working face was pushed to 225.9m) and March 30 (the working face was pushed to 232.0m), when the pushing distance is more than 1.2 times of the mining depth, the working face has reached the full mining, and the predicted value is close to the actual value, and the error is not more than 20%.

At the initial mining stage of Daliuta 52307 working face, due to the existence of 30m thick hard intact rock layer above the working face, the initial incoming pressure from the basic top fracture when advancing about 90m produced a 50cm step down near the advancing direction of 70m, and the surface A19 sunk 746.7mm. numerical simulation shows that: After the initial pressure, the surface step sinking lags behind the working face, and the coal wall of the working face is not directly cut down. The distribution of the step sinking is regular, and the spacing is about 10m.The statistics of the horizontal deformation of the crack on the side of the open cut eye versus the width of the crack are shown in Figure 5.

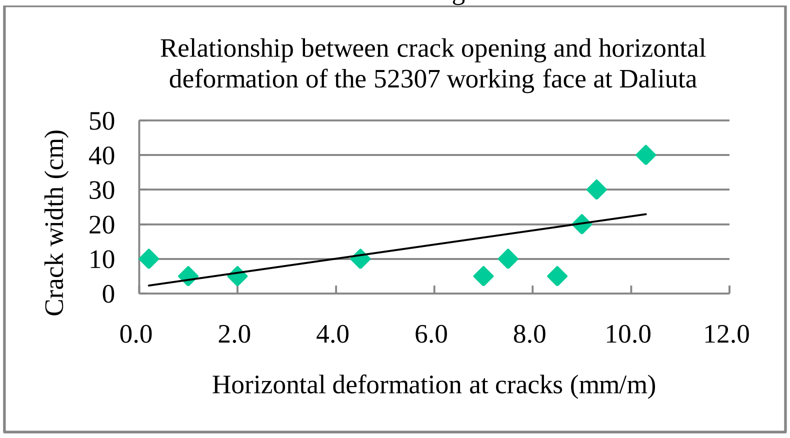

Fig. 5: Relationship between the working resistance of the support and surface deformation and cracking

The crack development and distribution pattern of 52307 working face has been measured on site, and the crack development is most intense in the 1-2 area, which corresponds to the tensile deformation area. Take LF27 for example, on March 10th, the width is 10mm, 4m ahead of the working face, the dynamic crack angle is 89°; on March 12th, the maximum width is 280mm, the crack reduction angle is 93°; on March 15th, the crack is basically closed, dynamic.

The maximum crack width, about 300mm; the maximum step down was near A19, with a drop of about 500mm; the maximum crack appeared at the junction of tensile and compressive deformation, proving that tensile deformation is the main cause of surface cracks.

If the downhole incoming pressure point is between 1.3 and 11.1m from the working face, the cracks above the surface will produce cracks between 4.9 and 23.5m from the lagging incoming pressure point; if the downhole incoming pressure point is less than 1.3m or more than 11.1m from the working face, the furthest cracks produced on the surface will exceed the downhole incoming pressure point.

IV. Conclusions

All the cracks in the working face of 52307 in Daliuta coal mine were studied, and the development time of tensile, extrusion and stepped cracks was analyzed, and both extrusion and stepped cracks lagged behind the working face. When the lag distance is more than 38m, it is extrusion type cracks; when the lag distance is less than 38m, it will produce stepped cracks. The dynamic crack angle generated by the cracks in the Daliuta coal mine is 89°, and the crack reduction angle is 93°.

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