In situ studies on service life and pick consumption characteristics of shearer drums

by B. Tiryaki*

Synopsis

Longwall shearers usually suffer from excessive pick and pickholder consumptions and severe wear of the backplate of the clearance ring section of shearer drums. In practice, most of the drums were seen to be withdrawn from the face due to the abovementioned problems, while vane picks and their holders were intact due to the improper lacing design of the clearance ring picks. However, few underground investigations and their results on the effect of lacing arrangement of clearance picks on the service life of shearer drums have been published. Nevertheless, the pick consumption characteristics of shearer drums were not investigated in detail, since these are fewer pick consumptions with shearers when compared to roadheaders.

This paper is concerned with the comprehensive *in situ* trials on the effect of lacing of clearance ring picks on the lifespan of shearer drums, and the pick consumption characteristics of longwall shearers at Cayirhan Coal Mine in Turkey. The lifespan of shearer drums employed with shearers in this mine increased 70 per cent, while the consumption rate of clearance ring picks decreased three fold through using an alternative lacing for clearance picks, indicating the significance of utilizing proper design techniques for clearance ring picks for the service life of shearer drums. Statistical analyses carried out, using the raw pick consumption data, implied that the clearance ring picks experienced much higher loads than vane picks, revealing that special attention must be paid to designing clearance ring picks. An average maximum consumption value of 41 was determined for clearance ring picks, with corner-cutting picks having the most replacements, while it was 35 for vane picks, on three-day based pick replacements.

Introduction

Coal excavation by longwall shearers has been extensively employed for mining projects throughout the world. All these machines, of different types and models, cut the coal by using picks (or drag tools) with cemented tungsten carbide tips inserted into a hardened steel body. Drums mounted with picks inside their holders attack the rock or coal as they rotate and advance into the coalface (Figure 1).

The performance of these machines may be limited by excessive pick consumption along with machine vibrations, especially in cutting hard and abrasive strata. Therefore, pick selection is of crucial importance, especially where the rock conditions are difficult to overcome by longwall shearers. Despite the fact that the longwall shearers find easier grounds in practice than those encountered by roadheaders, requirements arising from other longwall components compell these machines to cut the hard and abrasive floor and roof strata. In cases where these strata are excavated by the longwall shearer, the pick consumption increases to a higher level where it affects the economics of the overall longwall operation. A relatively low pick cost of about 5p per ton of coal was reported to increase to over £1, sometimes £1.5, per ton of coal when difficult cutting conditions were encountered for longwall shearers mounted with radial picks at British Coal[1] collieries.

Downtimes in longwall mining are estimated to cost up to one thousand dollars per minute. Shearer downtimes due to the replacement of picks and damaged drums are a significant part of maintenance activity, which must be dealt with in longwall shearers. Maintenance is a significant activity directly affecting the availability, utilization, and productivity of longwall machinery and equipment. Maintenance costs due to downtimes account for share in the overall operating cost of the longwall system. For an underground mine operation, maintenance-related costs were found to make up 30 or 40 per cent of overall operating costs. It was also determined that 1 per cent improvement in productivity or availability of mining machinery, through optimizing the maintenance activity, causes an improvement of about 3 per cent in profit[2]. Employing drum designs that enable both the drum and its

* *The University of Queensland, Department of Mechanical Engineering, Australia, and CRC Mining, Australia.*

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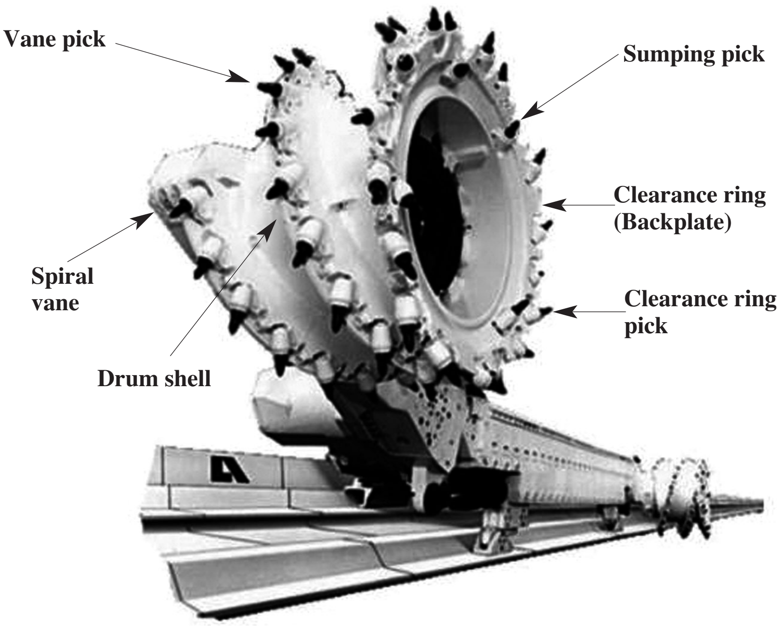

Figure 1—A typical double-ended ranging longwall shearer

picks to have long service lives can improve the availability of shearers, thus lowering the maintenance costs of shearers to a degree.

In situ investigations and observations revealed that most of the shearer drums were seen to be drawn from longwall faces due to the excessive damage, especially of picks and pickholders, in the clearance ring section rather than in the vane section. The effective lifespan of shearer drums seems to depend on the degree of damage to the backplate itself and to the pickholders mounted on it. This problem, in most cases, was overcome by employing wear-resistant materials at the face side of the drum, instead of employing an appropriate lacing pattern for the clearance ring picks.

Clearance ring picks, usually used on the roadheader cutting heads due to the sumping requirements of the rock face, are positioned on the clearance ring section (backplate) of shearer drums. They are employed in order to prevent shearer drums from inefficient and dangerous surface friction contact with the coal-seam, which imposes excessive axial loads on the longwall shearer, causing catastrophic failures of the mechanical and structural components of the longwall shearer. These loads also tend to push the longwall shearer away from the coal-seam, preventing the coal-cutting operation and wasting the energy installed on the machine. There are no extensive studies found in the literature investigating the effects of the lacing arrangement of clearance ring picks on pick consumption and drum life of the shearer drums *in situ*.

There have also been very limited *in situ* investigations attempting to describe the pick consumption characteristics of longwall shearers. In previous research, the total numbers of picks and holders consumed, and the pick holders repaired underground for a double-ended ranging longwall shearer were collected to find a graphical method for modelling the rate of pick and holder consumption[3]. Weibull distribution was found to give the best fit for the pick consumption data obtained during an actual coal production operation of the longwall shearer.

This paper is concerned with the extensive long-term underground trials carried out during the actual coal production operations at Cayirhan Coal Mine in Turkey, and attempts to investigate the significance of the lacing arrangement for clearance ring picks on the service life of shearer drums and to clarify the pick consumption characteristics of longwall shearers. *In situ* studies revealed that the clearance ring picks are prone to damage due to their positions on shearer drums, and that the serious damage on the clearance rings and frequent drum changes can be prevented by employing proper lacing patterns for clearance ring picks. The results of underground trials are presented, together with statistical analyses on pick consumption and drum life, in this paper.

Picks employed for coal cutting

There have been two popular types of picks employed in practice, namely radial and point attack (Figure 2). Radial picks are designed to have the shank axis normal to the cutting direction. Point attack picks have a shank axis in line with the pick body. Point attack picks differ from the radial picks in having a shank axis angled backward from the cutting direction. Radial picks have tips similar to a wedge and they are found to be suitable for cutting soft and medium-soft rocks. Their shanks are rectangular in shape, which prevents these picks from rotating in their holders.

Point attack picks have conical tips, shanks of circular cross-section, and are free to rotate in their holders. These picks resemble the common pencil shape and are sometimes called pencil point tools. The pick tip of these tools exhibits a uniform wear profile, resulting from the rotation of the pick shank in the holder, which is different from that for the radial picks. 'Self-sharpening' is the term sometimes misused to describe this wear profile, but the result is an improved

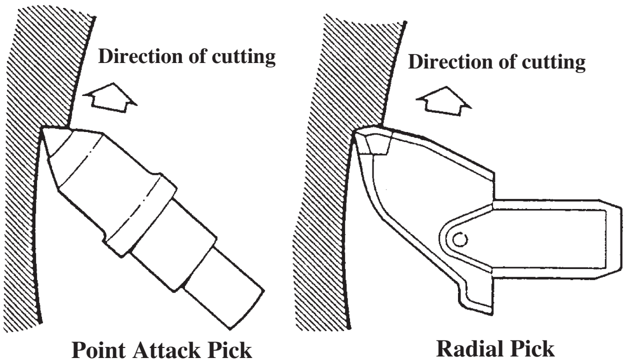

Figure 2—Picks employed for rock and coal cutting[4]

pick life. Therefore, these types of picks have been widely employed for cutting rocks ranging from soft to hard rocks on roadheaders and longwall shearers. Laboratory investigations have shown that point attack picks require the highest forces to cut the rock amongst all the other commercial rock-cutting picks, in identical operational conditions when sharp. However, the effect of degree of wear on the cutting forces is lower for the point attack pick and, after a certain degree of wear, point attack picks were reported to require the lowest forces to cut the rock[5].

Positioning picks on shearer drums

Shearer drums consist of several spiral vanes and a backplate welded on a hollow drum shell. The spiral vanes serve for cutting and loading, while the backplate is mainly used for corner cutting at the face side to relieve the cutting action of the vane picks. The linear advance of a shearer drum per entire revolution is produced by the combined cutting actions of the vanes. Spiral vanes and the backplate provide space for the picks to be mounted on drums (see Figure 1). Spiral vanes or cutting sequences on shearer drums are also known as 'starts', and the number of starts equal that of the spiral vanes. The total number of starts on a shearer drum varies depending on the shearer drum design[1,6].

Picks can be classified according to their tilt angles and positions on the cutting head. The tilt angle is the angle between the pick axis and a plane perpendicular to the axis of cutting head rotation (Figure 3a). Picks, with their axes perpendicular to the axis of cutting head rotation, are named traversing or arcing picks, while those mounted on the region closer to the nose section of the cutting head, with individual tilt angles, are termed gauge picks. Sumping picks are placed on the nose section of the cutting head with their axes parallel to the axis of rotation of the cutting head. The last gauge pick on the face side of the cutting head is known as the corner cutting pick.

A modern shearer drum also has three groups of picks cutting the coal seam while it rotates and transfers coal particles from the face onto the armoured face conveyor. The first group of picks that cuts most of the coal-seam, which are mounted on spiral vanes and correspond to the traversing picks on the roadheader cutting heads, are named vane picks. The second group of picks mounted on the backplate section of the shearer drum, and corresponding to the gauge picks on the roadheader cutting heads, are termed clearance

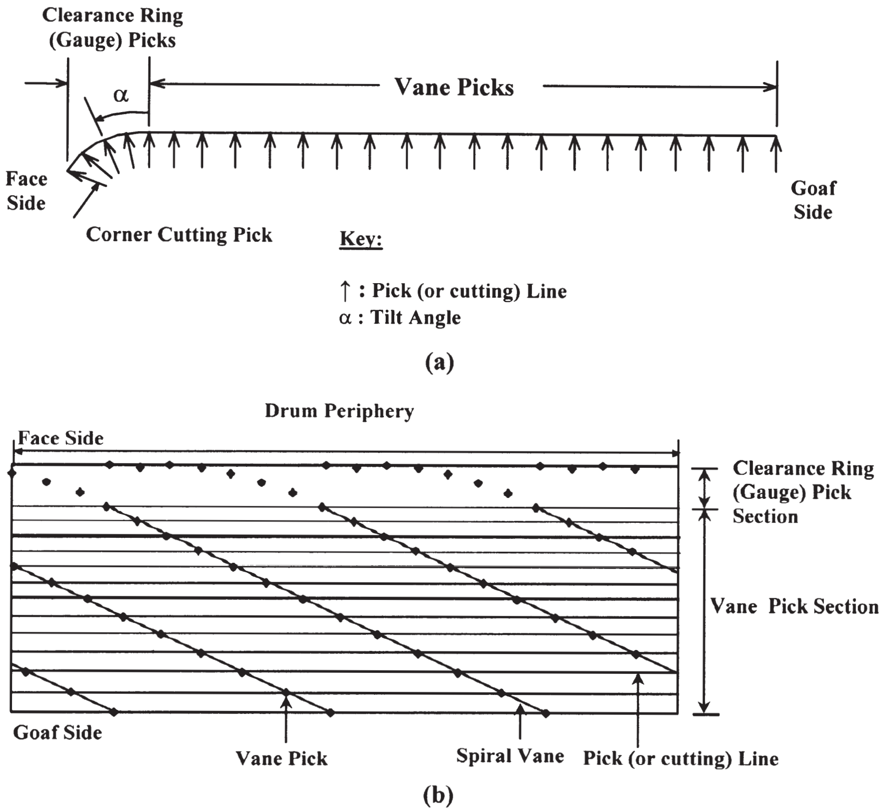

Figure 3—Pick positioning on a shearer drum: (a) profile view of the drum (b) lacing of spiral and clearance ring picks[7]

ring picks. Today's shearer drums also have some sumping picks mounted on the outer face of the clearance ring to provide extra protection for the drum (see Figures 1 and 3).

Clearance ring picks cut 9 per cent of the total amount of coal produced by the continuous miners while they are responsible for cutting up to 17 per cent of the total coal produced by the longwall shearers, depending on the shearer drum design[8,9]. The arrangement of clearance ring picks on the shearer drum was reported to be more complicated than that of vane picks[1]. These picks are arranged in a pattern of several cutting lines along the periphery of the backplate, depending on the thickness of the backplate and the pick lacing employed. Brooker[10] has proposed placing the clearance ring picks in a multi-tracking arrangement where more than one pick is employed on the same cutting line, as corner cutting line includes more picks than other lines. The lacing arrangement for clearance ring picks of 'ECADBA' is the most widely known design employing the multi-tracking concept (Figure 4).

Forces acting on gauge picks

Gauge picks were reported to have higher forces than picks without tilt angles in similar cutting conditions through *in situ* and laboratory studies[10–14]. The forces required to cut the coal at a certain depth by a clearance ring pick were reported to be two to ten times higher than the forces needed to cut the coal at the same depth by a vane pick[10,14]. This situation is known to be also valid for some other rocks[11].

Hekimoglu[15] studied the effect of tilt angle on the performance of corner cutting and other gauge picks. Laboratory studies revealed that, as tilt angle increases, mean cutting and normal forces of both corner cutting and gauge picks decrease. Corner cutting picks were seen to have the same forces as other gauge picks after tilt angles higher than 60°. When corner cutting picks are designed with tilt angles lower than 70°, forces acting on these picks are higher than for the other gauge picks (Figure 5). However, laboratory rock cutting studies of Hekimoglu[15] could not clarify the higher forces experienced by other gauge picks in practice when compared to vane picks (picks without tilt angles), possibly because the pick confinement or the actual corner cutting conditions were impossible to fully simulate with the test rig he has utilized.

Problems encountered with clearance ring picks in practice

The most widely encountered problems related to the clearance ring picks employed on the shearer drums of continuous miners and longwall shearers are as follows:

- Rapid pick and pick-holder failures leading to excessive wear on the backplate
- Excessive vibrations of the machine
- Increases in amounts of airborne respirable dust and fines.

These problems were reported to arise mainly from employing excessive numbers of clearance ring picks on the backplate of the shearer drums positioned in improper pick lacing arrangements[9,13,16–18]. The percentage of fines in excavated coal product was reported to decrease by reducing the total number of clearance ring picks on shearer drums. Pick lacing was reported to be the key factor in reducing the total number of clearance ring picks[1,9,17,18].

The ECADBA arrangement is intended to ensure the clearance ring picks are subjected to lower cutting forces during coal cutting, despite the fact that the inefficiency of multi-tracking arrangements has been revealed in laboratory and *in situ* studies[7,15, 19, 20–23]. These studies showed that the multi-tracking arrangement, when employed in the pick lacings of cutting heads and shearer drums, resulted in adverse effects on specific cutting energy and vibrations. Therefore, single tracking, i.e. employing one pick on each cutting line, was recommended. However, some shearer drum manufacturers have been persistently using various lacings for clearance ring picks employing the multi-tracking concept.

There have been discussions for many years on employing the multi-tracking concept that results in inefficient groove deepening cutting in most cases, in designing cutting heads and shearer drums. This may be because of the use of the term 'pick penetration' (or 'depth of penetration') for defining the maximum depth of the cut taken by the picks during cutting, which is derived by considering only the number of picks per cutting line rather than combining this parameter with the number of starts in calculations. Pick penetration was erroneously assumed to equal the depth of cut by some manufacturers. Since the forces acting on a pick during cutting are known to be directly proportional to the depth of cut, they have considered that a multi-tracking arrangement results in lower forces exerted on picks. This approach was proven ineffective by sophisticated studies specially performed at MRDE of British Coal in the 1980s[6,19–21].

Higher mean cutting and normal forces were reported for deepening an existing groove than those required to cut the same groove, even at the same depth of cut[10,19,24–27]. In

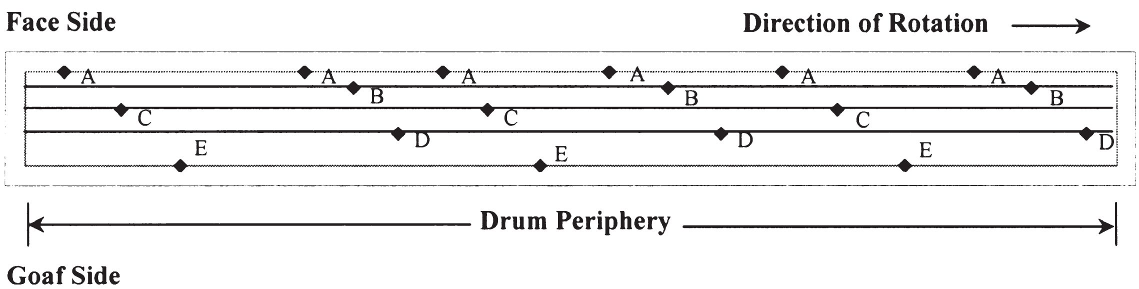

Figure 4—Clearance ring pick ECADBA[10] design

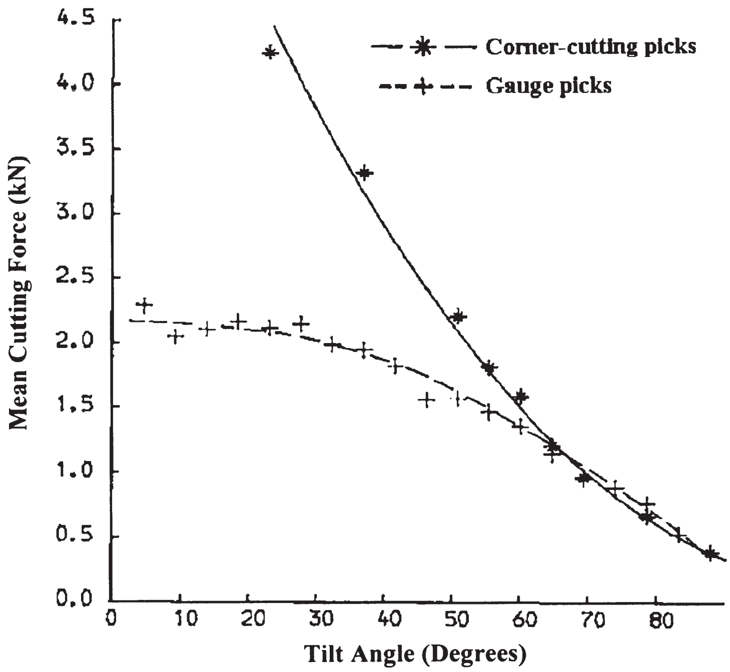

Figure 5—Variation of mean cutting force with tilt angle[15]

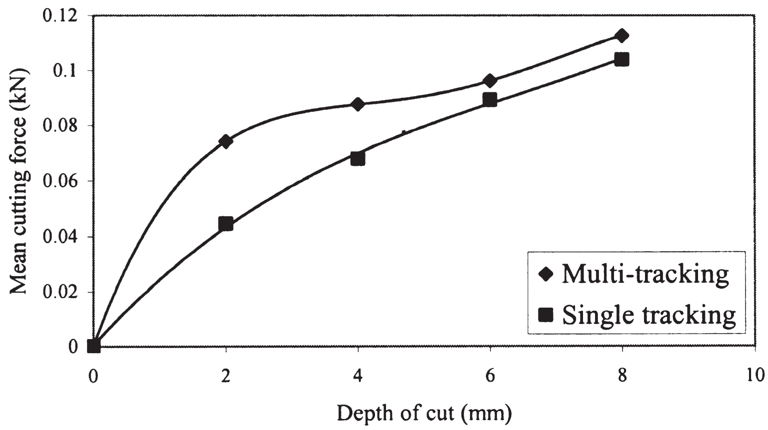

Figure 6—Variation of mean cutting force with depth of cut[27]

groove deepening cutting mode, as usually seen in multi-tracking arrangements, pick forces are independent of the depth of cut taken and are higher than those that are required to cut the same groove in isolated cutting conditions, below a certain depth of cut (Figure 6). Additionally, ridges formed between the successive grooves cause wear on picks and pickholders, which leads to higher forces and vibrations being exerted on the cutting head[21].

Hurt and McAndrew[28] performed rock cutting experiments using the boom of a roadheader, equipped with a cutting head employing different pick types, on hard limestone. Tests related to the effect of the cutting head design on the performance of the mechanical excavation process have revealed that even with the cutting heads of proper design, the pick consumption rates of gauge picks that correspond to the clearance ring picks of shearer drums are higher than those of traversing picks. Most of the pick consumption rates were recorded for the gauge picks on the cutting lines between 8 and 14 (Figure 7).

Underground studies

In situ investigations on the effects of the lacing arrangement of clearance ring picks on drum life and those related to the pick consumption characteristics of shearer drums were performed at Cayirhan Coal Mine, Turkey (Figure 8). Underground observations showed that the double ended ranging longwall shearers employed in the mine suffered from excessive pick consumption and pickholder wear, especially in the backplate section of shearer drums, lowering the lifespan of these drums, which were concluded to arise from the poor lacing arrangement of clearance ring picks. It was decided to employ heavy-duty point attack picks on the backplate while slender type picks were used on vanes, in an effort to overcome the excessive pick consumption rate of clearance ring picks by site engineers. Although there have been very slight reductions in the consumption rates of clearance ring picks, this approach did not lead to solving the problem.

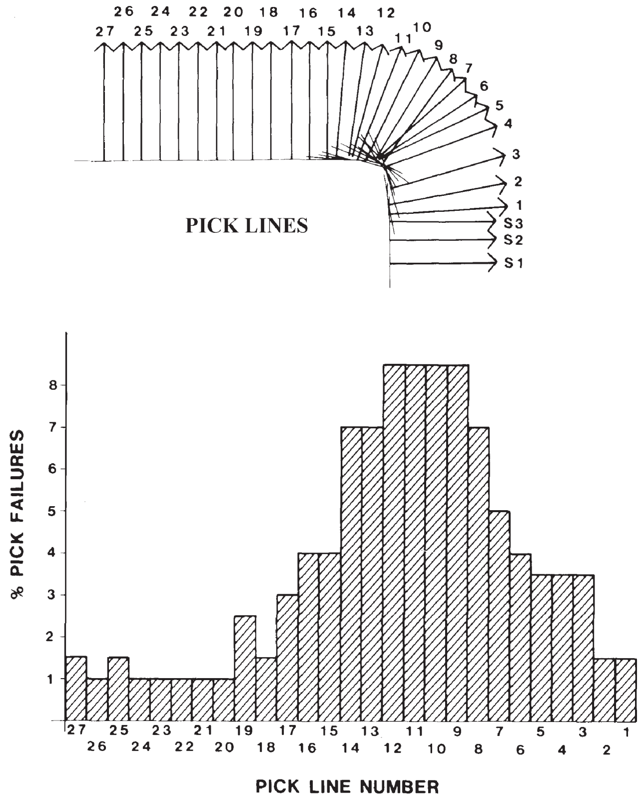

Figure 7—Pick failure characteristics of a roadheader cutting head[28]

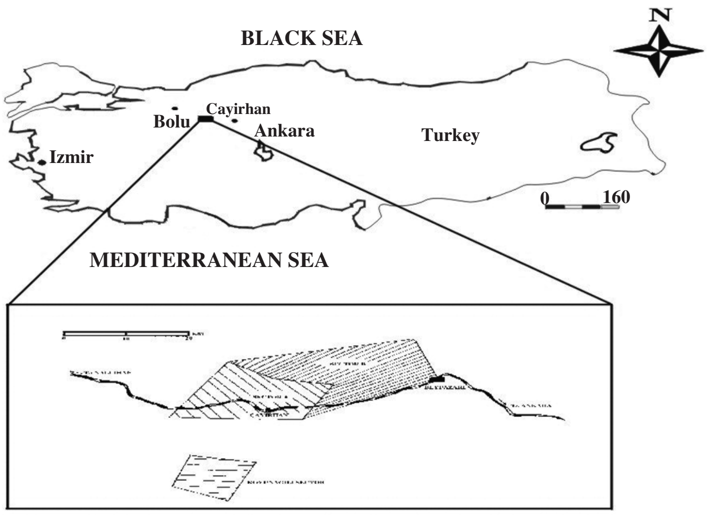

Figure 8—Location map and coalfields for Cayirhan Coal Mine

Cayirhan Coal Mine is the first fully mechanized underground coalmine in Turkey. Formerly operated by Turkish Coal Enterprises, it is now run by the private sector. With a planned annual production of about 5 Mt, it has a view to feeding a coal-fired power station of 4 x 150 kW. The Cayirhan coal basin contains two coal-seams separated by interburden sediments. The total thickness of interburden sediments varies from 120 to 150 m. The upper coal-seam that has been extracted is separated into two coal-beds by a siltstone interlayer varying from 0.4 to 1 m in thickness. The thickness of the upper and lower coal-beds varies from 1.5 to 2.6 m throughout the coal basin. These beds are extracted individually using a fully mechanized retreat longwall method with caving (Figure 9).

Experimental methodology

Performance of several pairs of shearer drums with different lacing arrangements for clearance ring picks was monitored continuously in actual coal production operations. Kennametal U47 equivalent heavy-duty point attack picks were used as the clearance ring picks, while Kennametal U40

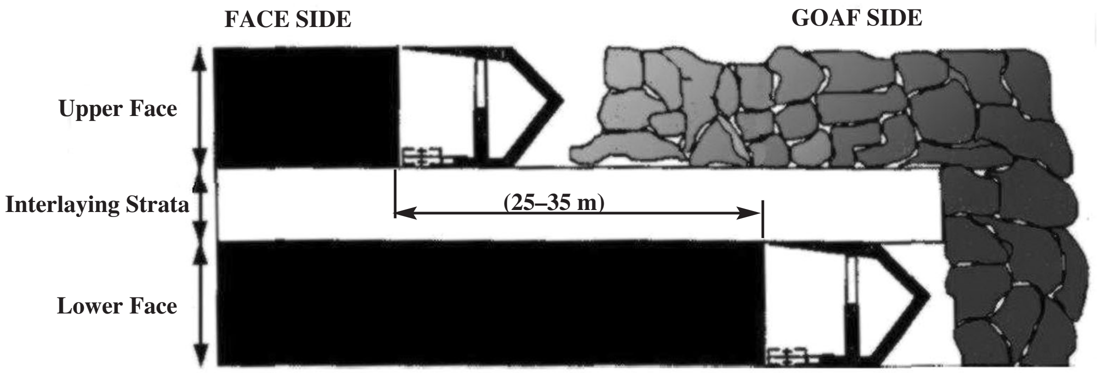

Figure 9—Panel layout of Cayirhan Coal Mine

equivalent slender point attack picks were used as vane picks both on Drums A and B during underground trials. Heavy-duty picks have been employed by Cayirhan Coal Mine on some of the drums as clearance ring picks so that they can tackle with the higher forces experienced during coal cutting, since they are stronger than the slender picks, having a higher tip angle, larger pick body, and stronger pickholder. Tests with Drums A and B aimed to investigate the effects of some pick lacing parameters on the service life of shearer drums. Kennametal G60KB90–17.5C type point attack long-reach picks were employed as both clearance ring and vane picks on Drums C. Therefore, pick consumption data obtained from *in situ* trials carried out using Drums C were statistically analysed to clarify the pick consumption characteristics of the shearer drums.

Pick consumptions and pickholder damages, total coal production, and the changes in the cutting conditions were carefully observed and recorded throughout the underground studies with Drums A. When Drums A reached the end of their service lives, they were replaced by Drums B. Then the same monitoring procedure was performed on these drums. In addition to the parameters mentioned above, pick identification numbers welded on each pickholder were recorded when the picks were replaced with new ones throughout the studies of Drums C, in an attempt to clarify the pick consumption characteristics of the shearer drums.

Studies of Drums A

Drums A consist of three spiral vanes with starting points, separated 120° from each other, and a backplate. Spiral vanes have a wrap angle of approximately 240°. The total number of 21 clearance ring picks was arranged in five pick lines, conforming to a multi-tracking arrangement. E and D pick lines include six picks each, while three picks are placed on C, B and A pick lines. All six corner cutting picks i.e. picks in the E line, were employed with a 60° tilt angle. A-line picks were mounted on the backplate without tilt angles, being transition picks between the vane and clearance ring picks (Figure 10). These shearer drums have been observed to suffer from serious damage particularly occurring at the backplate section of the drums, and this problem is, in most cases, overcome by employing wear-resistant materials (Figure 11). Shearer Drums A were replaced by the drums B after five months of operation on the longwall shearer.

Studies of Drums B

The clearance ring picks of Drums B were arranged in a new lacing design that was developed by modifying the original lacing of the clearance ring picks of Drums A, keeping the other drum construction parameters intact. A single tracking concept was utilized for the lacing arrangement of the clearance ring picks mounted on Drums B. The total number of 21 picks was arranged in such a way that there was only one pick per line. A corner cutting pick was mounted on the backplate with a tilt angle of 70°. Drums B were dismantled from the longwall shearer after six months of production, without any damage observed on either the backplate or the pickholders of the clearance ring picks.

Drums A were compared to drums B based on drum life and pick consumption rates for both the vane and clearance ring picks in Table I below. As can be seen from Table I, the following benefits were obtained by employing Drums B on the longwall shearer:

- ➤ The pick consumption rate for clearance ring picks decreased three fold, while the decrease in the consumption of vane picks was about 40 per cent.
- ➤ The overall pick consumption rate decreased by 45 per cent
- ➤ The life span of the drums increased by 70 per cent in terms of total coal production.

Studies of Drums C

Drums C consist of three spiral vanes, each mounted with 11 picks, with starting points separated 120° from each other, and a backplate. Spiral vanes have a wrap angle of approximately 287°. The total number of 33 vane picks was arranged in a lacing where three picks were located on each cutting line. The total number of 15 clearance ring picks was arranged in five pick lines (A, B, C, D, and E), each including three picks. E-line picks were employed with a 70° tilt angle. A-line picks were mounted on the backplate without tilt angles, being transition picks between the vane and clearance ring picks (Figure 12).

Trials with Drums C were mainly aimed at investigating the pick consumption characteristics of shearer drums in the Cayirhan Coal Mine. For this purpose, numbers indicating the cutting sequence of individual picks (seen in Figure 13), being the pick identification numbers, were welded on the pickholders of both the vane and the clearance ring picks, before Drums C were mounted on the longwall shearer. Thus, the number of replacements related to an individual pick

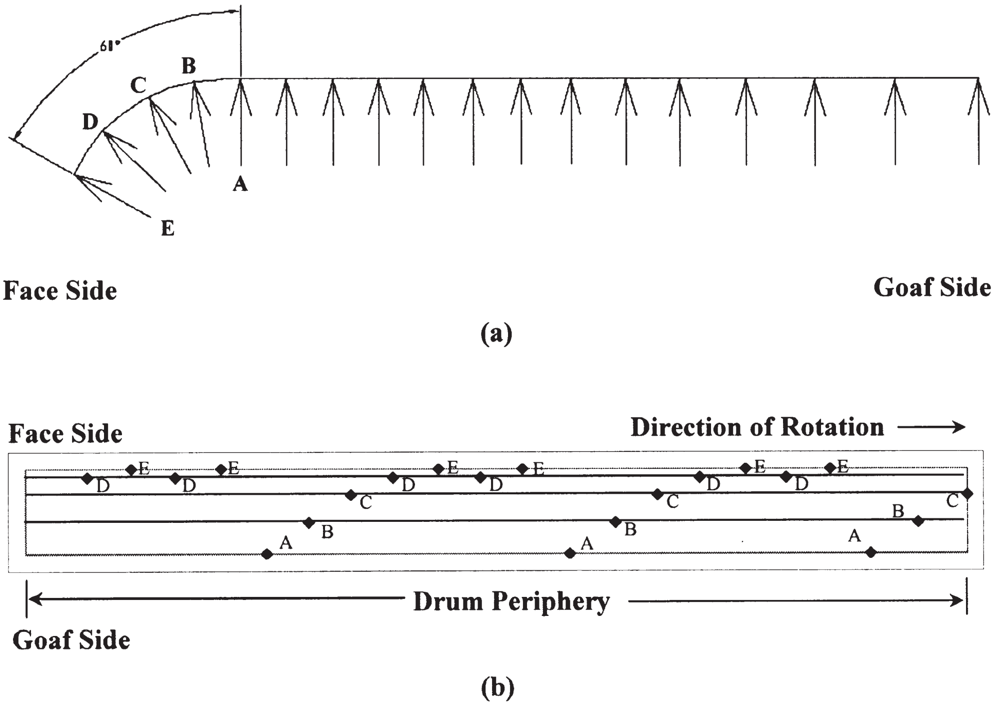

Figure 10—Clearance ring pick arrangement for Drums A (not to scale): (a) profile view of the drum (b) lacing of clearance ring picks

Figure 11—Typical damage to backplate and clearance pickholders of Drums A

Table I

Comparison of the pick consumption rate of Drums A and B

		Drums A	Drums B
Total coal production (tons)		77 676	133 120
Effective excavation time (minutes)		33 048	51 150
Number of picks consumed	Vane	606	692
	Clearance ring	215	162
	Total	821	854
Overall pick consumption rate (/1000 t)		11	6
Consumption rate for vane picks (/1000 t)		8	5
Consumption rate for clearance ring picks (/1000 t)		3	1

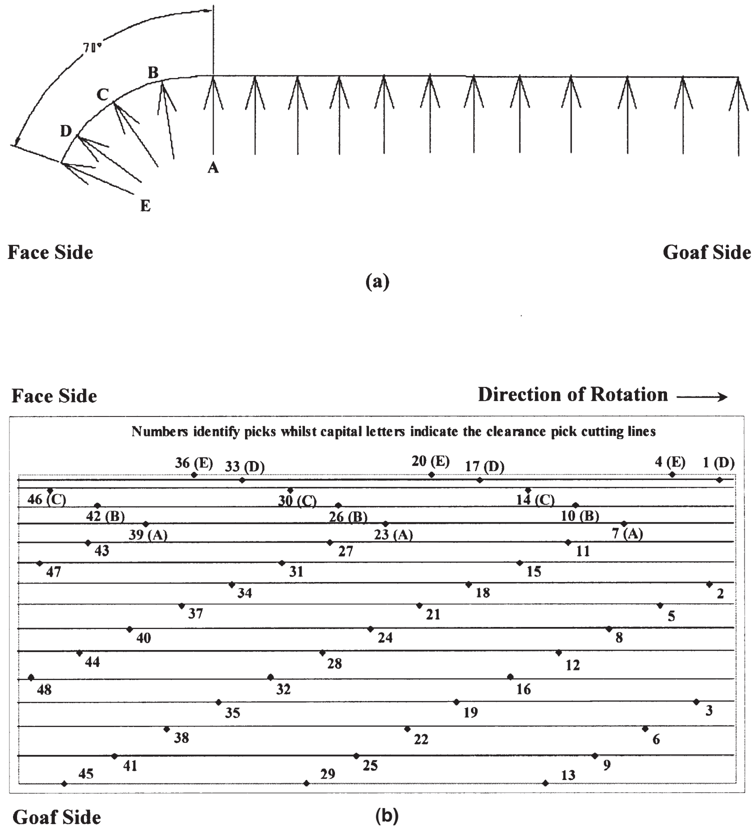

Figure 12—Arrangements of clearance ring and vane picks of Drums C (not to scale): (a) profile view of the drum (b) lacing of spiral and clearance ring picks

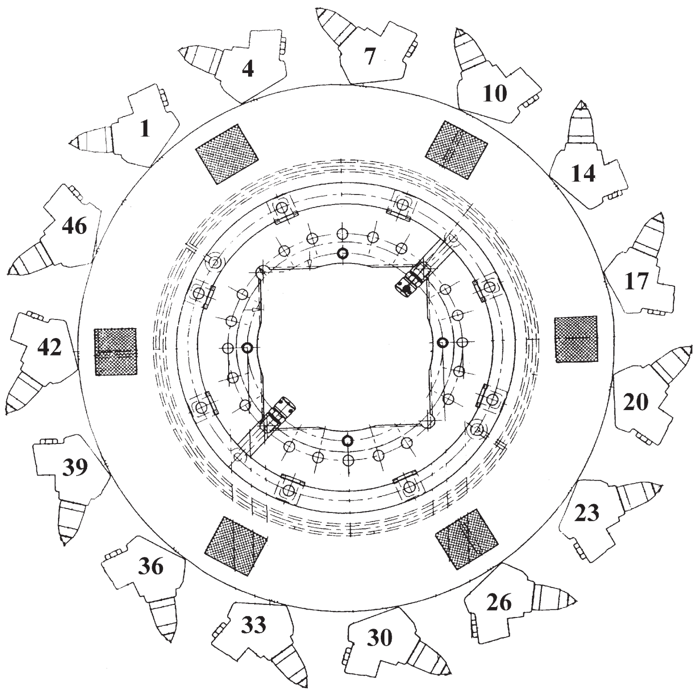

Figure 13—Numbering the picks on shearer drum by welding electrodes

would be easy to record by the maintenance crew.

The operation of the longwall shearer when fitted with Drums C was observed for a period of 49 days until the holder of vane pick number 13 was totally destroyed. Taking into account the fact that the increased line spacing due to the pickholder failure will increase the forces acting on the vane picks in the neighbourhood of pick number 13, no further recordings were performed on these drums. After the underground trials of Drums C were completed, data gained was subjected to a detailed statistical analysis. Only the pick consumption values taken during the first month of total recording time of 49 days were used in the statistical analyses. The total number of 416 clearance ring picks was replaced whilst 326 vane picks, totalling 742 picks, were failed in this period.

Replacement rates of picks

In analysing pick replacement rates, the pick consumption value of an individual pick, which was characterized by a number, was considered the sum of pick consumption values recorded for that pick from both the left and right drums. A replacement rate graph was drawn for all the picks mounted on both drums of the shearer (Figure 14). When 3 per cent of replacement rate is adopted as the reference line, picks with numbers 4, 7, 10, 20, 23, 26, 36, 39, 42, and 46, all clearance ring picks, are seen to exceed this line (see Figure 12b). This situation implies that the clearance ring picks are subjected to higher loads than the vane picks; even they experience much lower depths of cut during the coal excavation process.

When all the clearance ring picks employed on both drums of the shearer are taken into consideration, apart from the vane picks, pick number 4, being one of the corner cutting picks, is understood to have the highest replacement rate among the clearance ring picks (Figure 15).

Picks numbered 13, 29, and 45, being the last picks on each vane of both drums at the goaf side on the shearer, had the highest replacement rates among the vane picks during the actual coal production operations (Figure 16).

Replacement frequencies of picks

Pick consumptions of clearance ring and vane picks of both the left and right drums of the shearer were also subjected to a statistical analysis based on the three-day based pick consumptions for one month, regardless of the pick numbers. For all four groups of data, the minimum pick consumption value was subtracted from the maximum value in order to find the rank of the raw data. Rank values were divided by ten, being the total number of intervals, as pick consumption values were classified into 3-day periods in one month. The lower limits of all intervals were found by adding the rank to the minimum value and then repeatedly adding the rank to the product until the tenth limit was set. Upper limits were set by beginning with the second lower value among the

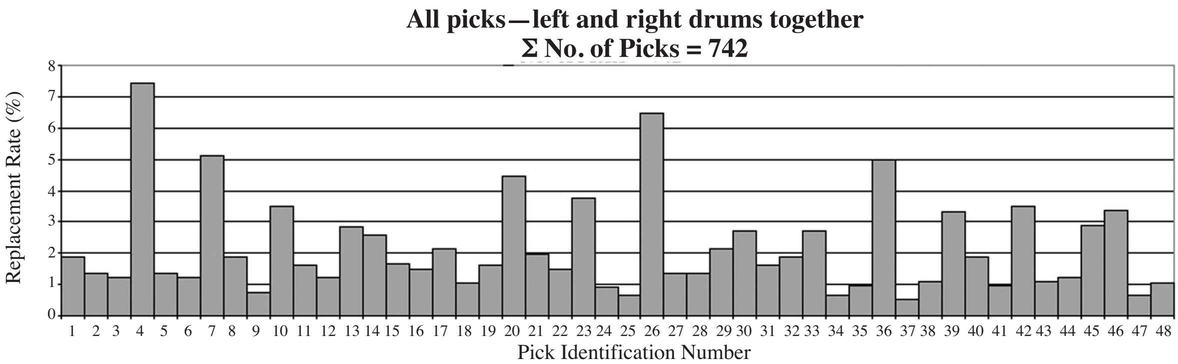

Figure 14—Replacement rates for all picks for both drums

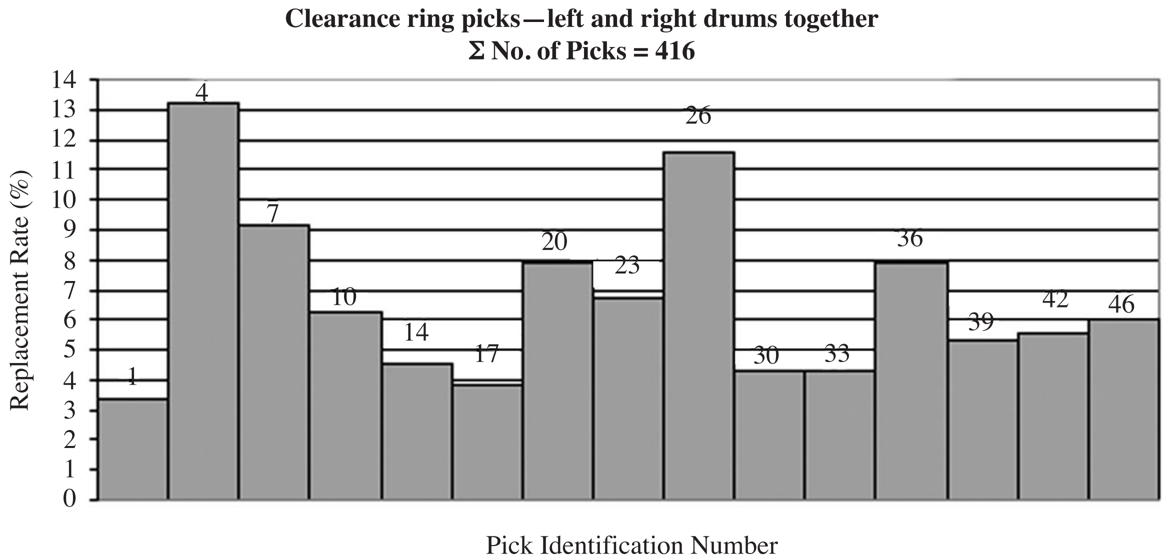

Figure 15—Replacement rates of clearance ring picks for both drums

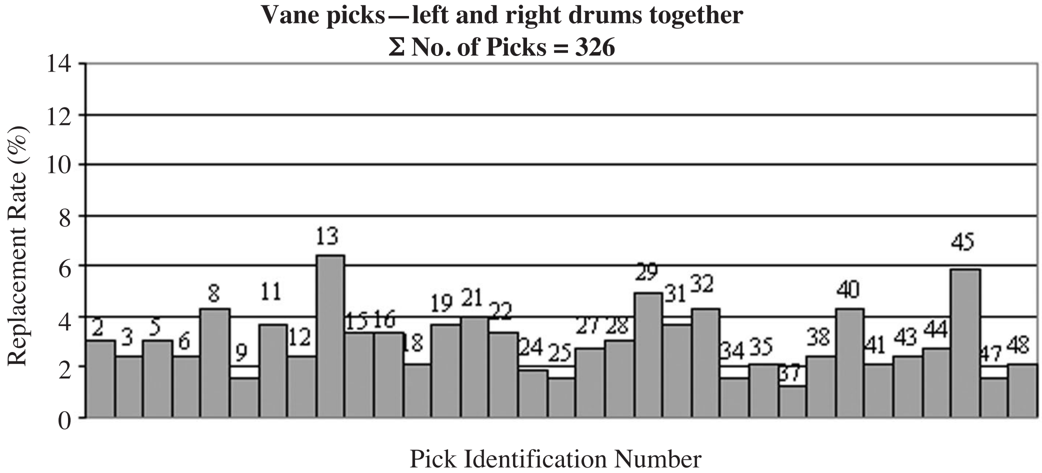

Figure 16—Replacement rates of vane picks for both drums

Table II

Descriptive statistics

Drums and picks		Maximum	Minimum	Mean	Standard deviation	Mode	Median
Left Drum	Vane picks	36	4	15.6	10.75	10	11
	Clearance ring picks	42	1	18.6	14.07	7	15
Right Drum	Vane picks	34	1	14.9	10.99	N/A	13
	Clearance ring picks	40	3	21.2	13.94	3	21.5

lower limits and adding the rank to this value. Then the rank value was repeatedly added to the product until the maximum value was reached. The upper limits of each interval was shown in the graphs. Observations recorded for any interval were considered the frequency of that interval. Descriptive statistical parameters related to this analysis are given in Table II.

When the relative frequency graph drawn for the vane picks of the left drum is evaluated, it can be seen that the interval of 4–7.2 has the highest frequency among the others (Figure 17). It means that 30 per cent of the entire group is in this interval. In other words, in the pick consumption records entered per three days for a month, most frequently encountered pick consumption values lay in the interval of 4 to 7.2. The cumulative relative frequency graph reveals that 50 per cent of the vane pick replacements performed in the three-day period for a month includes the change of vane picks less then 10.4 (Figure 18). The highest relative frequency for the clearance ring picks of this drum is for the interval of 5.1 –9.2 by 30 per cent, which is higher than that of vane picks (Figure 19). The cumulative relative frequency graph drawn for the clearance ring picks of the left drum shows that 50 per cent of the pick replacements performed per three-day period includes the change of picks less then 17.4 (Figure 20). This is also higher than that encountered for vane picks, as expected.

Relative and cumulative relative frequency graphs drawn for the right drum showed similar trends to those of the left drums. Twenty per cent of all pick replacements for vane picks was between both 4.3–7.6 and 10.9–14.2 intervals (Figure 21). In this period, 50 per cent of the vane pick replacements performed includes the change of vane picks less then 10.9 (Figure 22). The most frequently encountered pick consumption values for clearance ring picks were in the interval of 3.0 to 6.7 by 30 per cent (Figure 23). The cumulative relative frequency graph drawn for the clearance picks of the right drum revealed that the 50 per cent of the pick replacements performed per three days includes the change of picks less then 21.5 (Figure 24).

The most frequent pick consumptions recorded for clearance ring picks on both the left and right drums are almost in the same interval. However, for the vane picks of the right drum, there are two different intervals where most of the pick consumptions occurred, which are also higher than those for clearance ring picks opposing the case of the left drum. This was possibly because of the difficult cutting conditions that the right drum encountered during the large amount of manoeuvres at the maingate section of the longwall for a new cut, due to the severe undulations of the floor strata, as it served as a maingate drum.

Discussion and conclusions

Underground experiments performed on longwall shearers at Cayirhan Coal Mine put forward the significance of the pick lacing in positioning the clearance ring picks on the shearer. Results revealed the superiority of Drums B employing the

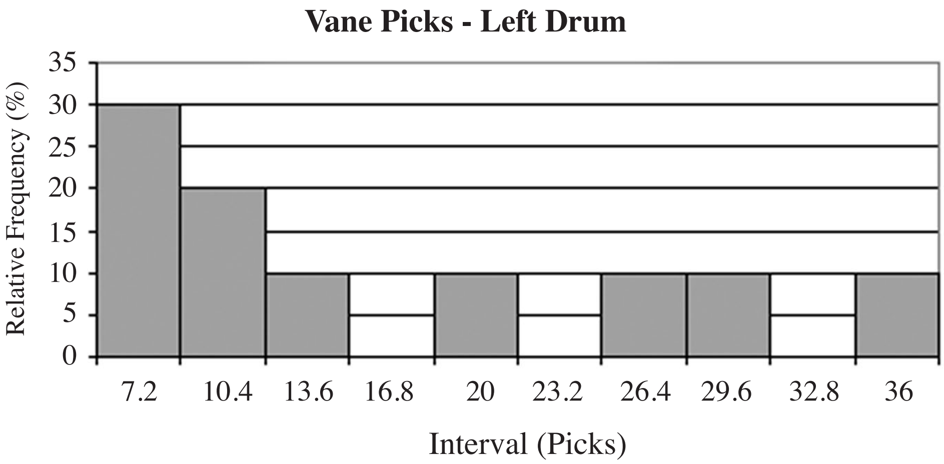

Figure 17—Relative frequencies for vane picks on the left drum

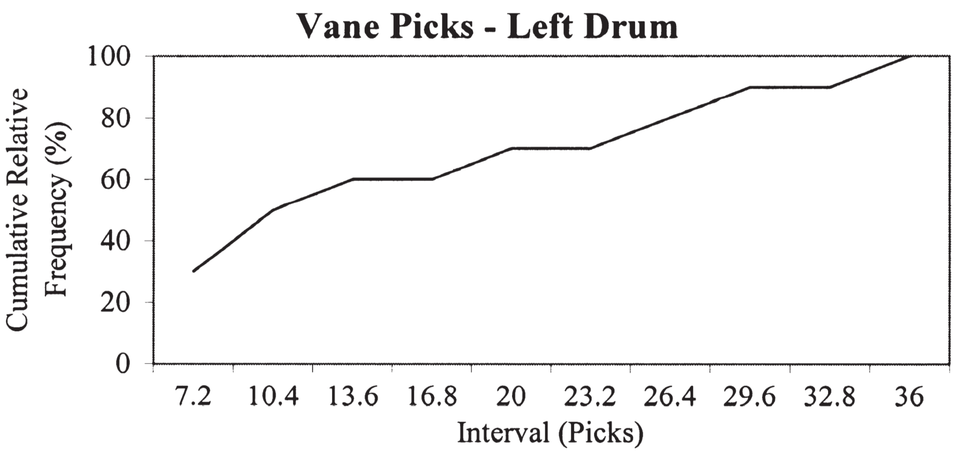

Figure 18—Cumulative relative frequencies for vane picks on the left drum

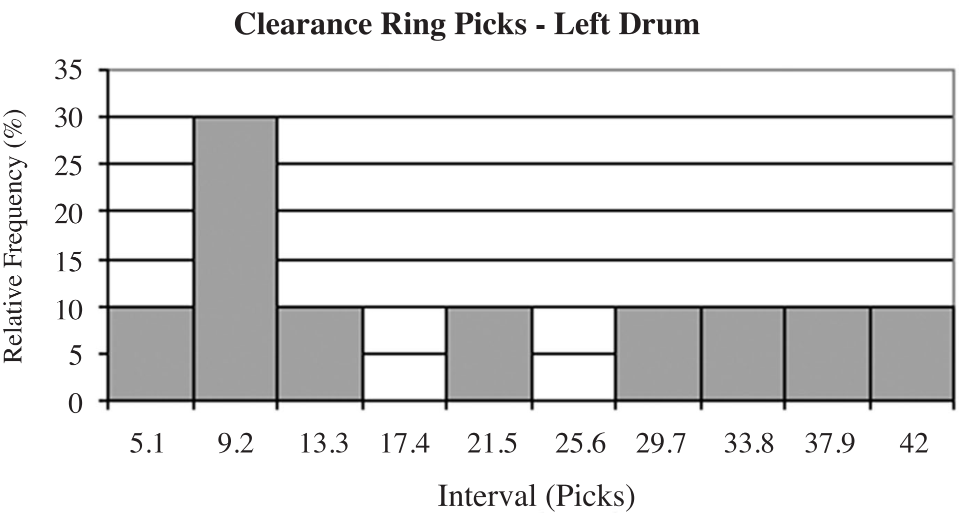

Figure 19—Relative frequencies for clearance ring picks on the left drum

single tracking concept with a corner cutting pick of 70° tilt angle, over Drums A employing the multi-tracking concept with a corner cutting pick of 60° tilt angle, in terms of lifespan and pick consumption rate of shearer drums. The pick consumption rate for clearance ring picks decreased three fold and the service life of shearer drums increased by 70 per cent, while the overall pick consumption rate decreased by 45 per cent, when the longwall shearer was fitted with Drums B. *In situ* trials performed in the course of this study showed that the increased lifespan of Drums B can be attributed to the design of the clearance ring picks.

Picks on the backplate of a shearer drum operate in the

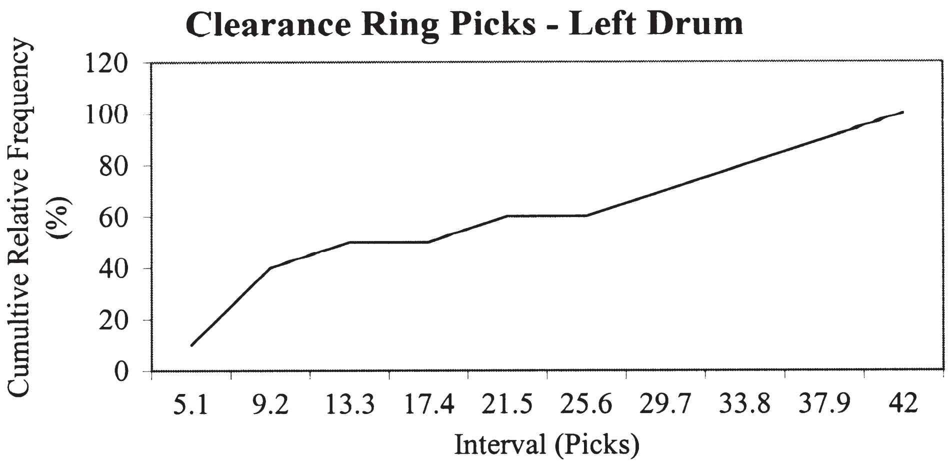

Figure 20—Cumulative relative frequencies for clearance ring picks on the left drum

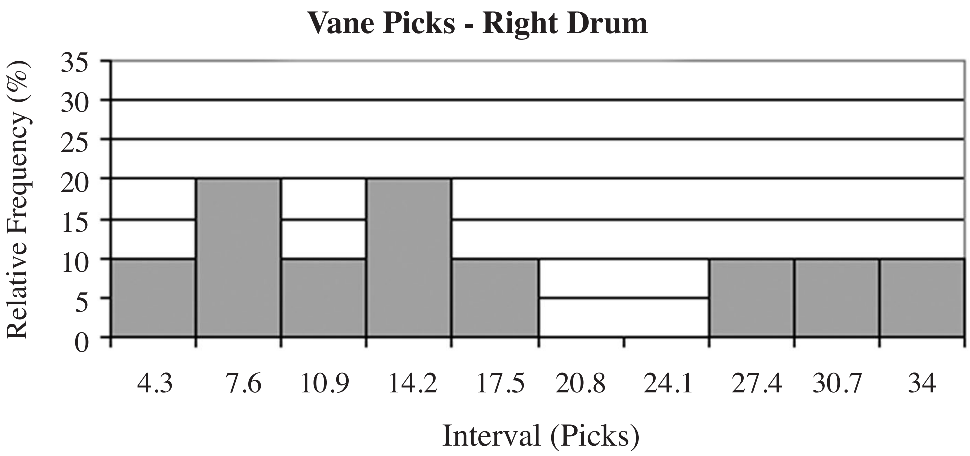

Figure 21—Relative frequencies for vane picks on the right drum

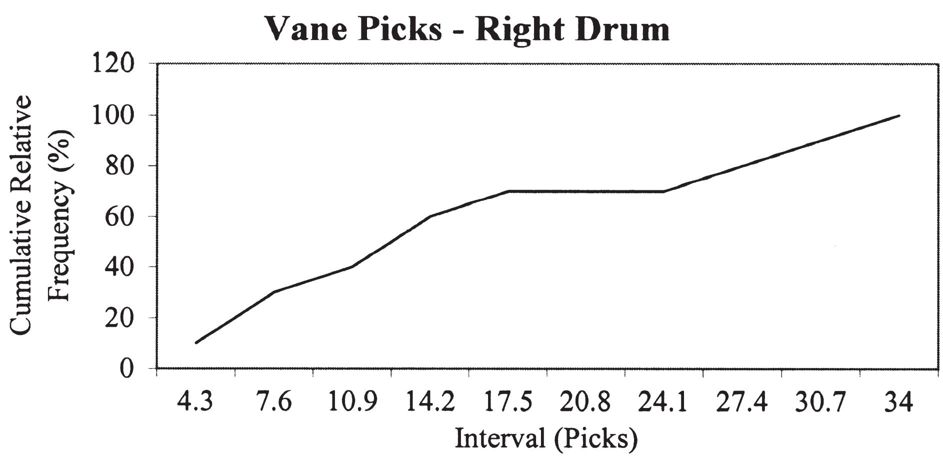

Figure 22—Cumulative relative frequencies for vane picks on the right drum

corner far away from the free coal surface. Pick confinement due to the corner-cutting conditions causes difficulty for coal breakage, leading to decreases in yield. As a result, the pick forces and specific cutting energy required to cut a certain amount of coal for clearance ring picks are higher than those for vane picks. Failure of clearance ring picks, when they operate in unsuitable design conditions, leads to rapid destruction of other gauge picks in a domino effect, causing the shearer drum to be withdrawn from the longwall. Therefore, the arrangement of the clearance ring picks must

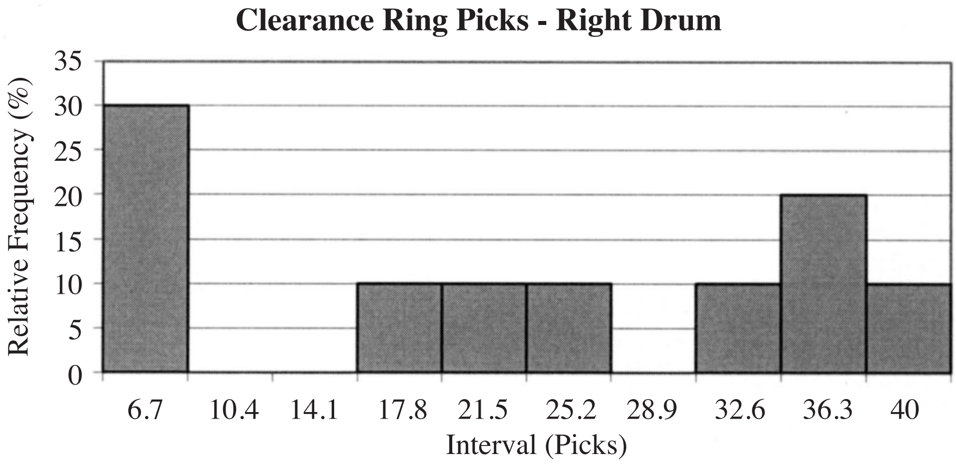

Figure 23—Relative frequencies for clearance ring picks on the right drum

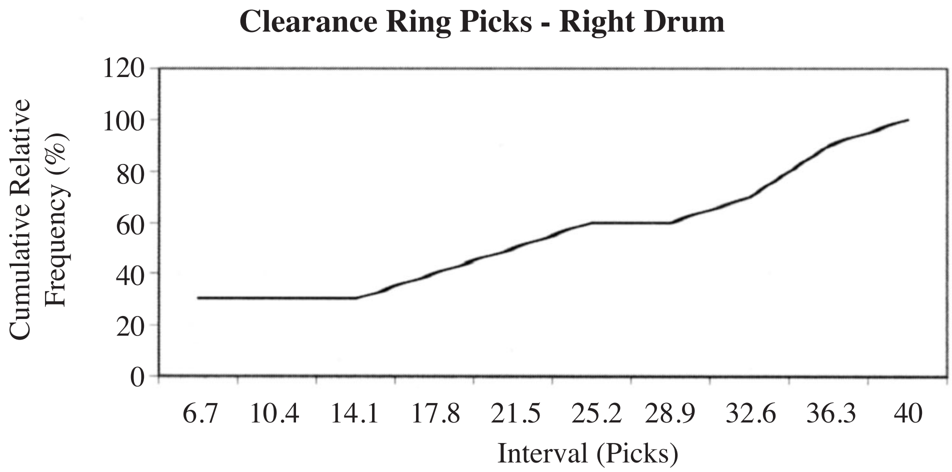

Figure 24—Cumulative relative frequencies for clearance ring picks on the right drum

be paid special attention in designing a shearer drum for a particular fully mechanized longwall mining operation. Power consumption, vibrations, and fines can be reduced, while pick life and the percentage of coarse material can be improved for longwall shearers when the following are maintained through the lacing of clearance ring picks:

- Each clearance ring pick has similar pick forces
- Clearance ring picks have similar cutting forces to those of vane picks
- Pick interaction is successful

Clearance ring picks with optimum tilt angles must be arranged in such a way that they obtain relief both from each other and from the vane picks for efficient coal cutting. A lacing design considering single tracking and equal circumferential pick spacing concepts for clearance ring picks, with a corner-cutting pick having a tilt angle higher than 60° and other clearance ring picks with tilt angles gradually decreasing to zero is recommended, relying upon the comprehensive underground studies in this respect.

In situ trials with longwall shearers used at Cayirhan Coal Mine also came up with important results for pick consumption characteristics of shearer drums. Statistical analysis of pick consumption records kept for Drums C showed that the clearance ring picks are replaced more frequently than vane picks. For the shearer used in Cayirhan Coal Mine, usually 3 to 7 clearance ring picks, with an average maximum value of 41, are replaced by new ones every three days. There is no clear interval for vane picks determined during the underground studies. The average maximum number of vane pick replacement for both drums is 35 picks per three days. This can be attributed to the higher level of forces acting on the clearance ring picks due to the tilt angles and cutting conditions during coal excavation, confirming the results of laboratory studies on gauge picks. Pick number 4, being a corner cutting pick had the highest number of replacements. This also confirms previous laboratory studies, which have proposed that corner cutting picks were likely to experience higher forces than other gauge picks on the shearer drums.

The last picks on the goaf side of each vane on shearer drums were seen to be the most frequently replaced picks among the vane picks. These picks are usually prone to damage because they hit the extension plates of shield supports when the shearer operates too close to the shield supports and, as a result, they suffer from impact shattering while the shearer advances along the coalface. The number of replacements related to those picks depends on the degree of snaking of the armoured face conveyor, strata conditions, and the method of shield support advance.

Keeping track of the pick consumption data for a longwall shearer operating in a certain longwall panel can guide the estimate of the maintenance costs related to the pick consumption. These data will also help the mine operators in deciding the critical storage level of new picks. By using reliable prediction models for pick consumption,the purchase of excessive numbers of picks can be avoided. These models will also prevent the mine operators from underestimating the number of new picks that must be stocked to carry on coal production operations. As a result, the longwall operation can be prevented from stopping due to the lack of new picks in stock, and an increase in the overall operating cost of coal production can be avoided.

References

1. HURT, K.G. and MCSTRAVICK, F.G. High performance shearer drum design. *Colliery Guardian*, 1988, vol. 236, no. 12, pp. 428–429.
2. MOORE, R. Maintaining the edge. *World Mining Equipment*, 1998, vol. 22, no. 10, December, pp. 75–78.
3. BRITTON, R.R. and GOZON, J.S. Grapho-analytical method of analyzing bit life and replacement. *Mining Science and Technology*, 1984. vol. 1, pp. 173–177.
4. POWELL, F. Design guidelines for picks. *Colliery Guardian*, 1991, vol. 239, no. 5, pp. 139–141.
5. HURT, K.G. and LAIDLAW, D.D. Laboratory comparison of three rock cutting tools. *Tunnels and Tunnelling*, 1979, May, pp. 13–16.
6. HURT, K.G. and MCANDREW, K.M. Designing roadheader cutting heads. *The Mining Engineer*, 1981b, vol. 141, no. 240, pp. 167–170.
7. TIRYAKI, B. Optimization of tool lacing parameters for drum shearers. Ph.D. Thesis, Hacettepe University, Ankara, Turkey, 1998 (unpublished).
8. ROXBOROUGH, F.F., KING, P., and PEDRONCELLI, E.J. Tests on the cutting performance of a continuous miner. *Journal of the South African Institute of Mining and Metallurgy*, 1981, January, pp. 9–25.
9. EVENDEN, M.P. and EDWARDS, J.S. Cutting theory and coal seam assessment techniques and their application to shearer design. *Mining Science and Technology*, 1985, vol. 2, pp. 253–270.
10. BROOKER, C.M. Theoretical and practical aspects of cutting and loading by shearer drums. *Colliery Guardian*, 1979, April, pp. 41–50.
11. Roxborough, F.F. and Rispin, A. A laboratory investigation into the application of picks for mechanized tunnel boring in the lower chalk. *The Mining Engineer*, 1973, vol. 133, October, pp. 1–13.
12. ROXBOROUGH, F.F. and PEDRONCELLI, E.J. A practical evaluation of some coal-cutting theories using a continuous miner. *The Mining Engineer*, 1982, vol. 142, no. 252, pp. 145–156.
13. KADIU, M., SELLAMI, H., and DEMOULIN, J. A new conception of clearance ring based on the study of inclined pick behavior. *Proceedings of the 1st International Symposium on Mine Mechanization and Automation*, Golden. Ozdemir, L., King, R., Hanna, K. (eds.), Colorado School of Mines, 1991, vol.1, pp. 1–1/1–10.
14. HOOD, M.C. and ROXBOROUGH, F.F. Rock breakage: Mechanical. *SME Mining Engineering Handbook,* Second Edition, SME, Howard L. Hartman (senior editor), vol. 1, 1992. pp. 680–721.
15. HEKIMOGLU, O.Z. Studies in the excavation of selected rock materials with mechanical tools. Ph.D. Thesis, The University of Newcastle Upon Tyne, 1984, (unpublished).
16. HAMILTON, R.J., FRENCH, A.G., and SPENCE, A.C. Developments in dust control in coal mines. *The Mining Engineer*, 1976, March, pp. 317–326.
17. OLSON, R.C. and ROEPKE, W.W. Respirable dust sources of longwall mining examined. *The Mining Engineer*, 1984, August, pp. 1158–1163.
18. HURT, K.G., MORRIS, C.J., and MULLINS, R. Developments in coal cutting techniques. *The Mining Engineer*, 1986, vol. 145, no. 296, pp. 467–477.
19. EVANS, I. and POMEROY C.D. *The strength, fracture, and workability of coa*l. Pergamon Press Ltd., 1973.
20. HURT, K.G. Roadheader cutting heads: A study of the layout of cutting tools and a rational procedure for design. MRDE Report No: 90, 1980, (unpublished).
21. HURT, K.G. and MCANDREW, K.M. Roadheader cutting heads: How many tools per line. MRDE Report No: 96, England, 1981a, (unpublished).
22. HEKIMOGLU, O.Z. and TIRYAKI, B. *In situ* investigations on shearer drum design. *Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Bulletin*, 1998, vol. 91, no. 1018, pp. 225–227.
23. TIRYAKI, B. An investigation on the effects of pick lacing parameters on the performance of drum shearer-loaders. Yerbilimleri, *Bulletin of Earth Science Application and Research Centre of Hacettepe University*, 2000, vol. 22, pp. 237–246 (in Turkish).
24. POMEROY, C.D. and BROWN, J.H. Laboratory investigations of cutting process applied to coal-winning machines. *Journal of Strain Analysis*, 1968, vol. 3, no. 3, pp. 232–243.
25. MELLOR, M. Mechanics of cutting and boring, Part IV: Dynamics and energetics of parallel motion tools. CRREL Report No. 7–7, 1977, April, (unpublished).
26. ANDERSON, S.J., MORRELL, R.J., and LARSON, D.A. A laboratory comparison of drag cutting methods in hard rock. Bureau of Mines Report of Investigations No. 9086, United States Department of the Interior, 1987, 12 pp.
27. AYHAN, M. Designing shearer drums and cutting heads with the aid of a computer programme. Ph.D. Thesis, Hacettepe University, Ankara, Turkey, 1998, (unpublished).
28. HURT, K.G. and MCANDREW, K.M. Cutting efficiency and life of rock-cutting picks. *Mining Science and Technology*, 1985, vol. 2, pp. 139–151. ◆

World iron ore production reaches record high*

New report analyses supply and demand worldwide

A new report from market analyst Roskill says that 2002 saw world production of iron ore at a record high of just over 1000 Mt, as crude steel production exceeded 900 Mt for the first time. *The Economics of Iron Ore* (5th edition, 2003) says that this is not an indication of booming global demand for steel but a reflection of the huge and largely unexpected growth in steel production and consumption in China since the start of the decade.

According to the report, the tonnage growth in China's steel output since 2000 is roughly equivalent to annual production in the USA. Although China has a very large iron ore industry, its output has long been insufficient to meet domestic demand and the country is heavily dependent upon imports, which doubled to 112 Mt between 1999 and 2002 and were 44% higher in the first quarter of 2003 than in the same period the previous year.

Supply likely to remain tight

This rapid growth appears to have taken the world's iron ore producers by surprise and, coming at a time when steel production in most other countries is also growing, has eliminated any surplus of iron ore output and exerted upward pressure on prices. Roskill's report says that, although iron ore producers are moving to bring new capacity on-stream, the supply situation is likely to remain tight for the next two or three years, and an estimated 100 Mtpy of new capacity is required in the fairly short-term. Worldwide, some 190–200 Mtpy of production capacity is in the pipeline, principally in Australia and Brazil. Between 2003 and 2005 up to 115 Mtpy will be brought into production, most of it towards the end of the period.

Not all the planned capacity increases are additional capacity: a significant proportion is intended to replace existing operations with almost depleted reserves. Roskill forecasts that steel demand will continue to rise in the medium term but at reduced rates, and the supply-demand balance for iron ore will be restored in the third quarter of the decade.

Africa to gain greater importance

Roskill says that there are unlikely to be any major changes to the pattern of world supply in the immediate future. Ten countries dominate world production and the supply to world markets is even more tightly controlled through seaborne trade. In the longer term Africa is set to gain greater prominence as a producing region, with South African output set to grow by 10 Mtpy by the end of the decade. The return to peace in Liberia could also see the rehabilitation of its iron ore industry, which once produced over 10 Mtpy for export.

Main producers join forces

Recent years have seen a spate of merger and acquisition activity that has concentrated much of the world's iron ore production capacity in the hands of a very few corporate groups. Brazil's CVRD was the world's leading producer even before it began to take control of the country's other miners in the late 1990s. Now almost complete, the company's acquisition programme has given it control over an estimated 95% of Brazil's iron ore production and all of its pellet capacity. In Australia, Rio Tinto, which already owned the iron ore giant Hamersley, became the world's second largest producer in 2000 when it gained control over Robe River Iron Associates. In 2001, BHP merged with Billiton after failing to join its iron operations with those of Rio Tinto.

Dominant companies push through price rises

Roskill says that these three companies are now responsible for 30% of world iron ore production and 70% of global exports. This dominance creates a strong bargaining position in the price negotiations that are conducted annually between the iron ore producers and steelmakers in Western Europe and Japan—regions that depend very heavily on imports from Brazil and Australia. In 2001 a weak global steel market forced iron ore producers to accept price cuts of 2.5 to 5.5% in the 2002 price negotiations.

Early in the 2003 negotiations, steelmakers were demanding further cuts, arguing the case of continued lacklustre market conditions. Iron ore producers were pushing for increases, and industry analysts were predicting a rise in prices of only 2% to 3%. When the first contract was eventually agreed, in mid-May, the increase was much higher than expected. CVRD's contract to supply Arcelor with 16 Mt of fines was at a price 9% higher than in the previous year and other producers quickly followed suit. Producers were able to push through these increases on the back of high steel prices and very strong demand for iron ore in China.

The Economics of Iron Ore (5th edition, 2003) is available at £1500/US$3000/€2625 from Roskill Information Services Ltd, 27a Leopold Road, London SW19 7BB, England. Tel: +44 (0) 20 8944 0066. Fax: +44 (0) 20 8947 9568, E-mail: info@roskill.co.uk ◆