
DRAG TOOLS EMPLOYED ON SHEARER DRUMS AND ROADHEADERS

Robert J.FOWELL (*)
Osman Z.HEKİMOĞLU (**)
Sabri ALTINOLUK (***)

ABSTRACT

This paper outlines some practical and theoretical aspects of drag tools being employed in the mining and civil engineering industries. Discussed in the paper are the selection and reservicing of cutter picks with appropriate holders, in terms of bulk material extraction and development operations. Results from in-situ investigations undertaken in Beypazarı Lignite Mine (OAL) show that the type of pick locking device influences the overall tool performance. Recovery of worn and damaged picks has been found to be economical.

ÖZET

Bildiride madencilik ve inşaat endüstrisinde kullanılan keskinin bazı pratik ve kuramsal yönlerinden söz edilmektedir. Bildiride uygun fincanlara (yuvalara) sahip olan keskinin, üretim ve hazırlık işleri açısından seçimleri ve yeniden kullanılabilirliği tartışılmaktadır. OAL'de yapılan yerinde çalışmalar, iyi bir keski kitleme mekanizması ile donatılmış fincanların keski performansı üzerinde etkin olduğunu ortaya koymaktadır. Ayrıca aşınmış ve kırık keskinin yeniden kullanılmasının kazançlı olacağı vurgulanmaktadır.

* Reader, The University of Newcastle upon Tyne NE1 7RU, ENGLAND

** Dr. Maden Yüksek Mühendisi, TKİ OAL Müessesesi Çayırhan, ANKARA

*** Dr. Maden Mühendisi, Etibank Volfram Madeni, BURSA

1 INTRODUCTION

As new powerful cutting machines have been introduced into the mining and civil engineering industries with a view to meeting the needs for hard rock cutting conditions, machine and pick manufacturers have responded with developments to improve the performance of drag tools.

The cutting tools selected for rock and coal excavation are of paramount importance and have a substantial influence on machine performance. Drag tools with extended life span are always desirable in all excavation operations. Worn and damaged tools generate high pick forces, being many times higher than those recorded for the sharp tool (1). The machines on which drag tools are employed are slewing force limited in the case of roadheaders and haulage force limited in the case of coalface shearers. The effect of the worn tools is to reduce the advance per revolution of the cutters. Inefficient cutting results in the failure of the grooves cut by the tools to interact to produce large debris. Rubbing cuts result and heat builds up in the tool producing an even more rapid development of the wearflat on the tool, and performance drops further.

Practical investigations have shown that an important component of machine downtime is due to worn tools (2). The worn picks, further, cause respirable dust and where methane is present may produce incendive ignitions.

In spite of their universal use on roadheaders and shearers, drag tools are limited in their application when excavating in very hard and abrasive conditions. There are several ways in which the effects of wear can be minimised: correct tool speeds, the use of well balanced drums and cutting heads, modification of tool geometry and tungsten carbide composition to suit the rocks being excavated. Perhaps the most promising development to reduce tool wear is the addition of high pressure water jet assistance to drag tools. At present this is only commercially available on roadheaders, though studies are underway to add jet assistance to shearers.

In this paper practical aspects of wear of drag tools are set out based on laboratory investigations undertaken at the Department of Mining Engineering in the University of Newcastle upon Tyne, and field studies conducted at the Middle Anatolian Lignite Mine (Beypazari), which is a subsidiary of Turkish Coal Enterprises (TKİ).

2.1. Drag Tool Materials

The principal tool tip material used in the mining and civil engineering industries is cemented carbide which is based upon the

binary compositions of tungsten carbide and cobalt. This composite material, in which fine particles of very hard tungsten carbide (WC) are cemented together with a tough cobalt (Co) binder, is used exclusively for roadheader and coal shearer drag tools. The WC-Co grades are known for their high hardness, high compressive strengths and modulus of elasticity. Since the use of WC-Co, considerable effort has been put into developing analogous materials. Although materials substantially harder than tungsten carbide are available, none have proved successful for rock cutting due to their low impact resistance.

2.1.1. Production of Tungsten Carbide Pick Tips

The stages followed during production are generally common for most tungsten carbide, and the raw materials and manufacturing techniques are significant factors influencing the ultimate performance of carbides. The manufacturing stages basically comprise the production of tungsten carbide powders and sintering (3).

In order to produce tungsten metal, the tungsten ore concentrate, being generally wolframite or scheelite, is processed to ammonium paratungstate, tungstic oxide or tungstic acid. The pure chemical is mixed with a pure carbon powder and heated in non-oxidising conditions with the objective of obtaining tungsten carbide. The next stage involves the milling of tungsten carbide and cobalt particles together, so that the carbide grains are coated with a layer of cobalt. This mixed powder should be free from impurities of the correct size. The size of the WC depends upon the type of produce required, whereas Co particle size is usually finer than 1.5 μm , since coarser grains cause the cobalt to flatten out and form platelets rather than smearing over the WC grains, resulting in a loss of strength. After quality control checks, the milled powder is pressed to produce the correct tip shape. The pressed compact is designed to account for a 20% reduction in linear dimension during sintering.

Sintering is the last stage in production of tungsten carbide materials in which the WC-Co composite gains its final strength and hardness. The compacts may be presintered in a hydrogen furnace at temperatures up to 800°C for about five hours. The presintered material can, at this stage, be machined, having the strength of chalk, though this is not usually necessary on rock cutting bits. The shaped carbides are then ready for final sintering in a vacuum furnace at 1360°C-1400°C for half an hour. During sintering up to 20% of the WC can form solution with the cobalt. Isostatic hot pressing produces dense pure free tips, thus guaranteeing the toughness of the finished product, though this is reserved for special applications.

2.1.2. Factors Influencing the Mechanical Properties of Tungsten Carbide Composites

Cobalt content, the structure of WC-Co, the particle size of the tungsten carbide and porosity exhibit remarkable effects on the mechanical properties of the finished carbide (4).

The hardness of WC-Co decreases with an increase in Co content, whereas the transverse rupture strength, being a measure of toughness, shows an increase with Co content. The high tensile strength value of WC-Co (exceeding 1540 MPa) is not realised in practice owing to the presence of surface or internal imperfections, at which stress propagation occurs. With these imperfections, if the stress concentrations are not relieved, local plastic deformation, "premature fracture" is likely to occur. Depending upon type of application, the cobalt content for mining grades may go up to 15%, though 10% is the most common grade.

The way in which WC and Co grains bond together is of importance in the strength of tungsten carbide composites. The WC-Co-WC grain boundaries respectively affect the alloy's strength. A weak bond exists at WC-WC boundaries, while Co areas offer a strong bond. The ratio of grain boundary surface (WC-WC interface) to the total surface (WC—WC+WC—Co interface) is termed the grain contiguity and its value varies with Co content, sintering time and temperature. At higher values of contiguity, hardness increases and transverse rupture strength, a measure of toughness, diminishes.

Porosity is one of the most important factors having adverse effects on the quality of the tungsten carbide composites. Minimal porosity in this alloy offers more uniform transverse rupture strength and better tool durability. Modern production techniques and freedom from impurities have contributed to improved field performance of tools (5).

2.2. Geometry of Tungsten Carbide Tips

There exists a number of factors affecting the performance of drag tools; these are rock properties, tungsten carbide grade, tip geometry and cutting head design. The forces acting on a tool, in general, change greatly with variations in tool geometry. Included in the tip geometry are rake angle, clearance angle, side rake and side clearance angle and base angle (Figure 1).

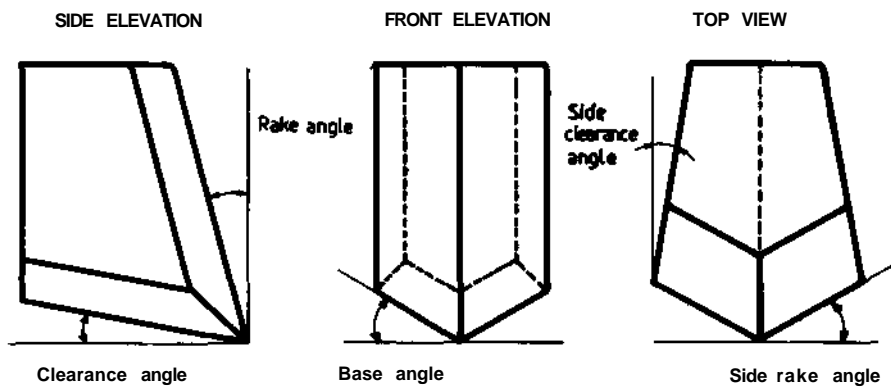


Figure 1 — Tool tip geometries

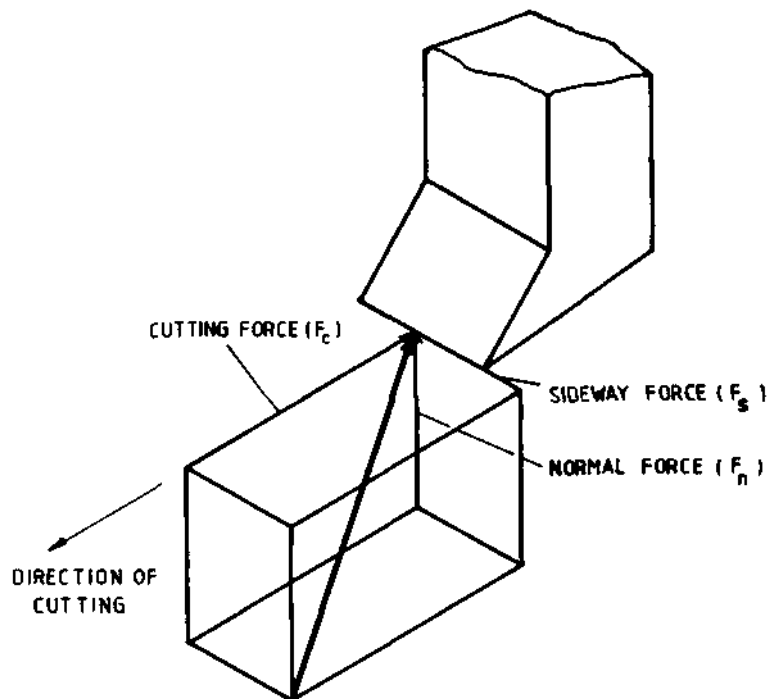


Figure 2 — Pick forces on a simple chisel pick

A simple chisel pick with the forces acting on it is illustrated in Figure 2. The resultant force P_a may be resolved into three mutually perpendicular components: cutting force f_c , acting in the direction of cutting; normal force (F_n) perpendicular to the direction of F_c ; and sideways force (F_s) normal to the plane on which F_c and F_n lie. In rock cutting, the tool forces continuously fluctuate due to the nature of the rock breakage which does not take a form of continuous chip as in metal cutting. The mechanisms of rock breakage under the action of a drag pick has been explained theoretically. Details of these theories can be found elsewhere (6-10).

The absolute magnitude of the pick forces shows a decrease as the positive rake angle increases (11) (Figure 3). This can be clearly seen over the values ranging -35 to 60 degrees at large depths of cut. This effect has, however, not been much observed with worn tools and at shallow depths of cut. Furthermore, in practice, high rake angles may not be beneficial since picks with these angles are more susceptible to gross failure. Rake angles between +20 and +30 degrees can be chosen for weak rocks and coal cutting.

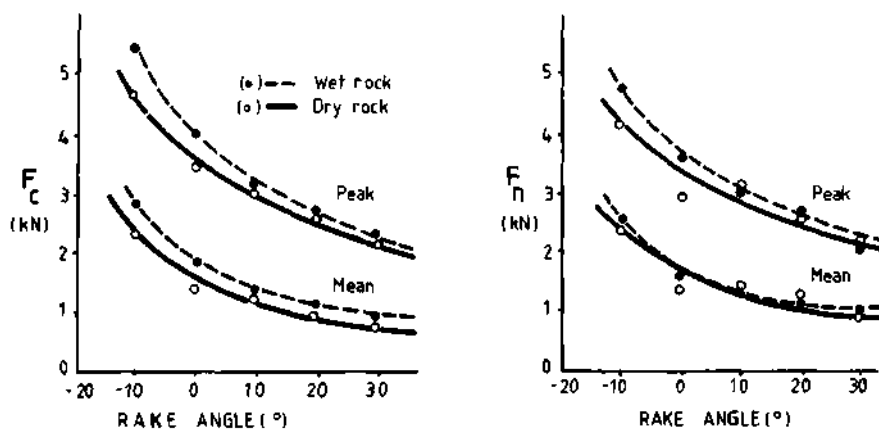


Figure 3 — Variations in pick forces with rake angles (11)

Clearance angle, which is between the lower surface of pick and a plane parallel to the cutting direction, also has pronounced effects on the pick forces. Investigations have shown that tool forces drop sharply after a value of around 5° and stay sensibly constant (Figure 4). To meet the kinematic needs, the clearance angle is generally designed to be around 10 degrees.

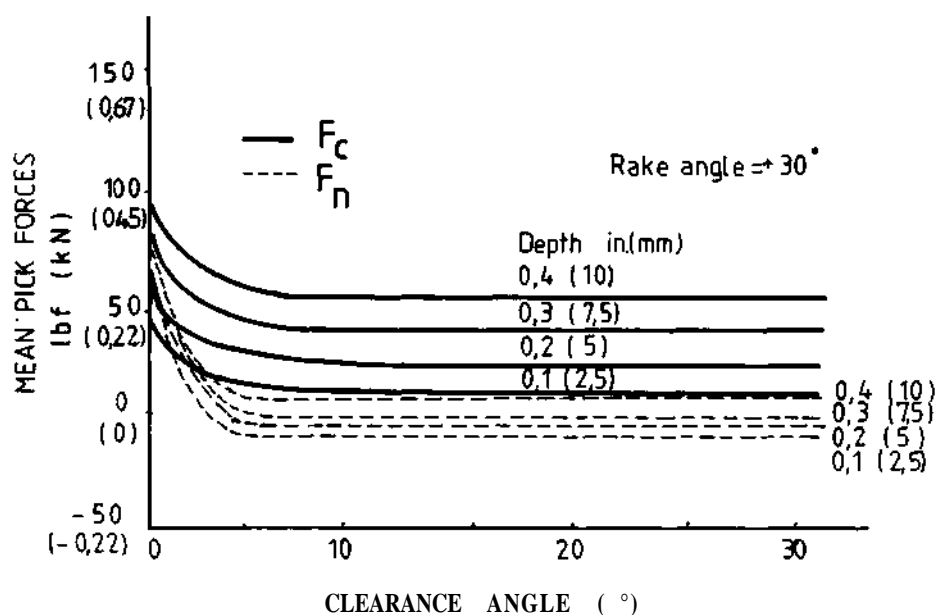


Figure 4 — Variations in pick forces with clearance angle (6)

Base angle and side rake angle, along with rake and clearance angles, also present some beneficial effects on pick forces. Although the geometry of simple chisel tools is very efficient, in rock cutting practice drag tools of complex geometries are preferred because of their improved durability (1).

2.3. Drag Tool Types Employed on Roadheading Machines and Shearer Drums

Three main types of drag tool, being radial, forward attack and point attack picks, are usually employed on shearer drums and roadheaders. Each pick type, as described below, is used for different applications.

2.3.1. Radial Picks

These tools are designed such that the axis of pick shank is normally parallel to the radial line of cutting head/drum (Figure 5). They are generally suitable for cutting soft and medium-hard rocks and coal. Radial picks generate lower forces than those of point attack tools, when pristine. The normal force is of low magnitude compared to cutting force; however, as the picks become blunt, the F_n/F_c ratio rises to several fold.

These picks are manufactured in various sizes to suit a particular cutting condition. The distance measured between the tool tip and the top of the pick shank is known as tool reach or pick gauge, and is of importance in cutting head design. Radial picks with short gauge are usually employed on roadheader cutting heads, while those having long reach are frequently found on shearer drums. In Middle Anatolian Lignite Mine (Beypazari), radial picks of 50mm and 75mm gauge have been used.

2.3.2. Forward Attack Picks

These picks are also termed tangential picks, together with point attack picks, due to the orientation of their tool axis. The design and the geometry of tool tip is similar to that found on radial picks (Figure 6). Radial picks are frequently employed on shearer drums and reported to have the following properties (12):

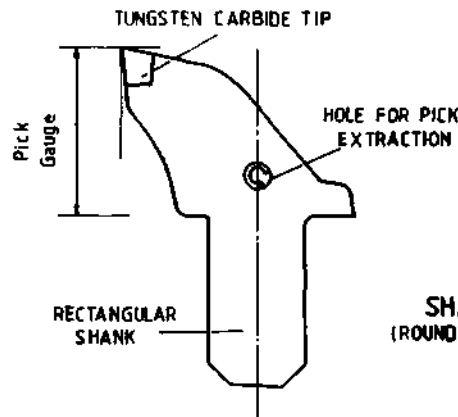


Figure 5 — Radial pick

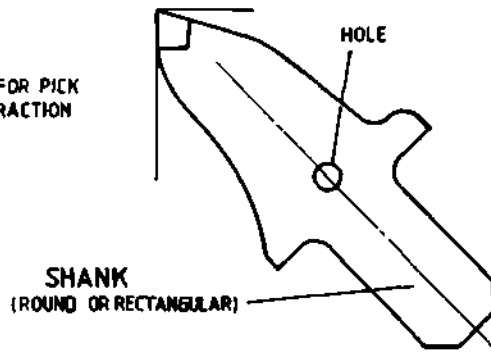


Figure 6 — Forward attack pick

- 1 The resultant pick force is substantially in line with the tool axis, hence affording increased resistance to shank breakage and diminishing tool holder wear.
2. The pick boxes become longer and better supported by the vanes, thus the possibility of box losses is reduced.
- 3 The 'triangular' space between the cut material and the front of the tool provides more effective tool-face flushing.
- 4 This space also allows a large area where the cut material can move thus reducing cutting forces, dust make, and wear.

It is further reported that the forward attack picks are not suitable for kerf cutting on shearer drums due to the plan length of the tool and the tool holder, which limit the number of boxes required. In-situ investigations in Beypazarı Mine have indicated that forward attack tools may also not be suitable for small types of roadheader cutting heads. This result was substantiated during trials with radial picks.

2.3.3. Point Attack Picks

Point attack picks are classified among the tangential picks and generally have the shape of the common pencil and hence are also known as 'Pencil Point Tools'. They consist of a conical tungsten carbide tip which is inserted symmetrically into a cylindrical body, hence the pick axis is in line with the conical tip (Figure 7). Point attack picks had previously found considerable use in coal cutting; however, today, they are no longer favoured in this field. They have been increasingly employed in medium and hard rock cutting and have become an inevitable tool on medium and heavy-duty roadheaders.

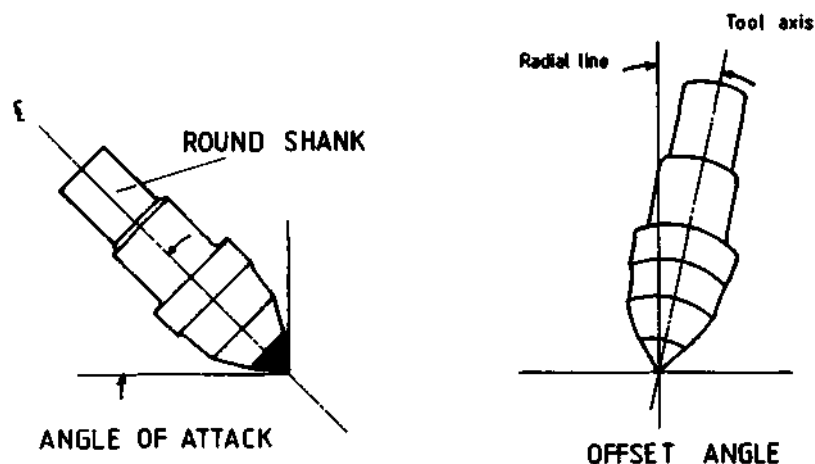


Figure 7 — Point attack pick

The point attack tool, in contrast to the radial pick, is distinguished by its self-sharpening character resulting from the action of rotation in the holder. In practical applications, these picks, therefore, last longer than the other picks. Laboratory investigations on three different picks have shown that in sharp conditions point attack picks generate the highest tool forces. However, when tools became blunt after 600m of cutting they had the lowest forces (13). The longer service life of the point attack tools provides an uninterrupted and hence an efficient excavation operation, on the condition that they rotate in service. In practice, the pick rotation is, though not always the case, due to operational and design reasons. It is claimed that introducing an offset angle may assist pick rotation. An optimum value for this angle is at present not available and it is reported to vary according to the cutting head type (14).

The angle of attack which is the angle between the tool axis and the tangent of the cutting path, is another parameter affecting the performance of point attack picks. This angle provides a good contact between the pick and rock and failure to position the pick at its correct angle of attack will significantly alter the effective tool geometry. The kinematic requirements are also taken into account and practically this is suggested to be 50 degrees, since at this value the lowest cutting forces were generated with the picks of 75 degrees cone angle (13). When cutting hard rock the cone angle is increased and, consequently, the rake angle emerges to be smaller. In order to offset the value of clearance angle, the angle of attack is to be larger, e.g. at 90 degrees cone angle, the angle of attack should be at least 55 degrees. It is also reported that at high rotational speed this angle should not exceed 48° (14).

Rock cutting experiments with point attack tools showed that the magnitude of F_c and F_n are inclined to be approximately equal and hence the direction of resultant force becomes in line with the tool axis, if F_s is ignored (15, 16). This situation implies that the pick shank and the holder may gain a longer service life.

2.4. Wear of Drag Tools

Cutting tools, like other materials, are subject to wear. The performance of the pick cutters is reduced substantially by wear since the properties of the pristine pick are altered. The effect and amount of wear depends upon rock properties, quartz content, the composition and the structure of the tool material and operational conditions such as cutting speed and cut distance. The cutting head or drum design also considerably affects tool wear. Under normal cutting

conditions, pick wear gradually develops as the tungsten carbide grains are removed from the tip. Severe cutting conditions can, however, lead to the fracture and detachment of the tip from the pick body. The wear mechanisms being most likely to be encountered are suggested to be in the form of abrasive wear, microchipping, gross failure and thermal cracking (13).

As can be seen in Figure 8, a wearflat develops under the tip of the tool in the mode of abrasive wear. The wearflat is almost parallel to the cutting direction; however, it generally tends to incline in the opposite direction and forms a wear angle. This angle is around a few degrees and becomes smaller for the hardest and strongest materials. Occurrence of wearflat changes the tool tip geometry and, consequently, results in the generation of higher tool forces. The normal force is the most affected component by the wear, e.g. a wearflat around 1mm can drastically increase F_n/F_c ratio. It is also reported that a large clearance angle relieves the wear effect and provides better overall efficiency even if, as a consequence, a small or slightly negative rake angle is introduced (17).

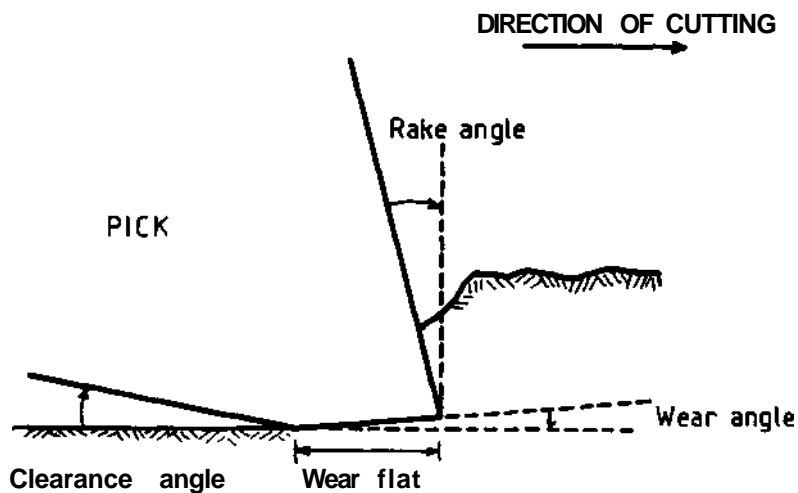


Figure 8 — Wear development on the tip of a cutter pick (17)

At higher cutting speeds the adverse effect of pick wear is accelerated due to the build-up of heat at the tool-rock contact, resulting in localised softening of the tungsten carbide. A compromise should, therefore, be reached between the tool wear and high cutting rate. Detailed information on tool wear can be found elsewhere (1, 3, 17).

3 ASPECTS OF THE PRACTICAL APPLICATION OF DRAG TOOLS

In practice there are many picks with various types, shapes, tungsten carbide grades and different dimensions, and each one is designed to be employed on a particular machine and operational condition. As roadheaders and shearer drums are the main concern of this paper, aspects of drag tools explained in this section refer to those associated with the above-mentioned machines.

3.1. The Picks

Selection of pick for a particular condition is of paramount importance and a wrong selection can drastically increase the cost of the cutting operation. A method for predicting the suitable pick and machine type, therefore, emerges to be very important. A technique developed by Fowell and Smith has proved to be most useful for a successful operation (18, 19).

The increasing need for cutting machines to excavate harder rock has led to the development of larger, heavier and more powerful machines. The pick manufacturers have subsequently moved towards the design of larger drag tools. Picks of long reach are successful for an efficient cutting in weaker rocks and coal. For hard rocks, short gauge picks are more suitable since short reach reduces the bending moment in the shank. For this reason, point attack picks with larger shank diameter and larger carbide inserts better suit hard cutting conditions. The shank diameter of the point attack picks has now been increased to approximately 30mm (20).

It is established in rock cutting mechanics that considerable benefits can be gained by employing the picks which are able to take large depths of cut. Though it should be noted that at deep cuts it is possible to increase pick spacing to a point beyond which severe vibrations are likely to occur which damage gear boxes and other machine components if the cutting head design is not balanced. On a cutting head or drum increased spacing allows a reduced number of cutters and a reduction in overall torque. Thus the rotational speed is reduced and the power available on the machine is better utilised. In Beypazarı Mine, radial picks with long gauge are employed on shearer drums while those with short gauge are fitted on roadheading machines.

3.2. Pick Holders

Pick holders, or picks boxes, are the means by which the cutters are attached to the cutting head or drum. Durability of picks, and

hence the efficiency of the excavation are substantially dependent upon the performance of the pick boxes. The picks and the boxes are to be designed such that their dimensions are accurate enough to fit each other. Any loose fit may rapidly deform or break the holder and, as a consequence, the picks can be easily lost from the boxes. This was evident from the results of in-situ trials in Beypazarı Mine. As shown in Table 1, the pick consumption rises significantly owing to worn pick boxes.

MONTHS WORKED (1985)	GALLERY ADVANCE (m)	PICK CONSUMPTION (Picks)	PICK CONSUMPTION RATE CPicks/m)
April	155	46	0.30
May	168	60	0.36
June	153	135	0.88
July	124	148	1.19
August 1-10 J	30	35	1.21
TOTAL	630	424	0.67 (Average)

Table 1 — The pick consumption (2)

According to the authors' experience, the following factors should also be considered for an efficient excavation:

- 1 The size of holder; pick boxes of small size, provided that they have adequate strength, may bring a twofold benefit. Firstly, they do not take much room at the nose section of the cutting head and hence the problem of pick box interference may be reduced. They can, additionally, allow wide distances between the vanes, thus assisting free flow of the material for loading.
- 2 Tool holder shape: the shape of pick box is also associated with pick box interference. Tool holders tapering from the top down to the bottom were found to fit better.
3. Pick locking mechanism: this is of considerable importance as the picks must be held firmly in the holder. The locking mechanism should be suitable for quick release of worn or broken tools and for easy pick extraction. Additionally, the locking system should not be easily damaged.

The shanks of radial picks are of rectangular shape since this firmly fits the pick in the holder. The boxes of radial picks are, therefore, of prism shape. There are a number of tool fastening mechanisms such as bayonet and side pull-lock system (Anderson, Strathclyde), button lock system (Hall and Pickles) and swifsure system (Matthias Spence and Sons). The locking systems which are employed in Beypazarı Mine are illustrated in Figure 9. The implications of in-situ observations on the roadheaders in this mine are such that a locking mechanism which involves the use of the upper portion of the box may not be so efficient, since top of the holder is more vulnerable to wear and damage.

The point attack picks have round shanks to allow them to rotate in the holders. These holders are, in some cases, designed to accept forward attack picks with round shapes. Also, the point attack picks of different dimensions can be fitted in the same holder with the aid of an adaptor; hence it is possible to employ different point attack picks on the same cutting head or drum (Figure 10). Type of pick fastening mechanism found in practice for point attack picks include retaining ring, retaining clip, roll pin and hose clamp.

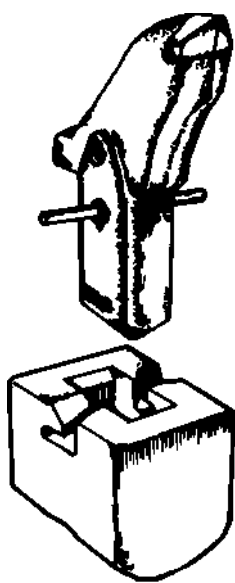
3.3. Effects of Cutting Head Design

Cutting head or drum design has a pronounced effect on the performance of the drag tools. This was evidenced by the results of the field trials (2). An inappropriate tool lacing can possibly result in the generation of asymmetrical pick forces, and hence lead to the destruction of picks and boxes. The boxes may further come into contact with the material to be cut.

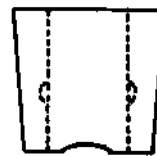
Another important parameter considered in this aspect is that of the attachment of the boxes onto the cutting head boss. Correct heat treatment should be carefully carried out during welding. If the above factors are not taken into account the picks and, consequently, the boxes, would fail to perform satisfactorily. The failure of the pick boxes is observed to be in the form of breaks or bell-mouthing.

4 RESERVICING OF WORN OR DAMAGED PICKS

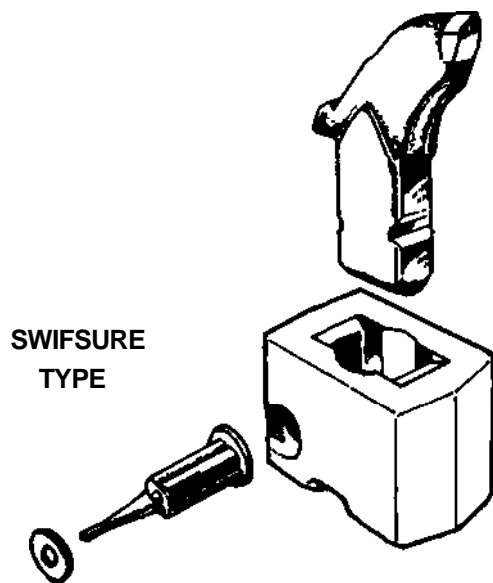
A typical pick cutter consists of a forged steel body and a tungsten carbide insert. The way in which the carbide inserts are attached to the tip of the pick is illustrated in Figure 11. Point attack picks are reported to have a better chance to retain the carbide tip as the carbide insert is recessed around 13mm into the pick body. With radial



BAYONET TYPE



BUTTON-LOCK TYPE



SWIFSURE
TYPE

Figure 9 — Pick locking mechanisms

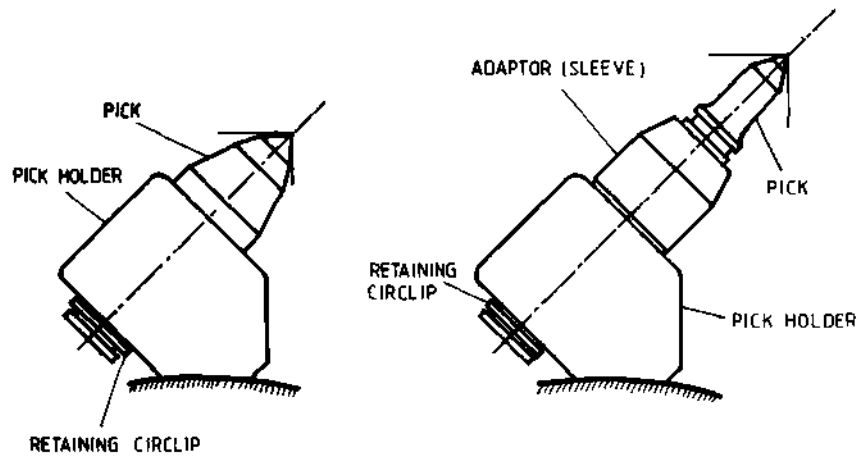


Figure 10 — Pick holder and adaptor for point attack tools.

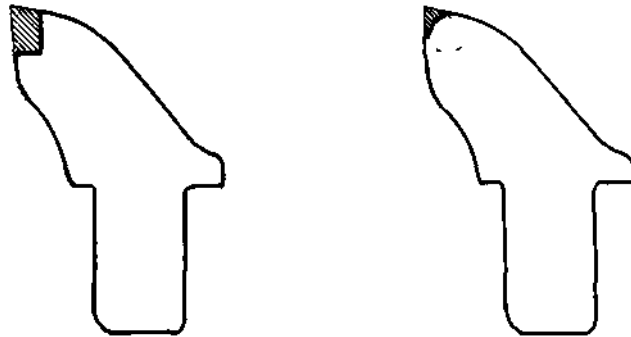


Figure 11 — Attachments of carbide inserts to the pick body

picks the tips are surface mounted and hence more vulnerable to impact shattering (20). The top portion of a point attack pick is harder since this part continuously rubs the rock surface because of the pick rotation and lack of side clearance.

The tungsten carbide insert generally accounts for a small percentage of the overall pick cost. The cost of carbide inserts for point attack picks is reported to be 5% and 10% of total pick cost and this value can go up to 25% for hard cutting conditions (20). In practice, the picks normally start to wear out from their tip and, as soon as the inserts cease to function, the picks need to be replaced. It therefore seems reasonable to repair the tip of the picks in order to save the main body which forms a large proportion of the total pick cost. This concept may prove of value to the Turkish Mining and Civil Engineering Industry which obtains the drag tools from external sources. A series of investigations has been undertaken in Beypazarı Mine on reservicing of the used picks in order to evaluate this concept.

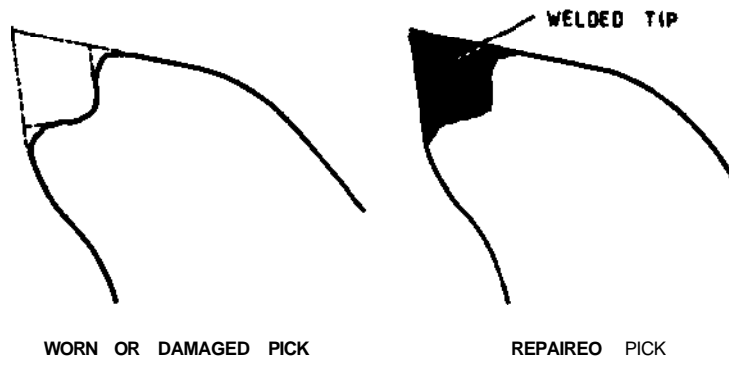
Some of the methods which have been employed or are proposed for radial picks are described below.

4.1. Use of Welding Electrodes

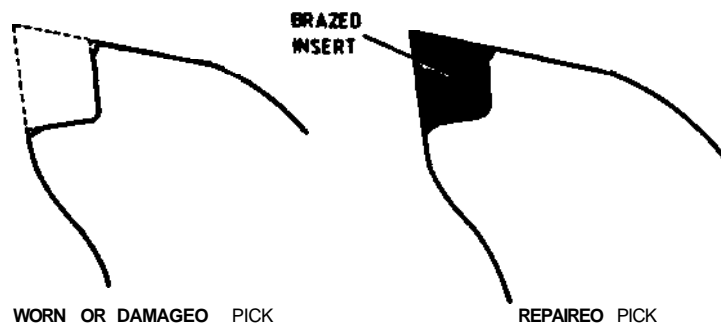
This is a straightforward technique and utilises special weld on deposits having high resistance to wear. The slot at the tip of the pick is filled with welding material (Figure 12a). The advantage of this method is that slot condition is not as important as is required for the following method, providing that the picks are not too severely damaged. The tips can be machined after welding to provide efficient cutting edges. Though in this technique the strength of the pick body may be weakened by thermal stresses induced by welding.

4.2. Brazing of Tungsten Carbide Inserts to the Pick Body

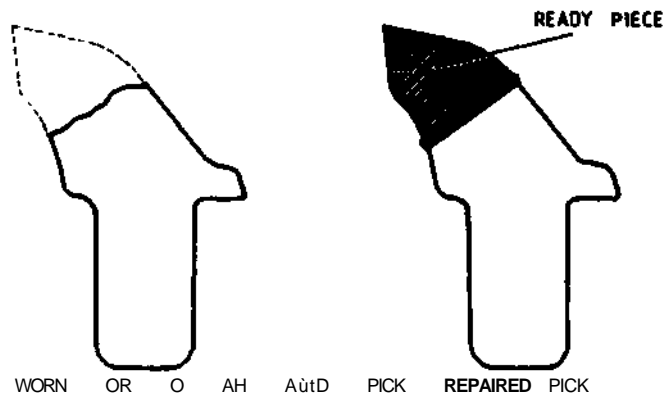
This method involves the brazing of carbide inserts to the body of the used picks. The slot shape of the pick tip should be reasonably intact as the carbide inserts can not be properly inserted into damaged slots (Figure 12b). The pick cutters are, therefore, required to be carefully observed during cutting so that the picks with worn or damaged tips can be removed immediately and replaced to maintain efficient cutting performance. One or two damaged tools can absorb a disproportionate amount of the power and slewing force available at the head, especially in hard rock cutting conditions.



a) **The use of welding electrodes as a tip**



b) **Brazing of tungsten carbide insert to the pick**



c) **Replacing the upper portion of the pick**

Figure 12 — Methods for pick resericing

4.3. Replacing the Upper Portion on the Cutter Pick

As illustrated in Figure 12c, the upper portion of a damaged pick is wholly replaced by a ready-made piece which bears the tungsten carbide tip. Provided the lower half of the tool body is in good condition this technique can be applied. The only process required is the welding of the replacement piece to the upper part of the pick body. Any misalignment while joining these parts can adversely affect pick performance. This is the most effective and reliable technique, although more costly than the other methods described due to the price of the pre-tipped replacement piece.

Methods of this type may also be suitable for reservicing of used point attack picks. However, no data is available at present.

5. HIGH PRESSURE WATER JET ASSISTANCE

There are a number of advantages to be gained from the addition of high pressure water jets to assist the action of the drag tool. By far the greatest advantage is the reduced rates of wear experienced by the tools. This is attributed to the cooling of the tool-rock interface; the tungsten carbide maintains its hardness and hence remains an efficient cutting tool for longer, with excavation rates maintained. The other advantages are: a reduction in tool forces and torque fluctuations from the cutting head; reduced dust make, and reduced ignition hazard.

A comprehensive programme of water jet assisted testing has just been completed in the University of Newcastle upon Tyne on a range of rock materials of varying strength and abrasivity on an instrumented linear planing machine (21). The primary object was to measure the force reductions obtainable and mechanisms of rock breakdown operating during water jet assisted cutting at practical hard rock operating speeds (up to 1.1 m/s).

The jet penetration characteristics were found to be of importance. Where jet penetration was achieved at the traverse speeds employed, significant reductions in tool forces were obtained; an optimum situation was found to exist when the jet penetrated 30% of the mechanical depth of cut (22). A model for the action of the water jet has been proposed (23) which accounts for the tool force reductions.

The aspect of tool life with water jet assistance has been studied in detail by the Rock Cutting Group at the Headquarters Technical Department of British Coal (24). Field results on roadheaders with high pressure jet assistance are promising, with doubling of excava-

tion rates reported (26). Pressures up to 70 MPa have been used, with jets acting 1mm ahead of the tool tip, though many of the advantages of jet assistance (extended tool life and reduced dust make) can be gained at much lower pressures than 70 MPa. The development of 'through-the-tool' jets looks more promising than the presently used external jets. This allows the jet to be applied at the tool tip without having to penetrate the the accumulated debris built up in front of the tool. Thus more efficient utilisation of the jet energy can be expected.

6. CONCLUSIONS

Careful selection of drag tool types is of crucial importance. The choice should be made on the basis of pick durability as inappropriate picks become worn quickly and subsequently halt cutting operations. Pick boxes have also been found to exhibit considerable effects on tool performance. The life of pick boxes with respect to the operational conditions is significantly affected by cutting head or drum design. Tool holders should also incorporate a suitable pick locking mechanism being capable of effectively retaining the tools in service and providing quick release for replacement.

Reservicing the used picks would appear to be most beneficial for the Turkish Mining and Civil Engineering Industry. Regular inspection and replacement of cutting tools is required to maintain cutting performance and allow renewal of the tool tip. Introducing a bonus system for machine operators and face crew may prove to be useful in this respect.

Water jet assistance to drag tools has been found to be the most promising development for extending the application of drag tools and the production of 'through-the-tool' jets has many practical advantages.

It is not possible to consider all the topics introduced in this paper in depth, as required by the practising engineer, though the refermées quoted in each section will amplify the points made and provide an understanding of the fundamentals of mechanical rock excavation by drag picks.

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